Proceedings of
A Symposium on Environmental, Economic, and Legal Issues Related to Rangeland Water Developments

November 13-15, 1997
Tempe, Arizona

Sponsored by:

The Center for the Study of Law, Science and Technology
Arizona State University

Arizona Game and Fish Department
Arizona Wildlife Federation
ASU School of Planning and Landscape Architecture
Sierra Club, Grand Canyon Chapter
The Wildlife Society, Arizona State Chapter
U.S.Bureau of Land Management
U.S. Fish and Wildlife Service
U.S. Forest Service

Published by: The Center for the Study of Law, Science and Technology, Arizona State University, 1998.

To order additional copies contact: Rosalind Pearlman, Arizona State University, College of Law, P.O.Box 877906, Tempe, AZ 85287-7906, (602) 965-2124, rosalind.pearlman@asu.edu.

Preface

The management of arid rangelands in the West has become an acutely controversial policy issue whose informed resolution has important implications for the future of the region. Public managers of land and natural resources, in particular, are frequently asked to make decisions about proposed uses that cut across a complex matrix of environmental science, competing economic interests and claims, and legal constraints. In the summer of 1996 the two of us, law professors at Arizona State University (ASU), began to perceive the potential value of a symposium that would approach the study of this larger policy problem through the exploration of a specific, concrete and recurring issue which such managers face: the decision whether, where, and under what circumstances to construct rangeland water developments, either for the management of grazing livestock or for the anticipated benefit of wildlife. Such decisions have often been made based on perception and past practices; hard data and analysis have been more difficult to come by.

One of us (Joe Feller) has had extensive experience with these issues, both in the real world of environmental policymaking and litigation, and in academic research and teaching. The other (Dan Strouse) is the Director of the ASU Center for the Study of Law, Science and Technology, one of whose missions is to advance the legal system's knowledge and use of relevant science in order to improve decisionmaking. It was our thought that by exploring this one specific aspect of the rangeland management problem in detail, and from several vantage points -- environmental, economic and legal -- we might begin to identify and better understand what is really known about it, what remains to be learned, and what might realistically be ascertained. The goals from the outset were to contribute, through research, to the formulation of wise policy; to eschew political rhetoric in favor of dispassionate study and analysis; and, to the extent that debate would arise over the meaning and implications of research presented at the Symposium, to conduct that debate as productively as possible.

Many state and federal agencies, and various interest and advocacy organizations, have stakes in the rangeland management debate of which water installations are such an important part. Accordingly, early on in the process we invited representatives of most of these groups to join us in planning the Symposium. A Steering Committee was soon formed, whose charge was to provide guidance in planning the contents of the Symposium and assistance in ensuring that it would succeed -- through topic selection, publicity, recruitment of speakers, and numerous other tasks both substantive and administrative. Over the course of the year preceding the Symposium this Committee met regularly, often monthly, and worked extremely hard to produce the Symposium whose contents are reflected in the materials that follow. We now want to recognize and publicly thank both the invididuals who constituted the Committee, and the organizations they represented -- who, along with the ASU Center, co-sponsored the Symposium. Accordingly, we express our enduring gratitude to our partners in this enterprise:

Eddie Alford, Biological Resources Group Leader, Tonto National Forest, USDA Forest Service

Professor John Brock, School of Planning and Landscape Architecture, Arizona State University
Al Burch, Group Administrator, Arizona U.S. Bureau of Land Management
Jeff Burgess, Sierra Club, Grand Canyon Chapter
Jim Burton, Branch Chief, Habitat Division, Arizona Game and Fish Department
Mike Ferguson, Deputy State Director (Arizona), Resources Division, U.S. Bureau of Land Management
Ray Lee, Wildlife Specialist Supervisor, Game Branch, Arizona Game and Fish Department
Larry Riley, Wildlife Specialist Supervisor, Habitat Division, Arizona Game and Fish Department
Sam Spiller, U.S. Fish and Wildlife Service
John H. Stephenson, Arizona Wildlife Federation
Ron Engle-Wilson, Wildlife Specialist Supervisor, Arizona Game and Fish Department and President, Arizona Chapter, Wildlife Society

The papers that constitute these Proceedings were submitted to the Steering Committee pursuant to both individual invitations and a Call for Abstracts. In order to attract work of the greatest relevance and highest quality, the Committee worked tirelessly to identify promising invited speakers, to publicize the event in order to encourage submission of Abstracts, and to review Abstracts once submitted. The Committee sought papers on a range of topics, which are reflected in the structure of the Symposium and serve as the organizational units of these Proceedings:

* Introduction: Agency Perspectives on Rangeland Water Developments
* Historical Perspectives on Rangeland Water Developments
* Rangeland Water Developments and Livestock Management
* Rangeland Water Developments and Wildlife I: Mammals
* Rangeland Water Developments and Wildlife II: Fish, Reptiles, and Amphibians
* Costs and Benefits of Rangeland Water Developments
* The Effects of Rangeland Water Developments on Soils and Watersheds
* Legal Issues Related to Rangeland Water Developments
* Planning, Decisionmaking, and Monitoring for Rangeland Water Developments
* Technical and Design Issues Related to Rangeland Water Developments
* Research Needs (Concluding With a Panel Discussion)

The Symposium was held November 13-15, 1997 at the ASU College of Law. Three days of lively, rigorous presentations and searching but balanced discussion passed quickly. We think the Symposium was successful, in at least three important senses. First, the range and quality of the papers, both invited and submitted in response to the Call for Abstracts, exceeded our most optimistic expectations. Second, we think significant progress was made toward the articulated goals of evaluating the state of present knowledge, identifying gaps in that knowledge, and, in some cases, suggesting promising avenues for additional research. Finally -- though we harbor no illusions that a policy issue as complex and divisive as rangeland management will be readily resolved by a single project like this -- we do believe, and surely hope, that in years to

come these materials will prove to be useful to decisionmakers, scholars and advocates seeking guidance as they struggle with concrete decisions about water installations in arid rangelands.

Joseph M. Feller, Professor of Law
Daniel S. Strouse, Director, Center for the Study of Law, Science and Technology and Professor of Law
Arizona State University College of Law
Tempe, Arizona

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INTRODUCTION

Symposium on Environmental, Economic, and Legal Issues Related to Rangeland Water Developments
November 13, 1997

The U.S. Bureau of Land Management Perspective on Rangeland Water Developments in Arizona

by

Alvin L. Burch and William F. Grossi
(presenter)

Introduction

On behalf of the Arizona U.S. Bureau of Land Management (BLM), let me welcome you to the Rangeland Water Development Symposium. I'm a group manager in the Arizona State Office of the BLM. I'm speaking to you today because our State Director, Associate State Director, and Deputy State Director for Resources have been sent by the Department of Interior managers to very high priority assignments elsewhere. Hopefully, with the help of other BLM specialists from the Arizona BLM who are seated in the audience, I'll be able to adequately convey to you our perspective on rangeland water development issues.

First I'd like to give you some background on the Arizona BLM and how we operate in case some of you in the audience are unfamiliar with our mission and authorities. Then, I'd like to talk with you about some of the tools we currently use in accomplishing our goals, namely the National Environmental Policy Act and the collaborative approach to resource management. Finally, after giving you this background information about how we operate, I'll attempt to summarize concisely our perspective on rangeland water developments.

Background

The U.S. Bureau of Land Management is an agency within the U.S. Department of Interior. We were born in 1946 from a merger between the Government Land

Office and Grazing Service and given the task of management of natural resources owned by the public and encompassed in about 270 million acreas of surface estate and about 570 million acres of subsurface mineral estate. The authority for managing the land and its resources was founded in numerous laws but was more recently updated and iterated in the Federal Land Policy and Management Act of 1976, known affectionately as FLPMA.

BLM in Arizona manages about 14.2 million acres of surface estate and 17 million acres of subsurface estate, or about 19.6 % of the land area of Arizona. We accomplish resource management with about 450 specialists from a variety of disciplines who are housed in our State Office in Phoenix and seven field offices, the Arizona Strip Office in St. George, Kingman, Phoenix, Yuma, Lake Havasu, Tucson, and Safford.

BLM manages public lands and resources to best serve the needs of the American people. We now emphasize a collaborative approach to management and routinely call upon the Arizona Resource Advisory Council (RAC) and other partners including other agencies, interest groups, and individuals.

Land Use Plans and the Decision Process

BLM performs a variety of functions on behalf of the public for the lands we administer. We are essentially the real estate agent of the federal government, the surveyor of the lands, and the administrator of leases and permits. Decisions concerning resources are made daily and follow variable but systematic processes.

Most of the actions we take are founded in a three tier land use planning system. Decisions are made for the management of resources at all levels in the planning and permitting process on the basis of legal constraints, technical analysis, and input from partners. Information availability, the topic of this symposium, is critical to effective analysis and management.

Land use plans, known by several names (management framework plans, resource management plans, and ecosystem management plans), provide a programmatic umbrella and guidance for management of specific public lands. All management decisions affecting resources on public lands must be in

conformance with our umbrella land use plans. The land use planning process seeks and incorporates public input through a National Environmental Policy Act (NEPA) analysis.

Activity level (or interdisciplinary) plans supplement the land use plans and provide an environmental analysis of expected on-the-ground activities. More specific management actions are identified in these plans, and the direction is set for steps we will take to accomplish the identified goals. Public involvement is routinely sought at this level as well.

Site specific environmental analysis is completed in processing public requests for permits, leases, or other specific actions. This essentially is the third tier in the planning process. Actions are first checked for conformance against all other plans. Then, an environmental analysis of the action is completed by our specialists. At this level, we again seek input from the public. Decisions on these actions are made within legal constraints and with the best scientific data available to us. Decisions are not always popular; however, we are obligated to recognize the rights of individuals and ensure multiple use and protection of all the resources.

NEPA as a Tool in the Decision Process

NEPA is the primary tool we use at all levels of planning to analyze environmental impacts and benefits during the decision making process. It underscores the responsibility to preserve the natural aspects of the environment and variety of habitat components.

NEPA declared national policy to encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the nation; and it established a Council on Environmental Quality.

NEPA requires federal agencies to utilize a systematic, interdisciplinary approach, ensuring the use of natural and social sciences and environmental design arts in any planning or decision making that may impact man's environment. It specifically directs federal agencies to initiate and utilize ecological information in the planning and development of resource oriented projects. The mechanism we use is the

development of environmental documents. Each proposed, major federal action requires development of detailed statements about environmental impacts. These may take the form of a categorical exclusion, environmental assessment, or, for larger or controversial actions, an environmental impact statement.

Since 1969, we've used an interdisciplinary approach through the NEPA process in making decisions that affect natural resources. Early in the development of the interdisciplinary approach, we worked directly with lessees and permittees and only occasionally involved constituent groups; however, we currently are emphasizing strongly an interdisciplinary and collaborative approach to management of all the public resources.

In light of our mission and the processes we use in making decisions, I'll give you our perspective about issues surrounding water developments, first for wildlife and second for livestock management.

Water Development and Wildlife Management

All of the 14 million acres of public lands in Arizona support big game, small game and nongame wildlife populations. Wildlife management on public lands is a partnership with the state wildlife management agency and others such as the Arizona Desert Bighorn Sheep Society, Quail Unlimited, and the Rocky Mountain Elk Foundation. Wildlife objectives for particular areas are determined based on legal constraints (e.g., threatened and endangered species), carrying capacity, and public desires.

Our perspective is that human activities (i.e., spring development, highways, railroads, agriculture, cities, etc.) have isolated wildlife populations and fragmented habitats, making it difficult in some areas for wildlife to utilize historic water sources.

Based on management goals and scientific data, BLM has assisted in the construction of scores of water developments on Arizona public lands to mitigate the effects of human activities. Before any wildlife water developments are constructed, an interdisciplinary team of resource specialists and managers analyze impacts and benefits to resources in their areas of expertise and ways to mitigate

any adverse effects. Concurrence is sought from the Arizona Game and Fish, State Historic Preservation Officer, Fish and Wildlife Service, and other affected interests.

Water Development and Livestock Management

Livestock management on public lands historically has been a partnership with the individual permittee and was coordinated with adjacent land management agencies such as the State Land Department, Forest Service, Park Service, etc.

Currently, our records show 1.4 million acres of BLM-administered allotments in Arizona. We work with about 850 permittees who graze about 56,000 head of cattle and 2,000 sheep.

Our perspective is that water developments can be an effective tool in management of our rangelands. Water developments were typically used as a tool to better distribute grazing utiilization over a given allotment. More recently, with the emphasis on the health of riparian areas, water developments are used to keep livestock from concentrating in riparian zones.

Similar to the decision process for wildlife water developments, before any rangeland water developments are constructed, an interdisciplinary team of resource specialists and managers analyze impacts and benefits to resources and ways to mitigate any effects. Concurrence is sought from Arizona Game and Fish, the State Historic Preservation Officer, Fish and Wildlife Service, and other affected interests.

Additionally, we are now implementing our Standards for Rangeland Health and Guidelines for Grazing Administration for Livestock Management (Standards and Guides). These rangeland standards, developed in partnership with the Arizona Resource Advisory Council, focus on the enhanced health and productivity of BLM-administered rangelands for the benefit of all resource uses, including the enhancement of habitat for wildlife. The most important concept underlying the Standards and Guides is that the goal is to achieve a specified resource condition instead of focusing on steps to maximize individual program accomplishments. The goal is to meet standards which were developed using a true interdisciplinary approach to the entire ecosystem rather than a program by program analysis. Guidelines for Livestock Management, through the partnership with the RAC and

the public, prescribes some measures to follow in achieving the rangeland health standards.

We have begun implementation of the Standards and Guides in Arizona. A pilot project is underway in our Arizona Strip Field Office.

Summary and the BLM Perspective

We face many issues in the decision process for rangeland water developments, and these vary from site to site. Tangential issues include impacts to threatened and endangered species and habitat, impacts to cultural resources and heritage sites, impacts to recreational use areas, impacts to wilderness or special use areas, etc. One significant issue concerns water rights. Should a water right be granted to the BLM or to the permittee? Some of these issues translate to legal cases.

We have traditionally supported and continue to support the position that water developments are an effective tool in the multiple use management of the public lands, to enhance wildlife habitat and control utilization of forage by livestock. We've traditionally viewed and continue to view water developments as replacements and supplements to natural water sources previously fragmented by human activities.

We've traditionally analyzed and continue to analyze impacts and benefits of water developments using our interdisciplinary decision making process that incorporates extensive data analysis. More recently, we've adjusted our interdisciplinary decision process to include more collaboration with affected interests to define, through consensus, rangeland standards.

Although we believe water developments are a viable management tool, we will remain objective in our use of the tool. The benefit of interdisciplinary collaboration is that it multiplies ideas and enhances both the accessibility and the analysis of sound scientific data. We believe that more ideas, better data, and better analysis will lead to better decisions.

We applaud this symposium as a forum for identifying areas where we need more and better information, and we thank the ASU law school for allowing us to participate.

HISTORICAL PERSPECTIVES ON RANGELAND WATER DEVELOPMENTS

WATER FOR WILDLIFE: Belief Before Science

David E. Brown

Abstract – The construction of water developments to benefit wildlife in arid areas is a management measure as old as the limiting factor axiom. Assumptions that providing water will improve wildlife reproductive rates, prevent declines in big-game survival rates, and increase distributional patterns, are so logical, and so empirical, as to be accepted as self evident. As a consequence, millions of dollars have been spent constructing wildlife water developments, and by providing additional water supplies, game departments and ranchers have argued that they have benefitted animal populations. Yet, with the possible exception of increasing some wildlife distributions, evidence indicating water developments increase game populations remains nebulous. Also, the potential negative effects of providing free water have tended to be downplayed or ignored. A series of controlled experiments to test past assumptions relating to water developments is therefore much needed.

I first came to Arizona in 1961 to work as a Wildlife Manager for the Arizona Game and Fish Department. After serving six months as a trainee, during which time I visited every region in the state, I was assigned a district headquartered in Gila Bend. Nine months later I transferred to Casa Grande, and three months after that I moved to Tucson where I was the Game Manager for Unit 37A from 1963 through 1968. Each of these units was within the Sonoran Desert and came with a number of rainwater catchments, windmills, and other "wildlife waters." These waters had been constructed through the Department's Federal-Aid to Wildlife Restoration program, and one of my primary duties was to twice a year visit each one, monitor the amount of water available, and report any needed repairs on either the structure or to the surrounding fence.

Water development was big then. The Department was engaged in a massive catchment construction program, as both sportsmen and biologists felt certain that water catchments would increase both the numbers and distribution of game animals. All of my early supervisors were advocates of water development. My closest colleagues were recommending water developments. And, after two years in the field, so was I.

To spend a June night watching wildlife come into a waterhole, as I did on many an occasion, removes all doubt as to the efficacy of water developments. May is the driest month in Arizona and by June daytime temperatures are brutal. Even the nights are hot, and many of the desert mule deer I saw coming into water were obviously stressed from heat and thirst. The does, pregnant since February, appeared to suffer the most. Oftentimes they would cluster just outside the fence, frantic for dark to fall so that they might at last slake their thirst. Fearful of predators, yet driven on by the closeness of the water, the deer might take hours to partake of the precious liquid. Later, javelina would come in, as would gray foxes, coyotes, bobcats, badgers, and a procession of other desert critters.

With the coming of the dawn, other animals take their turn. Even as the deer would melt back into the desert, the first birds would be arriving. Usually the thrashers would be the first to come, to be shortly followed by mourning doves, Gila woodpeckers, and finally the late-sleeping white-winged doves. So numerous were the latter, that they literally flocked to the water, sometimes bending the ocotillo stalks that they waited on while taking their turn to drink nearly to the ground. But the images of drinking quail were the most impressive -- in good years there were dozens upon dozens of them, each bird working its way into the proper position for its share of the bounty that we had provided. Even after the sun would rise, and temperatures were again ascending toward 100, wild bees and other insects would continue their jihad to these desert oases. To doubt the value of these waters to wildlife was to doubt what you saw with your own eyes.

Reason as well as emotion told us that water developments were good. Daniel Axelrod had told us that North America's deserts were brand new from an evolutionary perspective. More recent work by Tom Vandevender and other researchers concurred. Our deserts were less than 10,000 years

old, and that the Sonoran Desert had only been in Arizona in the last 5,000 years. Unlike such animals as the Sahara's addax, scimitar-horned oryx, and Dorcas gazelle, which have evolved water conservation strategies over tens of thousands of years, Arizona's big game animals are relative newcomers to an arid existence. Even the Gambel's Quail, one of the few birds centered in the Sonoran Desert, is obviously closely related to its California Quail cousin, and only a recent desert dweller. We logically assumed that water must be a limiting factor for our desert animals.

When I first took responsibility for Game Management Unit 37A there were 12 water catchments in my district, not counting three windmills in the Tucson Mountain Wildlife Area. Six of the catchments had been built primarily for quail, and six were designed to benefit desert mule deer and other wildlife. During my tenure in the district, I more than doubled the number of catchments to 25. All except one of these was located so as to attract a multitude of game animals. The last one that I recommended, built by the department's development crew in 1968, was intended to benefit a newly discovered herd of desert bighorn sheep near Silverbell Mine. Later, other wildlife managers recommended five additional catchments -- all in or adjacent to bighorn sheep habitat.

By the time I moved to Phoenix in 1968 some people were beginning to question the value of water developments. And, they had some disturbing statistics to back them up. Years earlier, several biologists, Charles T. Vorhies, Aldo Leopold, and David M. Gorsuch, for example, had pointed out that Gambel's Quail did not need free water, and could thrive in areas where permanent water was completely lacking. A study had just been completed by the Department's Research Division in 1962 showing that quail numbers in an area where standing water had been denied to quail were equal to, or greater than, those in an adjacent area where year-long water was available in rainwater catchments. Furthermore, Ron Smith and Steve Gallizioli had concluded that water

developments, while concentrating quail, had little affect on either quail reproduction or survival. Other research by Roger Hungerford at the University of Arizona had shown that the factor limiting quail numbers was the availability of green feed in the spring due to the effects of vitamin A on reproductive success, and probably, chick survival.

Still, no one questioned the value of water developments to big game. And, as for small game, so what if water developments only improved their distribution and not their numbers? The more areas occupied by quail, mourning doves, and white-wing doves, the more game birds you would have. It just made good sense. Water had to be the limiting factor for some aspect of every desert animal's existence. If water could not improve the survival of fawns, it would at least get the does through the worst time of the year. Then, when things improved, there would be more deer to rebuild a herd from. So inured was I in the value of game waters that the first citation I remember pleading in court was to achieve a conviction for camping within a 1/4 mile of a waterhole -- a violation then viewed as a major infraction of Arizona's game laws.

But that was 30 years ago. Keeping in mind that the primary purpose of this investment in water developments was increased game numbers, I now have to ask the hard question. What are the results of all those water catchments? To paraphrase the old Wendy's commercial, "Where's the venison?"

This year, deer permits are at an all time low. Javelina permits too, are down. Quail hunt success, and presumably population levels, are miserable. Drought is said to be the reason. So what happened? Was not our present situation exactly what water development was supposed to prevent, or at least forestall? I think we need to take a closer look.

During the years that I was a Wildlife Manager in Unit 37A -- 1963 to 1968, the average

annual deer harvest was 84 animals. During the last 10 years the average annual harvest in this unit has been 85 deer. By any accounting, the returns on the capital investment of the 13 catchments that I had built during my tenure, are rather meager.

Statewide, the deer situation is more ambiguous. The average statewide harvest of desert mule deer between 1962 and 1968 was 3256 bucks. For the same number of years approximately 20 years later, from 1981 through 1987, the annual kill averaged 4107 deer -- a 26% increase. But now, in 1996, the total harvest of south zone mule deer has fallen back to 3583, a figure within 10% of the 1962-1968 mean. Again, one wonders where the venison is that we purchased by building catchments as an insurance against drought?

Gambel's Quail populations certainly have not been helped by water development. Between 1962 and 1968, the average daily bag per hunter was 4.4 birds. Twenty years later, between 1981 and 1987, the daily bag averaged only 3.3 birds. For the most recent seven years, from 1990 to 1996, hunters only bagged an average of 2.8 quail per day. Whatever is ailing Arizona's Quail, be it drought or overgrazing, it has certainly not been alleviated by providing rainwater catchments.

Javelina might be a different story. The harvest of these little desert pigs averaged 6539 animals a year between 1981 and 1987, or 39% more than the average annual take of 4688 animals between 1962-1968. Increases since then are also dramatic. An average of 7353 javelina a year were bagged during the last three years -- an increase of 12% since the 1980s. These increases could arguably be related to additional waters and an expanded distribution, just as elk have obviously benefitted from artificial waters in the north. Although more javelina was not emphasized as a management goal, the Department's water development program may have facilitated these essentially tropical and brushland animals to increase both their range and numbers. I want to

emphasize the word "may." What we are seeing today may simply be a continuation of a long time trend.

Bighorn sheep are of course the cause celebre for desert water development. But again, one has to ask if these expenditures of time and treasure are warranted by more mutton. At first glance, the answer appears to be a qualified yes. In my old district of 37A the annual harvest of these animals has gone from an annual take of none of these animals during my tenure to just over one ram a year for the period 1994-1997. Whether this modest increase justifies the costs incurred by the construction and maintenance of six catchments is of course debatable. A larger view is called for. During the seven years 1962 to 1968 , an average of 34 rams a year were harvested in Arizona. From 1981 through 1987, this number increased to 50 a year -- a nearly 50% increase. Most recently, for the three years 1994 through 1996, a yearly mean of 104 rams has been taken -- a more than 100% increase. Many sheep advocates have used such figures to justify what all agree has been an aggressive water development program for Arizona's desert bighorns. But are these claims justified? Again, we need to take a closer look.

The KOFA National Wildlife Refuge is Arizona's premier sheep habitat. Water developments are numerous, more than 40, and by desert standards, the KOFA's mountains are well watered with man-made watering structures. Three intensive surveys of the entire refuge using Bell Jet-ranger helicopters, conducted between 1992 and 1997, yielded observations ranging from 6.2 to 8.9 bighorn sheep per hour -- or an average of 8.2 sheep per hour per year. Surprisingly then, at least to me, was a comparison with Sonora's Sierra Viejo south of Caborca. This rugged, limestone range is poorly watered, if indeed it has any permanent water at all. Nor have these mountains been the beneficiary of even a single waterhole development project. Nonetheless, a 1992 helicopter survey, not unlike

those conducted in Arizona, yielded 126 bighorn sheep in 2.9 hours of flight time. The resulting 43.4 sheep seen per hour is more than five times the rate of animals observed in the KOFA National Wildlife Refuge!

Other comparisons with Sonoran sheep ranges are equally interesting and perhaps more representative. The numbers of bighorns observed per hour on Arizona surveys in 1991 and 1992 were 10.8 and 11.5 respectively, for an average of 11.2. Similar surveys in the "unmanaged" ranges of northern Sonora in 1992 and 1994 averaged 11.3 sheep per hour. Farther south in Sonora, in ranges which also are largely water development free, helicopter surveys respectively logged 37.3 and 42.7 desert bighorn sheep per hour.

So how come? Why do "undeveloped" Sonora ranges support the same or more numbers of sheep than Arizona mountain ranges? I do not have all of the answers, but I do have some suspicions. Regardless of the reasons, it appears to me that the case for artificial sheep waters has been overstated. In my opinion, sheep transplants and removing competing livestock from the KOFA and Cabeza Prieta game ranges, and other mountain ranges along the Colorado River, did more for sheep populations in Arizona than waterhole developments. It may even be possible that water developments are detrimental in some cases. Many times I have seen predator kills near catchments, carcasses of deer that had been easy prey for carnivores drawn to water for their own purposes. Might not it be possible that these same carnivores require water even more than their prey, and that by providing them water, we have merely substituted one limiting factor for another? And, may it not also be true, that by increasing the distribution and density of targeted animals in the short term, larger numbers are detrimental over the long term due to stress aggravated pathogens and other diseases? What facts we do have seem to indicate that available forage and forage moisture are more

limiting to most desert animals populations than water per se.

But these are mere speculations on my part. The data I have presented here are not intended as science, or even definitive information. What is needed is some real research on the subject of water development, not just anecdotal references to someone seeing a Sonoran Antelope or a Mountain Lion drinking. Nor will it do to record the average distances animals are found from water. I want to see some real cost/benefit figures derived from a study that has paired control areas and employs all aspects of the scientific method including repeatability. Then, and only then, will we have some idea of what is or is not accomplished by developing artificial waters.

This, however, is not likely to happen. As a resource management supervisor once said to me, "No research is as unwanted, as a study that might tell us something that we don't want to know." With millions of dollars and years of good-will invested in water development, I had to admit that he had a point.

I want to thank Jim Heffelfinger, Raymond Lee, Bob Henry, Richard Ockenfels, and John Hervert of the Arizona Game and Fish Department for providing me with the hunt statistics and other data which I have shamelessly used to illustrate those points I wished to raise. These biologists are in no way responsible for any of the commentary presented here, all of which are strictly my own.

Water Harvesting for Rangeland Water Supplies: A Historic Perspective

Gary W. Frasier[1]

Abstract –Water harvesting is an ancient method of water supply that has received renewed interest in recent times. Water harvesting has been used and is still being used in many places as a technique for providing drinking water supplies for livestock, wildlife, and domestic uses. The earliest forms of water harvesting were probably the collection of water from "natural" impermeable surfaces such as rock faces. Twentieth century technology has made it possible to use other means of providing water collection surfaces. Some of the earliest water harvesting research in the United States was pioneered by the late C. W. Lauritzen of the USDA, Agricultural Research Service, Logan, Utah, who in the 1950's developed "raintraps" using butyl rubber to collect and store rainwater. In the early 1960's the U. S. Water Conservation Laboratory in Phoenix, Arizona, under the direction of Lloyd E. Myers, launched a comprehensive research program to develop low cost techniques of water harvesting. Other researchers in many places in the world, such as at the University of Arizona in the United States and various locations in Israel, Mexico, and India were also investigating methods of collecting and storing precipitation. Many techniques were developed and tried, some more successful than others. There is no universally "best" system. Each site has unique characteristics that influence the design of the most optimal system. There will be some type of system that will be the "best" for a given location. Only when all factors--technical, social, and economic--are considered can the correct system for the site and conditions be provided.

INTRODUCTION

Water harvesting is a technique used to provide local water supplies for livestock and wildlife drinking water, domestic use, and runoff farming. Water harvesting is not new. There is evidence in the Edom mountains of southern Jordan of ancient water harvesting systems used over 9,000 years ago (Bruins et al,. 1986). Water harvesting was practiced as early as 4500 B.C. by the people of Ur and later by the Nabateans and other people of the Middle East. The basic principles of water harvesting are still being used today but in a slightly different context. How did we get to the current level of technology and what are the changes from the earliest systems? This paper will take a brief look over time at the technology of water harvesting.

DEFINITIONS

Water harvesting techniques have been identified by a variety of expressions. In some areas the USDA-Forest Service refer to water harvesting systems as a "trick tanks," whereas, personnel in game and fish departments have used the term "guzzlers." In the 1960's, C.W. Lauritzen of the USDA-ARS used the term "rain-traps" in describing water harvesting systems

[1] Research Hydraulic Engineer, USDA Agricultural Research Service, Rangeland Resources Research Unit, Fort Collins, Colorado

(Lauritzen, 1960(a)). H.J. Geddes of the University of Sidney is credited with the first use of the term "water harvesting" as "the collection and storage of any farm waters, either runoff or creek flow, for irrigation use" (Geddes, 1963). In 1974, L.E. Myers generalized the definition to "water harvesting is the practice of collecting water from an area treated to increase runoff from rainfall and snowmelt" (Myers, 1975). I use the term "water harvesting" as "the process of collecting and storing precipitation (rain or snow) for beneficial use from an area that has been treated to increase precipitation runoff." A "water-harvesting system" is the complete facility for collecting and storing the runoff water. It is composed of a catchment or water collecting area, the water storage facility, and various auxiliary components such as fencing, sediment or trash traps, and evaporation control (Frasier, 1984).

THE BEGINNING

It is probable that the first water-harvesting system was simply a depression that collected and held water that had runoff from an uphill area. These conditions still exist in many parts of the world, especially in arid and semi-arid regions. Many desert areas have small rain-filled depressions at the bottom of rock outcroppings that provide wildlife drinking water. It was a small step in water harvesting technology to artificially create depressions for water storage at the outfall of a rocky ledge to collect runoff from rainstorms that might otherwise be lost. The next evolutionary advance might have been the construction of a rock diversion wall or gutter to direct water from a larger collection area to a central storage area. There is evidence in Iraq that these simple forms of water harvesting were routinely practiced 5,000 years ago. Along the desert roads, from the Arabian Gulf to Mecca there still exist water-harvesting systems that were constructed to supply water for trade caravans (Hardan, 1975).

These early water harvesting systems not only provided water for drinking but also for growing crops (runoff farming). One of the earliest runoff farming installations, dated to approximately 4,000 years age, is located in the Negev Desert of Israel. Hillsides were cleared and the soil smoothed to increase runoff. Contour ditches conveyed the collected water to lower lying fields for irrigating crops. These systems operated in an area that today has an average annual precipitation of approximately 100 mm. (4 inches) (Evanari et al., 1961). There is evidence that similar systems were used 500 years ago by Native Americans in the Southwestern region of the United States (Woodbury, 1963).

RECENT PAST

A common method of water harvesting in the recent past was collecting runoff from the roofs of buildings and storing the water in cisterns or tanks. During the early settlement period of the United States, and other countries, rooftop water was often the only source of domestic water. This technique is still used today in areas of limited surface and groundwater, such as Hawaii and other volcanic tropical islands.

In the early 1950's, there became an increased awareness for a need to achieve better livestock distribution on our rangelands. Additional water sources were frequently identified as the major need to achieve the required distribution. Some of the first catchments, constructed

solely as a drinking water supply, were rooflike structures of galvanized sheet metal on a wooden frame, essentially a roof without the sidewalls. These catchments were effective means of water supply, but also relatively expensive. One of the next steps was the placement of the sheet metal panels directly on the soil surface. A wooden framework held the panels in place (Lauritzen, 1960(a)). One of the largest sheet metal catchments is located on the Rock of Giberaltor, which for a long period of time was the major source of drinking water for the area. Other materials such as concrete, asphalt paving road mix, tar paper, and soil cement have been used as catchment treatments (Chiarella and Beck, 1975). Unfortunately, the life and runoff effectiveness of these materials did not justify the cost of materials or labor for installation.

The 1950's were also a time when several large companies had developed the techniques of manufacturing large sheets of synthetic rubber (butyl) membranes. The butyl membranes were waterproof, had good resistance to sunlight deterioration and were relatively easy to install. All that was necessary to provide an effective, impervious surface for collecting precipitation was to clear the vegetation from a hillside and unroll the butyl membrane on the soil surface. Unfortunately, many of these catchments failed within 5 to 10 years, usually from wind damage, but improper installation and lack of maintenance were also contributing factors (Dedrick, 1973; Dedrick, 1974; Dedrick and Williamson, 1973).

WATER HARVESTING RESEARCH

Catchment Areas

The potential of synthetic rubber and other plastics for effective catchment coverings prompted C. W. Lauritzen, USDA-Agricultural Research Service, Logan, Utah to initiate a research program in the early 1950's to evaluate various plastic and rubber materials that would have potential for water harvesting applications (Lauritzen, 1960(b)). Lauritzen's work served as the basis for the installation of numerous butyl rubber catchments, most notably in the state of Hawaii with more than 300 catchments and lined reservoirs (Myers, 1975).

In 1961, the USDA-Agricultural Research Service, U.S. Water Conservation Laboratory, Phoenix, Arizona, under the direction of L.E. Myers, initiated a program to develop improved water harvesting techniques. This research effort investigated various techniques that might use the soil itself as the basic catchment structure. Initial studies investigated sprayable materials (ie., metallic salts, soaps, silicones) that would make the soil hydrophobic or water repellent (Myers and Frasier, 1969) and later paraffin waxes (Fink et al., 1973). Other studies investigated sprayable asphaltic compounds (Myers et al., 1967), bonding plastic and metal films to the soil surface (Frasier and Myers, 1972), soil compaction, soil dispersion and field fabricated asphaltic membranes (Myers and Frasier, 1974).

Other research programs such as at the University of Arizona, plus various locations in Israel, Mexico, and India were also investigating various methods of collecting and storing precipitation (Cluff, 1975; Carmona-Ruiz and Velesco-Molina, 1981). Much of these efforts were directed toward finding materials and techniques that were lower cost than "traditional" sheet metal or concrete. Some typical approaches investigated included sodium salts for sealing soil surfaces (Cluff and Dutt, 1966) and petroleum fuels for sealing the soils (Hillel, 1967).

Studies were conducted at Logan, Utah, to better understand the wind effects on synthetic rubber membrane coverings (Dedrick, 1974).

By the middle 1970's, several materials had been developed that showed considerable promise as a suitable water harvesting catchment treatment. Typical materials included asphalt-fabric membranes, gravel covered plastic, sodium salt, and paraffin waxes (Frasier et al., 1979; Frasier et al., 1987). At the same time, installation techniques were being developed (ie., low berms, trash screens and sediment traps design) that increased the performance of the catchment for collecting runoff and reduced the potential for mechanical damage (wind, rodents, etc.).

Water Storage

Concurrent with the investigations of catchment treatments, other studies were being conducted to develop low cost ways of storing and conserving the collected water. Initially the water storage facility for a water-harvesting system consisted of traditional steel, wood, and concrete tanks. These were usually effective but expensive to construct, especially in remote areas. In many instances, water storage was the most expensive components of a water-harvesting system. Again, in the 1950's, considerable investigations were conducted to develop techniques of using large bags constructed from butyl sheetings. These bag storages were potentially simple to install in remote areas. While the butyl bags were suitable for some installations, there were several problems that limited their use in the remote unattended sites, most notably sediment and trash collecting in the bags and animal damage (Dedrick and Williamson, 1973).

Other water storage techniques included plastic (Dedrick and Lauritzen, 1969) and asphalt-fabric tank liners, plastered concrete tanks (Welchert and McDougal, 1965), and membrane lined reservoirs. Information was developed to assist in determining the proper catchment and storage sizes that would provide the needed water under the existing precipitation patterns at the lowest total system cost (Frasier and Myers, 1983).

Evaporation Control

In most instances, the collected water is used at a later date, sometimes several months after being collected. Protecting the collected water from being lost by evaporative process has long been recognized as a cost-effective method of maintaining an adequate water supply. In the early 1950's extensive research was conducted using monolayers of long-chain alcohols (cetyl alcohol) floating on the water surface to reduce evaporation. Even though techniques were developed that allowed the materials to be efficiently applied, studies showed that it was less than 25% effective in the field. Wind would cause the monomolecular films to drift across the water surface leaving large areas unprotected (Myers, 1965; Frasier and Myers, 1968). Another technique investigated with limited success was the use of floating granular materials on the water surface that reflect incoming solar radiation (Myers and Frasier, 1970). On small tanks in hot climates, a low melting point paraffin wax was an effective means of evaporation control (Cooley and Myers, 1973).

One of the most effective means of reducing evaporative losses from water harvesting storage facilities is covering or shading the water surface with floating covers fabricated from sheets of synthetic foam rubber (Dedrick et al., 1973), or roof-type shades (Frasier and Myers, 1983). These techniques are relatively successful on vertical walled tanks with fixed size exposed surface areas. It is significantly more difficult and expensive to control evaporation losses on reservoirs with sloping sides where the water surface area changes with depth.

THE FUTURE

Water-harvesting is a technically sound method for supplying water for many parts of the world. What is not often realized is that water harvesting is also a relatively expensive method of water supply. During the past decades many water harvesting systems have been constructed and evaluated at many places in the world. There have been outstanding successes in some places and complete failures in other places.

If there is a predictable source of precipitation, a water harvesting system can be constructed that will provide the required quantity of water. It may not be low-cost but it will provide water. In 1975, A. Hardan commented "...in many areas, water harvesting can mean the difference between life and death and the economic aspects are thus of minor importance in these cases." (Frasier, 1975).

In the past, many water harvesting systems failed because the required maintenance was not performed in a timely manner. Other systems failed, despite proper design and materials, because of social and economic factors. A successful system must be:

(1) technically sound, properly designed, and maintained,

(2) socially acceptable to the water user, and

(3) economically feasible in both initial cost and maintenance at the user level.

There is no universally "best" system. Some type of system will be "best" for the given location. Each site has unique characteristics that influence the design of the optimum system. All factors--technical, social and economic--must be considered. We do have adequate technology to construct effective water-harvesting systems. Unfortunately, the cost of the facilities limit their potential use for rangeland water supplies.

There is still a need in many areas for new water developments. There are large expanses of semi-arid lands in Africa, the Middle East and Asia where water harvesting is currently the only source of water for animal and domestic use. In these places, they are using a mixture of new and old techniques. Currently, there is little research effort on water harvesting techniques or materials being conducted in the United States.

A review of the past shows that the use of water harvesting for water supply has "come" and "gone" several times. It is expected that this will happen again in the future and that the only thing that will change are some materials for constructing the systems.

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RANGELAND WATER DEVELOPMENTS AND LIVESTOCK MANAGEMENT

WATERSHED RESTORATION THROUGH INTEGRATED RESOURCE MANAGEMENT ON PUBLIC AND PRIVATE RANGELANDS

By

Sid Goodloe*

*Owner/Operator Carrizon Valley Ranch Box 598, Capitan, NM 88316

ABSTRACT

Until recently much of the rangeland in the western United States was in a serious downward trend. Water quality and quantity was declining as the result of the continuous livestock grazing practices employed at the turn of the century followed by 80 years of fire suppression. Thirty-five years of integrated/holistic resource management at the Carrizo Valley Ranch site has reversed this trend. In addition to restoration of rangeland productivity, the riparian area on the ranch has been restored, wildlife populations enhanced and perennial streamflow restored. The practical experience gained at the ranch should be useful to private landowners, public land managers, and water quality agencies throughout the brittle ecosystems of the southwestern United States. Some of the techniques perfected at Carrizo Valley Ranch are being demonstrated on an adjacent watershed in the Smokey Bear Ranger District of the Lincoln National Forest.

BACKGROUND

The shortgrass rangelands found in the western United States are generally harsh ecosystems. Careful management of these areas is essential if they are to maintain sustained production or recover from past land management mistakes (Stoddart et al. 1975). Many watersheds in the west contribute massive loads of sediment washed from the land surface or scoured from eroding gullies and stream banks to the streams and rivers which drain them. The New Mexico Environment Department reports that 95% of the states surface water is impacted by nonpoint source pollution (NMED 1990) and that turbidity is one of the major causes of use impairment in these waters (NMED 1988). Reports by early surveyors, naturalists and trappers detail the abundance of grass and clear, clean water found on these same watersheds (Leopold 1933/1991), a sharp contrast to the conditions seen today.

Many factors have contributed to the drastic changes that can be seen in the rangeland watersheds of the western United States, but most range management professionals agree that the heavy stocking rates and the continuous grazing practiced by stockmen at the end of the 1800's followed by increasingly efficient fire suppression are the leading causes of these changes. H.L. Bently and E.O. Wooten, early agricultural agents in Texas and New Mexico, described the situation "In a short time every acre of grass was stocked beyond its fullest capacity. . . The grasses were entirely consumed; their very short roots were trampled into the dust and destroyed" (Bently 1898). "The stockman could not protect the range from himself, because any improvement of his range was only an inducement for someone else to bring stock in upon it; so he put the extra stock on himself" (Wooten 1908). As a result, native grasses were replaced by sagebrush, mesquite, juniper, and other invading brush species that were less suited for holding soil in place (Chaney et al. 1990), and which were more efficient at water extraction (Stoddart et al 1975). Topsoil, which requires thousands of years to develop in harsh ecosystems (Brady 1974) washed away; gullies formed from unchecked, concentrated runoff; stream banks eroded and downcut; water tables lowered; and perennial streams became intermittent or dry (Chaney et al. 1990, Platts 1990).

The ability of the land to recover from these effects has been greatly reduced because the entire ecosystem had been so radically altered. The harshness of the environment contributes to the difficulty in reestablishing the climax or the highest ecological condition of the range. As a result, simple manipulation of a single range management factor, such as reducing livestock numbers, is not sufficient to result in significant environmental improvement (DeBano & Schmidt 1989). These systems will take many years to recover by themselves. Direct actions aimed at total watershed rehabilitation and applied in a holistic and integrated system are necessary to

ensure the restoration of western watersheds and associated natural resources of water, timber, grass, wildlife and fisheries (Platts 1990). This type of integrated or holistic resource management has been successfully demonstrated on the Carrizo Valley Ranch.

INTEGRATED RESOURCE MANAGEMENT ON PRIVATE LANDS

There are many definitions of Integrated/Holistic Resource Management (IRM) but I like to define it as the integration of all components, economic, human and environmental into a synergistic, comprehensive plan that allows management for long-term sustainability rather than short-term production. This type of management is essential for protecting valuable natural resources found in our western watersheds and is also an essential management tool for protecting the entire planet. Considering the unlimited supply of examples of bad natural resource management in every state of the U.S. and in every country in the world, it is clear that we are now charged with the responsibility of not only managing the resources under our jurisdiction in an integrated manner, but we must also inform politicians and populations everywhere that we are no longer in the pioneering/unplanned development mode. We have reached the point that resource interrelationships must be recognized and development planned accordingly. Pressing needs of growing populations must be met but not at the expense of the ecosystems sustainability.

INITIAL ACTIONS

My ranch is located in the South Central Mountains of New Mexico at about 7000' elevation. Average annual precipitation is about 46 cm (18 inches) one-half of which falls as snow. The soils range from gravelly hillsides to clay and clay loam bottoms. Watercourses on the ranch were actively eroded and brush infestation flourishing when I purchased the property. My

most demanding problem was the homogeneous vegetation composition and low herbage production. The major portion of the ranch had scattered to thick stands of pinon-juniper that were even aged populations. Areas between the trees as well as directly under the canopy were bare and subject to erosion.

I began to study the origination of this eroded, brush infested condition. I realized that year long grazing and brush infestation were severely limiting herbage production. My initial strategies were 1) to divide the ranch into summer and winter pastures, so I could at least reserve some winter grazing and 2) to begin a systematic brush control program. Although these changes were beneficial, it was not until I spent time in Rhodesia (Zimbabwe) in 1964, that I experienced first hand and began to understand the principles of Short Duration Grazing in action, and the dynamics of an open savannah ecosystem. I recorded my findings in a paper published in the November 1969 issue of the *Journal of Range Management*, returned to my ranch, and after some very low budget fencing, put these principles into practice.

ROTATIONAL GRAZING SYSTEM

I divided large paddocks into much smaller ones using posts cut on the ranch to support a three-wire suspension fence. Paddock division was planned according to topography, existing fences and available water -- not in the wagon wheel or grazing cell pattern often advocated. Once the rotation had become established, the cattle practically moved themselves -- anticipating paddock changes. I found that graze and rest periods could be adjusted to fit the current precipitation and season of use. I also found that as the vegetative growth rate increases, so should the frequency of rotation and that rotation during the dormant season was not necessary. My initial goal now became "to produce the maximum pounds of marketable beef per hectare

while improving range condition." This naive, but commendable goal was economically impractical in a period of low beef prices, so I needed to find other profitable uses of available resources.

ADDITIONAL INCOME SOURCE

Fee hunting of deer and turkey became a significant income producer immediately after I built a cabin to facilitate game harvest. As a result, improved wildlife habitat and overall aesthetic quality became my secondary goal.

RETURN TO CLIMAX CONDITION AS THE PRIMARY GOAL

The pieces of the puzzle then began to fall into place. I realized that if fish and beaver appeared on the 600 year old Indian Petroglyphs on my place, there certainly must have been running streams where I now found only arroyos with steep banks and dry rocky bottoms. I researched 100 year old surveyors notes that described the terrain as an open savannah rather than an almost solid canopy of invading brush species. I realized that the invading brush, made possible by year-long grazing and 80 years of total fire suppression was not only removing most of the moisture from the soil, but was also shutting down herbage growth, thereby causing sheet and gully erosion. I recognized that although I had previously discounted a return to climax or near climax condition, I might be able to make economic sense out of that approach if it became my primary goal. I visualized the open savanna as it was over 100 years ago, with mixed confers on the north slopes and the highly productive riparian areas that made up the mosaic of the Carrizo Valley.

BRUSH MANAGEMENT AND WATERSHED STABILIZATION

I then began to implement a cautious return to climax in a manner that was economically justifiable in my situation. Mechanical removal of invading pinon-juniper in an area that requires 10-15 hectares per animal unit could not be justified because costs were higher than land values. However, some mechanical brush control in the better soil types was required as was erosion control (i.e. reseeding, pushing invading brush into active gullies and building water retention dams). It was necessary to finance this using other available resources.

Selective thinning of young invaders, followed by prescribed burning and reseeding with native grass species became the major thrust of the plan to return to a climax ecosystem. The by-products: fence posts, fuel wood, vigas, trees for landscaping, and Christmas trees financed the plan. Another beneficial by-product was the increase in mule deer population, not only because of habitat improvement, but because ponderosa pine vigas must be cut and peeled during the winter months. This provided an adequate supply of green browse (tree tops) throughout the winter, resulting in a significant (30-50%) increase in the fawn crop. The open savanna created contained 500-800 year-old juniper trees, scattered ponderosa pines, and is carpeted with a mix of warm and cool season grasses and forbs. I have found that because deer and turkey evolved under this type of ecosystem they seem to prefer it to the contiguous brush infested public land. This is what I call an "eco-recreation benefit". These factors sharply increased income from hunting and paid for more of the necessary mechanical rehabilitation work.

THE ROLE OF FIRE

The long sought-after open savanna is now well established in the Carrizo Valley, but it must be maintained with periodic fire as it was in the climax. Tree ring research in New Mexico

indicates that most forest areas burned, on the average, at 7 to 10 year intervals (Stoddart et. al. 1975) before fire suppression began. The key to the successful maintenance burn is the fuel load (as well as the climatic conditions of course). There must be enough herbaceous material to carry a fire which is hot enough to kill brush but cool enough not to damage the beneficial species. The damaging fires in Yellowstone a few years ago demonstrated that the no-burn policy, which originated in the ecologically different European forests, was an incorrect choice for western watersheds. Now after many years of fire suppression, similar fuel loading is evident throughout the Western United States, and has made the initial prescribed burn risky, to say the least.

LIVESTOCK SUITED TO THEIR ENVIRONMENT

The pivotal economic component of my operation is the production of weaner calves, but for breeding and beef. Low-input, sustained production is my goal and is achieved by using an animal that is fine tuned to the environment and produces a desirable, marketable product. The hostile factors in our environment are snow, cold, wind, and dry weather. A cow that can produce under these conditions must be, first of all fertile in that environment. She should be black so that wind and snow will not cause or aggravate pink eye and cancer eye. Black, of course, absorbs as much sparse winter sunlight as is possible and black udders do not blister in spring snow storms. The animal that fulfills all these requirements is a composite breed that I have developed through 20 years of selective breeding, called the Alpine Black -- three-quarters Angus and one-quarter beef-type Brown Swiss. Just as the Zebu composites fit the Gulf Coast and southern deserts, the Alpine Black fits the western mountains of Northern America.

TANGIBLE BENEFITS

The road back to climax has revealed many changes in 30 years. Water sources that were dry now have permanent running water and lush riparian areas. Grass production has increased dramatically and provided more carrying capacity. Alpine Black cattle are in sync with their environment and their habitat has improved as well. Recreation potential is greatly enhanced due to a more pleasing aesthetic atmosphere and larger wildlife population.

APPLICABILITY OF CASE STUDY RESULTS TO WESTERN WATERSHEDS

The pinon-juniper (PJ) complex comprises more than 63 million acres of the rangeland in the southwest. This ecotype is a critical component of the arid region. Pinon and juniper generally form the intermediary boundary between the flatter grassland type climax community found on the lower slopes and the conifer forest climax community of the mountain tops. Considerable debate regarding the density of the PJ canopy in climax conditions has hindered some watershed restoration efforts. Most range conservationists agree, however, that much of the PJ found on the lower slopes has escaped its original range and modified some of the original savannah type ecosystem to a more woodland type. Originally the PJ occupied a discrete ecotone in many watersheds but lack of fire and overuse by livestock have left these once stable areas in poor condition. Many, however, have a high potential for range improvement and re-vegetation. In areas where the PJ complex is in especially poor condition, range improvement can substantially reduce the erosion and sedimentation originating from these degraded areas (Stoddart et al. 1975). Some of the most informed members of the environmental community support restoration of western watersheds but question the removal of pinon and juniper vegetation from those areas where the species are in the climax community. As opposed to brush

removal and range reseeding on areas historically known or reasoned to be grassland, brush removal on certain areas can have the potential to increase sedimentation and erosion rather than decrease it. Information gained from the Carrizo Valley Ranch can be useful to managers needing to determine if brush management can be reasonably and safely completed and a sustainable system established.

Riparian areas and the water they surround are of special consequence in arid ecosystems. These areas constitute about 2% of the total western acreage, yet they are among the most productive and valuable lands. DeBano & Schmidt (1989) have described the relationship of upland watershed condition to riparian condition and found, not surprisingly, a direct correlation between degraded upland watershed condition and degraded riparian area condition. They concluded that adequate treatment of all critical areas in the upper watershed is necessary to provide a stable and sustainable riparian area and is critical when attempting any riparian restoration project. On Carrizo Valley Ranch, we completed most of the upper watershed work (stabilizing gullies, removing invading brush, and re-vegetating bare ground) before being able to maintain a stable riparian area. Chaney and his coworkers (1990) and Platts (1990) found that maintenance of riparian areas, once restored, requires a different grazing strategy than upland sites. Although I have done some riparian corridor fencing which works to protect the riparian area from livestock access, I have demonstrated that as long as the principle-limited and managed access -- is applied, fencing is not always a required component. The key to the effective riparian protection demonstrated at Carrizo Valley Ranch is protection during the growing season, if possible, and rapid rotation when not.

IRM ON PUBLIC LANDS – CARRIZO DEMONSTRATION AREA

The watershed about the Carrizo Valley Ranch is part of the Smokey Bear Ranger District of the Lincoln National Forest. In 1989 the USFS began a watershed restoration and demonstration project on 55,000 acres of National Forest and private land as part of its ecological approach to multiple-use management of the PJ ecosystem. The project area contains large expanses of continuous canopy pinon-juniper, that prior to the introduction of livestock in the 1800's and subsequent fire suppression, supported a wide variety of native grass plants. As the range degraded, trees out-competed grass for available moisture and soon much of the productive soil beneath these dense woodland stands eroded away leaving behind an extensive and active gully system that continues to transport silt laden water into streams and rivers (Edwards/USFS 1990). With the urging of private land owners that for years had to contend with the deposition of millions of tons of sediment that originated on National Forest Land, and who had demonstrated that watershed rehabilitation was not possible on their private land holdings, a unique, cooperative watershed based project was begun. The project focuses on soil stabilization practices, vegetation management, water resource development, vehicular travel management and sound grazing management practices. The project's goals include control of soil erosion, stabilization of steep gully slopes, restoration of permanent riparian vegetation and the rehabilitation of native rangelands to support a sustainable mix of native grass and woody plants.

As the result of treatments –begun in 1989 – cool season native species of grass and forbs long absent from the National Forest have returned; in several drainage springs have begun to flow again and a wide variety of upland and riparian wildlife species have returned to the area making use of the increased edge areas, water supplies and additional food sources. On private lands adjacent to the forest, benefits have also been reported. In one area, 4,800 cubic yards of

sediment from gully and sheet erosion originating on National Forest land was cleaned out of a pond. The following Spring, after implementation of watershed restoration treatments on the forest, a spring which had not run for 50 years, began to flow and continued to flow throughout the summer, filling the pond with clear water. The pond has now been stocked with trout and catfish.

SUMMARY

Integrated resource management is the professional vernacular describing what managers do who are in tune with efficient, sustained use of the resources that are their responsibility. If the use of one resource affects the health or production of another adversely, then the whole is diminished and economic and environmental costs are guaranteed to surface somewhere sometime. Common sense and vision provide the foundation for bringing all parts of the whole together into a comprehensive management plan. Interestingly enough, as are many things in life, it is elusive because it is so simple. And yet, if we entered long term survival, we must implement this approach in every phase of Natural Resource Management. As watershed restoration and rehabilitation work continues, it is important to understand that there will never be sufficient government resources to treat every problem in every area. Thus, success lies in demonstrating techniques such as those developed on Carrizo Valley Ranch which provide internal and self-sustaining motivation for adoption on both private and public lands.

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THE EFFECTS OF RANGELAND WATER DEVELOPMENTS ON LIVESTOCK PRODUCTION AND DISTRIBUTION[1]

by

Jerry L. Holechek, Ph.D.
Professor, Range Science
Dept. of Animal and Range Sciences
New Mexico State University
Las Cruces, NM 88003

for

"Symposium on Environmental, Economic, and Legal Issues Related to Rangeland Water Development"

at

ASU College of Law, Tempe, AZ
November 13, 14, and 15, 1997

Sponsored by

Center for the Study of Law, Science and Technology
Arizona State University

[1]This paper was supported by the New Mexico Agr. Exp. Sta., Las Cruces, New Mexico and was part of project 1-5-27417.

Abstract

Objectives of this paper were to evaluate how the level of water development on rangelands impacts livestock production and distribution. Information on this subject is somewhat restricted even though it is one of the most important considerations in range management. Limited information from the United States and Australia shows cow-calf production is significantly reduced when cows must travel over a mile between feed and water. Cattle will use areas over 2 miles from water only after forage is severely depleted in the zone 1.5 miles for water. Generally areas over 2 miles from water should be considered unusable by cattle because high energy expenditure in animal travel nullifies weight gains, heavy trampling loss of forage occurs from excessive trailing, and severe grazing will occur on forage plants within 1 mile of water. Because sheep are often herded and require water only every other day, areas 2 to 3 miles from water can be used by mature animals without young. However studies from Australia show sharp reductions in lamb daily gains occur when daily travel distances exceed 1 mile.

Water quality can have a major impact on livestock performance. Stock pond water heavily contaminated with urine and feces has severely depressed cattle daily gains compared to those with access to clean water.

Generally watering point development is justified when areas with over 120 lbs/acre/year of perennial forage production exist over 2 miles from water. On most desert rangelands a permanent watering point spacing of 2 1/2 - 3 miles apart will be ideal. This means about 4,000 to 6,500 acres per watering point. On the more humid prairie ranges 2 - 2 1/2 mile spacings of permanent watering points is most practical. This means about 2,000 to 4,000 acres per permanent watering point. A closer spacing of watering points is justified for rangelands in high ecological condition and under

rotational grazing systems than for areas in low ecological condition and/or grazed continuously or season long.

Key Words: Range management, cattle, nutrition

Introduction

Proper water development is one of the most critical factors affecting ranching sustainability in the western United States and other arid regions of the world. However the amount of research on this subject is surprisingly restricted. This is particularly the case for the influence of water developments on range livestock productivity. Information is more available for the impacts of water developments on livestock distribution. From a practical standpoint both subjects are closely related and determine the spacing and type of watering points required to efficiently operate any particular ranch.

In this paper I will address the subjects of how watering point spacing influences range livestock productivity and efficiency of use of rangeland forage resources. I will also review information on how water quality affects rangeland livestock productivity. Then I will provide practical guidelines on how rangelands can be capitalized with watering points to optimize costs, forage harvest efficiency and livestock productivity. Important sources of information for my review are Vallentine (1990) and Holechek et al. (1998).

Influences of Watering Points on Range Livestock Productivity

Travel Distance to Water

Although livestock will travel great distances to water, this is not in the best interest of the animal or the range resource. Travel increases energy expenditure by the animal that otherwise would go into production (weight gain and milk production), and take away from grazing and resting time (Squires 1978). Unfortunately actual research on how travel distance to water impacts livestock

performance is limited to one study with cattle on cold desert rangeland in southeastern Oregon (Sneva et al. 1973, 1977) and one study with sheep from Australia (Squires 1970). Both studies indicate that young animals experience major reductions in productivity when travel distance between feed and water exceeds 1 mile. I will review in detail the Sneva et al. (1973, 1977) study with cattle.

Table 1 provides a summary of average daily gains for different classes of cattle when trailed 1 mile to water compared to those with water close by (Sneva et al. 1973, 1977). This study was well replicated in time and space. Traveling lanes devoid of forage were used to obtain the 1 mile travel distance. In this study calf performance more affected by trailing than yearling or cow performance. Daily water consumption was studied during the second year of study (1971). It was reduced about 27% for trailing compared to non-trailing animals.

Calf behavior in this study had important implications. Calves did not always trail with their dams to water, but lay down at various distances from water to await their dam's return. On hot days when temperatures were over 80°F cows tended to linger at water and calves were less likely to accompany cows to water. This indicates in warmer areas, such as southern Arizona and New Mexico, where summer day time temperatures are usually above 90°F trailing to water may have a more adverse impact on calf performance. However calf age and succulence of vegetation would probably influence this relationship. Calves depend less on milk and more on forage when over 75 days in age. Therefore calves under 2 1/2 months in age should be less affected by cow trailing distance to water than those that are older.

Sneva et al. (1973) questioned the financial benefits of watering point spacing closer than 2 miles apart even from the standpoint of calves and yearlings. However this study indicated that if cattle must trail much over a mile between feed and water major reductions in calf weight gains can

be expected.

Squires (1970), in Australia, compared performance of confined lambs with those forced to travel gradually increasing distances from 0.5 to 2.5 miles. The confined lambs gained 219 grams per day compared to 126 grams per day for lambs that were trailed. This study, like Sneva et al. (1973) with cattle, indicated major reductions in livestock performance occur when trailing distances to water exceed 1 mile.

On many arid western rangelands in the United States it is a common practice to haul water to livestock. On salt desert range in Utah, sheep supplied with water by hauling gained several more pounds than those trailed to water (Hutchings 1946). Hauling water greatly improved uniformity of rangeland use.

In the shortgrass prairie of Wyoming, Hart et al. (1993) found calves gained 20% more on moderately stocked pastures with a 1 mile maximum distance to water compared to a similarly stocked pasture with a 3 mile maximum distance to water. Animals in the pasture with a 3 mile maximum distance to water had nearly double the daily travel distance (3.8 miles) of cattle in pastures with a 1 mile maximum distance to water (2.0 miles).

Both mature cattle and sheep without young will use areas 2-4 miles from water during periods of cool temperatures and when forage is succulent (Herbel and Nelson 1966, Squires et al. 1972). However limited research indicates that when livestock must travel over 2 miles between feed and water the nutritional benefits of range forage are likely to nullified by the high energy cost associated with travel (Squires 1978, Havstad and Malechek 1982). Table 2 provides a summary of effective travel distances from water of various types of livestock based on research previously reviewed.

More research is needed on how differing travel distances between feed and water affects performance of different types and breeds of livestock.

Water Requirements

Livestock vary greatly in their water requirements, watering frequency, and distance they will travel from water. Table 3 shows the daily water intake and frequency of watering for various types of livestock in arid areas. For best results, cattle should be watered daily but sheep and goats can be watered every 2 to 3 days. Horses may require water daily if vegetation is mature and dry but can go without water up to 3 days when vegetation is succulent. Sheep have gone without water for up to 11 days under hot conditions without adverse affects when the moisture content of the feed was high (Lynch 1974).

On salt desert range Hutchings (1946) found that sheep watered daily, every second day, and every third day gained 3.3 lbs, 0.8 lbs, and lost 5.9 lbs, respectively over a 40 day period. Sheep watered daily ate a greater variety of plants, ate more dry material, grazed more quietly, and utilized the range more uniformly. This study indicated that, if possible, sheep on dry ranges should be watered daily.

In Kenya, Musimba et al. (1987) found that zebu cattle watered every other day and every third day had forage intake reductions of 48% and 50%, respectively, compared to cattle watered every day during the dry season. These differences, however, were greatly reduced in the wet season. In his study, watering frequency had small influence on weight changes over the entire study period. However, cattle during the dry season lost weight under the intermittent water regime, while those watered daily maintained weight.

A final point concerns temperature. As temperature increases, livestock water requirements increase. Above 85°F, livestock water requirements increase sharply. This is important to recognize when planning water provision for livestock in desert areas.

Importance of Water Quality

Salinity content of the water and forage can affect watering frequency. Sheep grazing saltbush (*Atriplex* sp.) have been observed to drink twice daily (Squires and Wilson 1970). Cattle have been observed to drink twice daily in New Mexico when the water was high in total dissolved solids (TDS) (over 4,000 mg/L TDS). Most animals can tolerate TDS levels up to 3,000 ppm TDS. Beyond this level the tolerance varies greatly between animals. Sheep and goats have a higher tolerance than cattle to salt. Young, pregnant, and lactating animals have less salt tolerance than do nonproducing animals.

When water is low in either quantity or quality , animal production can be reduced. Forage intake is well associated with water intake (Hyder et al. 1968). When water intake is reduced, animal gain drops due to reduced forage consumption.

On northeastern Oregon mountain range, daily weight gains in late spring were 1.78 lb. per day for yearling cattle with a good supply of clean water, compared to 0.18 lb. for yearling cattle watering from small ponds contaminated by urine and feces (Holechek 1980). When cattle with the contaminated water were provided with clean water their daily gains and forage intake both sharply increased (Table 4). This study shows the critical importance of a good supply of clean water to range livestock production.

Water Influences on Livestock Distribution

Several studies have evaluated the influence of watering points on livestock distribution. These include Valentine (1947), Holscher and Woolfolk (1953), Mueggler (1965), Martin and Ward (1973), Beck (1978), Gillen et al. (1984), Pinchak et al. (1991), Hart et al. (1993), Fusco et al. (1995), and Kie and Boroski (1996). Poor water distribution has been the primary cause of poor livestock distribution. Valentine (1947), in the Chihuahuan desert of southern New Mexico, documented cattle use patterns at varying distances rom water under moderate, continuous grazing and flat terrain. His study showed very little use occurred in the zone over 2 miles from water (Table 5). Use in the zone 1-2 miles from water was only about 50% of that in the zone 1 mile from water. A more recent study in the same area showed long term heavy continuous grazing (50-60% forage use) severely depleted forage in the zone 0-1 miles from water (Fusco et al. 1995). However under long term continuous conservative stocking, involving about 35%, forage was only depleted in zone under one quarter mile from water (Figure 1). Other studies have indicated that under moderate grazing intensities the reduction in forage availability occurs mostly in the zone under 500 yards from water (Holscher and Woolfolk 1953, Martin and Ward 1970, Soltero et al. 1989). After considering the various studies on livestock performance and distribution in relation to water availability, Holechek (1988) developed guidelines for adjusting stocking rates for zones different distances from water (Table 6).

Although many studies have been conducted evaluating rotation grazing systems, very few have evaluated how these systems affected forage resources at varying distances from water. Theoretically one of the biggest benefits of rotation grazing systems should be to provide a recovery period for the zone around watering points. A well designed study on desert grassland in Arizona

showed rotation of cattle access to watering points improved the uniformity of pasture use and provided vegetation around watering points the opportunity to recover (Martin and Ward 1970) (Table 7). Rotation of access to watering points is a very sound practice in arid and desert areas. This practice is often economically much more feasible than implementation of a specialized grazing system (high fencing costs).

Recommendations on Watering Point Spacing

Several range researchers and experienced range managers have made recommendations on watering point spacings for different types of rangelands. These are discussed by Bell (1973), Stoddart et al. (1975), Vallentine (1990), and Holechek et al. (1995). There is general consensus among these authorities that distances between watering points for different rangeland physical conditions should be as follows:

Rough country	=	1 mile
Rolling, hilly country	=	2 miles
Flat country	=	4 miles
Smooth, sandy country	=	3 miles
Undulating, sandy country (dunes)	=	2 miles

Barnes (1914) recommended that cattle in rough topography should not have to travel over 1 mile to water. In flat country, he suggested travel distances should not exceed 2 miles. On mountain range in northeastern Oregon, Goebel (1956) believed 0.5 to 0.8 mi was the ideal distance

between watering points.

Two studies are available from mountain rangeland in the western United States that evaluated cattle preferences for areas different distances from water (Gillen et al. 1984, Pinchak et al. 1991). Both studies showed cattle had a high preference for areas within a quarter miles from water, but made little use of areas over a half mile from water. In the Pinchak et al. (1991) study, 77% of observed cattle use occurred within 400 yards of water. In this study approximately 65% of the land area was beyond 800 yards from water, but it received only 12% of observed cattle use. Both studies support the standard recommendation by range authorities that watering point spacings be no more than 1 mile apart in mountainous or rugged, hilly terrain.

Financial Considerations

One of the most important questions confronting ranchers centers around how much infrastructure (corrals, fences, and watering points) they need to efficiently use their forage resources. On the smaller ranches there has been a historic tendency to substitute watering points and fence for grass when the goal was increased grazing capacity. However, knowledgeable ranch buyers look for ranches with minimal infrastructure and high amounts of forage. They know it's usually much cheaper to create infrastructure than increase forage.

On most arid land ranches in the Chihuahuan desert or sagebrush type, infrastructure costs become excessive relative to potential earnings when permanent watering points exceed one per 4,000 acres (2 1/2 miles spacing) (Holechek and Hawkes 1993). In the more productive prairie areas of the Great Plains less than 2,600 acres per watering point (2 miles spacing) would usually represent excessive capitalization. However, it is important to point out that more watering points are justified

on ranches with high grazing capacity than those that are degraded, or have low forage production potential. Watering points improve the efficiency of range forage use. As forage production per acre increases, there is more potential to increase financial returns from improvements in forage harvest efficiency with water development (Holechek 1992). The key here is to know future value of the extra forage that can be used compared to the cost of the watering points.

Holechek (1992) evaluated permanent watering point spacings on Chihuahuan Desert rangeland in southern New Mexico. He found the average spacing was 4 to 4 1/2 miles apart. Changing spacings to 2 to 3 miles apart could increase grazing capacity by 25 to 35% on many of the ranches evaluated (Holechek 1992). The primary criteria for successful water development was that perennial forage production must be at least 120 lbs/acre in the zone 2 to 3 miles from water. Under these conditions, return on investment from water development would usually be quite favorable (8-16%).

In many desert areas water development will involve less risk and give greater financial returns if used to improve livestock distribution rather than increase grazing capacity (Holechek 1992). Improved cattle performance will usually make this a sound investment (over 10% return) even on a short term (3-5 years) basis.

Perhaps the greatest problem with development of water in the 2 to 3 mile zone is degradation of rangeland in high ecological condition. Jensen and Schumacher (1969) reported that adding a third watering point to a prairie pasture about 1200 acres in size resulted in slight improvement in the good and fair condition areas, but degraded the excellent condition portion. Excellent (high seral) condition rangeland is rare in most arid areas of the western United States, and usually occurs well away from water. On public lands, the social benefits of sustaining existing excellent condition

rangeland may outweigh the benefits of increasing grazing capacity for ranchers through water development. Regrettably I have observed the degradation of many publicly owned, high condition Chihuahuan Desert rangelands when permanent water developments were installed.

A 3 mile spacing of permanent watering points may have some advantages for arid rangelands in poor or fair condition (Holechek 1996). This spacing of watering points is farther apart than the commonly recommended 2 miles. However it minimizes the amount of sacrifice area that typically results from continuous grazing at moderate or heavy stocking rates. It provides a forage reserve that can be beneficial to livestock and wildlife when drought occurs. Further, it reduces some of the depreciation, maintenance, and tax costs associated with infrastructure.

Annual costs to maintain watering points can vary greatly with climatic conditions, terrain, big game use and recreational activity. However a rough guideline on annual maintenance costs for wells are $200-$350 (Holechek and Hawkes 1993). Maintenance costs for pipelines are about 100 per mile per year. The useful lives of wells, dirt tanks, and pipelines are about 27 years, 40 years, and 20 years, respectively.

Rising production costs and low livestock prices in recent years have caused many ranchers to take a close look at their infrastructure needs. Not only are watering points costly to build and maintain but they are also depreciating taxable assets. Selecting the proper number of watering points to meet specific objectives is a critical part of range management. Approaches for evaluating costs and returns from watering point development are provided by Holechek (1992) and Williams and Lacey (1995).

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Table 1. Average daily gain (lb) of cattle in southeastern Oregon as affected by trailing one mile to water and no trailing.

Period	Treatment	
	Trailing 1 mile	No trailing
May 20 - Aug 17, 1970		
Cows	1.11	1.32
Calves	1.68	2.05
Yearlings	1.10	1.37
April 16 - Aug 3, 1971		
Cows	0.48	0.41
Calves	1.70	1.80
Yearlings	1.32	1.86

Source: Sneva et al. 1973, 1977.

Table 2. Effective travel distances from water of cattle and sheep based on available research.

	Effective travel distance from water (miles)
Cattle	
Hereford cows (dry)	2.45
Santa Gertrudis (dry)	3.90
Cow - calf	1.00
Yearlings	1.2 - 1.70
Sheep	
Dorset Horn (dry)	2.80
Merino (dry)	4.20
Border Leicester (dry)	4.30
Ewe - lamb	1.0 - 1.20

Sources: Herbel and Nelson 1966, Squires 1970, Squires et al. 1972, Sneva et al. 1973, Sneva et al. 1977, Squires 1978, Hart et al. 1993.

Table 3. Daily intake and frequency of watering of range animals in the dry season.

Animal	Daily intake (gallons)	Daily intake (liters)	Frequency of drinking
Sheep	1.0 - 1.5	4 - 5	Once every 2 days
Goats	1.0 - 1.5	4 - 5	Once a day
Asses and donkeys	2.5 - 4.0	10 - 15	Once a day
Horses	6.0 - 12.0	23 - 45	Once or twice a day
Cattle	8.0 - 11.0	30 - 40	Once a day or once every 2 days
Camels	15.0 - 22.0	60 - 80	Once in 4 or 5 days

Source: Baudelaire 1972, from Stoddart et al. 1975

Table 4. Influence of water quality on nutrition and weight gains of yearling cattle in northeastern Oregon during summer 1976.

	June 20 - July 19, 1976	
	Treatment pastures (water contaminated with urine and feces)	Control pastures (clean water)
Diet crude protein %	11.7	12.2
Diet digestibility %	53.1	58.1
Forage intake (%/body wt.)	1.3	—
Daily gain (lb.)	0.18	1.66
	July 20 - Aug 17, 1976	
	Treatment pastures (clean water)	Control pastures (clean water)
Diet crude protein %	9.1	9.6
Diet digestibility %	51.8	49.2
Forage intake (%/body wt.)	2.0	—
Daily gain (lb.)	1.14	1.33

Source: Holechek 1980.

Table 5. Average percent utilization of forage by cattle on flat, good condition, Chihuahuan Desert Rangeland with varying distances from water.

Distance from water	% Utilization
0 - 0.5 mile	50
0.5 - 1.0 mile	38
1.0 - 1.5 mile	26
1.5 - 2.0 mile	17
2.0 - 2.5 mile	12

Source: Valentine 1947.

Table 6. Suggested reductions in cattle grazing capacity with distance from water.

Distance from water		
miles	km	Percent reduction in grazing capacity[a]
0 - 1	0 - 1.6	None
1 - 2	1.6 - 3.2	50
2	Over 3.2	100 (consider this area ungrazable)

Source: J. L. Holechek, 1988. An approach for setting the stocking rate. Rangelands 10:10-14, Table 4.

[a]Supporting literature includes Valentine (1947), Martin and Ward (1973), Sneva et al. (1973, 1977), Squires (1973), Beck (1978), Pinchak et al. (1991), and Hart et al. (1993).

Table 7. Herbage yield (lb/acre) of perennial grasses from part-time and yearlong access to water on southern Arizona range.

Water availability	Distance from water (yards)					
	100	200	300	400	500	Average
Part-time	14	105	167	66	101	91
Yearlong	1	22	37	61	112	47
Average	8	64	102	64	106	69

Source: Martin and Ward 1970.

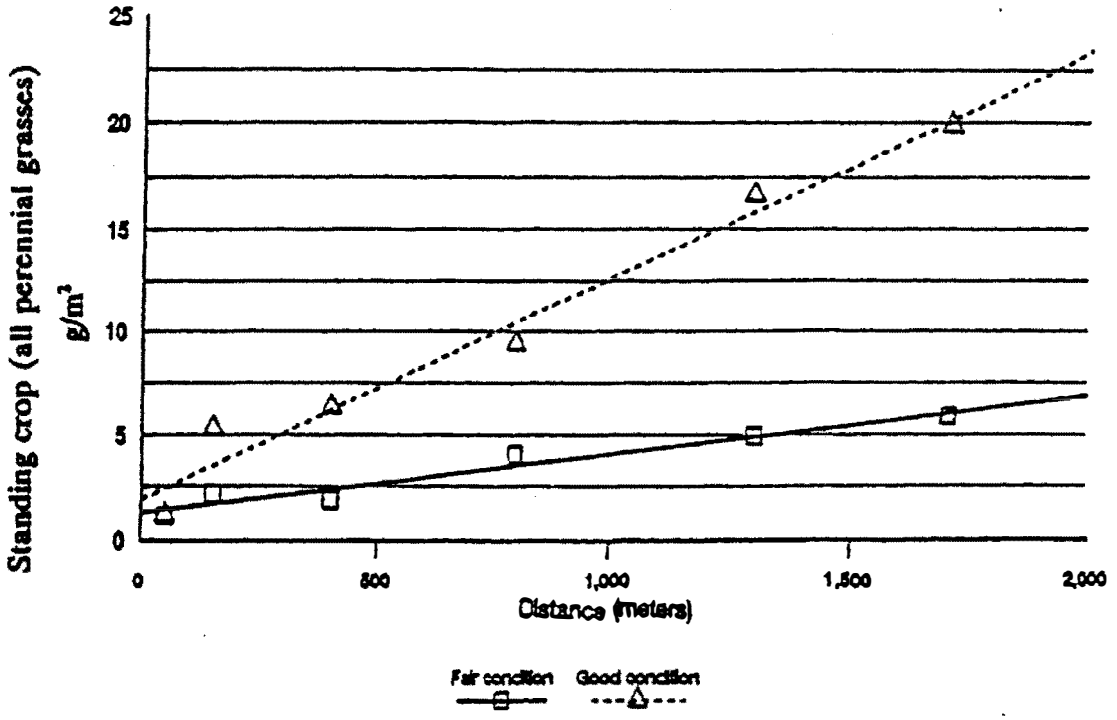

Figure 1. Standing crop (g/m^2) of all perennial grasses for data pooled across years on good and fair condition Chihuahuan Desert ranges at 6 distances from water. (From Fusco et al. 1995).

RANGELAND WATER DEVELOPMENTS AND WILDLIFE I: MAMMALS

THE EFFECTS OF ARTIFICIAL WATER DEVELOPMENTS ON UNGULATES AND LARGE CARNIVORES IN THE SOUTHWEST

Warren B. Ballard[1], Steve S. Rosenstock[1], and James C. deVos, Jr.[1]

Abstract– Since the mid-1940s the Arizona Game and Fish Department, in addition to several other Southwest state and federal agencies have pursued active wildlife water development programs. Until the mid-1960s water developments were constructed primarily to benefit game bird populations. Since that time, water developments have been directed, in part, towards benefitting several ungulate species, including, mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), pronghorn (*Antilocapra americana*), and Coues white-tailed deer (*Odocoileus virginanus couesi*). Provision of water also has been a principal management strategy for desert bighorn sheep (*Ovis canadensis mexicana)* in the Southwest. Recently, water development programs have been criticized with respect to their benefits for wildlife populations, and the possibility that they may in fact be detrimental; by enhancing predator populations and concentrating predators at water units resulting in mortality sinks for prey species. To evaluate these concerns we reviewed literature concerning the physiological importance of water and the effects of water developments on ungulates and large carnivore populations in the Southwest.

Water is an essential physiological requirement for all wildlife. A wide variety of

[1] Arizona Game and Fish Department, 2221 W. Greenway Road, Phoenix, AZ 85023

wildlife species use free water when it is available. Evidence strongly suggests that availability of free waters plays an important role in the distribution, movement, habitat use, reproduction, or survival of wildlife.

Some desert bighorn sheep populations may have benefitted as a result of water development. A number of studies have demonstrated correlations between sheep distribution and availability of water. However, the developments have not always resulted in increased sheep populations and several sheep populations exist apparently in the absence of free-standing water. Mule deer, white-tailed deer, elk, and possibly pronghorn distribution or population performance have been enhanced by water developments. Apart from anecdotal observations of predation events at water units, there is little information on the effects of water developments on carnivore densities, distributions, or kill rates. We concluded that additional research is necessary to document the effect of water developments on ungulates, carnivores, and their interrelationships.

INTRODUCTION

When Europeans arrived in the United States, they found a tremendous diversity and abundance of wildlife. However, as human populations grew, unrestricted hunting, habitat alteration, and other human impacts took a heavy toll on native fauna. By the late 1800s, populations of many North American wildlife species were greatly reduced or nearly extirpated. The first response to these declines was the establishment of laws restricting harvest of game species. The foundation of modern wildlife management in North America was laid in the early 20th century, with the publication of "Game Management" (Leopold 1933). Leopold defined fundamental requirements (e.g., food, water, cover, and space) of

wildlife populations and the principles by which they could be manipulated to meet human demands.

Early wildlife managers undertook a number of actions intended to restore or enhance wildlife populations, including reintroductions, establishing seasons and bag limits, wildlife surveys, habitat protection, and direct manipulation of habitat components. While the discipline of wildlife management has evolved since 1933, the fundamental principles and practices have not changed. In particular, management efforts have always emphasized manipulation of factors that limit wildlife populations.

In arid portions of the southwestern United States, the scarcity of free-standing water has been considered a limiting factor for many wildlife species. Wildlife managers believed that development of new water sources would increase populations of wildlife species, such as bighorn sheep, elk, mule deer, chukar (*Alectoris chukar)*, Gambel's quail (*Callipepla gambellii)*, California quail (*Lophortyx californicus*), and mourning dove (*Zenaida macroura)* (Russo 1956, Buechner 1960, Blong and Pollard 1968, Turner 1979, Bleich 1990).

The Arizona Game and Fish Department (AGFD) initiated a water development program in 1946. The initial objective of the program was to provide additional water sources in arid habitats that would allow wildlife populations to expand into unoccupied, but otherwise suitable habitats (Wright 1959). However, as rapid human population growth and the associated impacts began to affect wildlife habitat in Arizona, water developments were viewed as a means to mitigate the loss of natural water sources resulting from diversion for agriculture, farming, ranching, domestic, and industrial use; human-created barriers to wildlife movements (e.g., highways, fences); and other impacts (Wright 1959, deVos et al. 1983).

The AGFD continues to build and maintain developments designed to provide water for a variety of wildlife species. Similar programs have been carried out by resource management agencies throughout arid and semi-arid areas of the western United States (Campbell 1961, Bleich 1990).

The AGFD is mandated by Arizona statute to manage the state's wildlife populations. This direction is implemented through the Arizona Game and Fish Commission's Mission Statement that reads in part: "To conserve, enhance, and restore Arizona's diverse wildlife resources and habitats through aggressive protection and management programs..." The *Wildlife 2000 Strategic Plan* (AGFD 1995) describes strategies that AGFD will use to meet overall management goals and to maintain populations of terrestrial and aquatic wildlife species. For many species, maintaining or enhancing occupied habitats (which can include water development) is identified as a primary strategy to meet management goals. For desert bighorn sheep, water developments are specifically identified as 1 of several strategies to be employed in meeting population objectives.

For many years, the need for and value of water developments was unquestioned. Recently, however, concern has been expressed that wildlife water developments have failed to achieve desired results, and in some cases, may actually be detrimental (Broyles 1995). Two questions surrounding water developments include (Brickler et al. 1986, Broyles 1995) whether artificial water developments actually result in increased wildlife populations, and whether they facilitate range expansions by predators and potential competitors and therefore adversely affect species expected to benefit from water development.

The purpose of this paper is to review available literature concerning the physiological

water requirements of ungulates and large carnivores, and to examine the impacts of water development projects on ungulates and associated predator species.

METHODS

We reviewed available literature concerning water requirements and the effects of water developments on ungulates and carnivores. We focused on peer-reviewed scientific literature, but used other sources such as unpublished reports where peer-reviewed references were lacking. In cases where no literature existed for North America we also reviewed literature concerning ungulates and predators on the African continent.

WATER REQUIREMENTS OF MAMMALS IN ARID ENVIRONMENTS

Physiological Role of Water

Water is the most abundant compound in birds and mammals. For example, water represents >63% of the body weight of mature mule deer (Anderson 1981). Water is required for a number of physiological functions, including dissipation of heat, maintaining electrolyte and acid-base balances, nutrient transport, biochemical reactions, digestion, catabolism, excretion of waste products, and lactation. Water is essential to the survival of all animals, and wildlife species vary in the manner by which they meet their water requirements.

Two key aspects of water physiology in animals are water balance and water turnover rate. An animal is in water balance when the amount of water lost is equal to the amount gained, and adequate water is present within the body to meet physiological requirements. Water turnover rate is the total amount of water exchanged between the animal and its environment per unit of time. Thus, turnover rate is a measure of daily requirements when an animal is in a state of water balance. Water turnover is affected by many factors including

extrinsic factors (e.g., weather, food quality, food availability) and intrinsic physiological costs of different behaviors and activities (e.g., locomotion, lactation) (MacFarlane and Howard 1972). Water turnover also is positively correlated with metabolic rate; the amount of water exchanged increases along with the metabolism of the animal (MacFarlane et al. 1971). When water balance becomes negative, more water is lost than is gained. This results in dehydration, which can lead to a number of physiological changes, including reduced food intake, reduced urinary excretion, increased reabsorbtion of water from feces, increased plasma concentration, loss of extra-cellular water, alterations of blood chemistry and electrolyte balance, and reduced ability to thermoregulate. Dehydration will eventually lead to the death of an animal unless rehydration occurs.

Water Requirements

Overall, mammals living in arid environments have lower water turnover rates than their counterparts in more mesic habitats (MacFarlane and Howard 1972, Nicol 1978, Degen et al. 1982, Ambrose and Bradshaw 1988). Survival in harsh desert environments is often facilitated by low rates of movement of water and energy through animals (MacFarlane and Howard 1972). For some animals, free water is required for survival, whereas others can survive without free water if food supplies are not limiting, and temperatures do not exceed critical thresholds.

Mammalian species vary with respect to their water requirements, and these differences have a strong evolutionary component. For example, mammals that evolved in desert environments have low metabolic and water turnover rates, whereas species that evolved in mesic environments and then migrated to arid environments have higher metabolism and water

turnover rates (MacFarlane and Howard 1972).

Some arid-adapted ungulates apparently can live without water for extended periods of time. For example, desert bighorn can live for up to 10 days without drinking water (Krausman et al. 1985). Moreover, some mammals (or populations thereof) may not need free water on a seasonal or year-round basis. These species include the collared peccary (Zervanos and Day 1977), kit fox (*Vulpes macrotis*) (Golightly and Ohmart 1984), springbok (*Antidorcas marsupialis*) (Nagy and Knight 1994), the mulgara (*Dasyercus cristicauda*) (Schmidt-Nielsen and Newsome 1962), eland (*Taurotragus oryx*) (Taylor 1969a), oryx (*Oryx gazella*) (Taylor 1969b), desert bighorn (Watts 1979), and spotted hyena (*Crocuta crocuta*) (Green et al. 1984).

Water requirements are strongly affected by ambient temperatures, particularly in desert environments. Water turnover rates of mammals typically increase with ambient temperatures and are higher in summer than in winter. This seasonal change has been documented in studies of ringtail (*Bassariscus astutus*) in the Sonoran Desert (Chevalier 1984). If water is unavailable, mammals living in desert environments may have reduced survival when exposed to high temperatures. MacFarlane (1969) studied mortality of domestic animals exposed to temperatures of 40-42° C. Survival times of cattle (*Bos taurus*), Merino sheep, and camels deprived of water were 3-4 days, 6-8 days, and 15-20 days, respectively.

Herbivorous mammals, particularly ungulates, can obtain significant amounts of water from their forage, depending upon the succulence of the vegetation (Short 1981). Verme and Ullrey (1972) demonstrated experimentally that captive white-tailed deer fed succulent browse drank 0.5 kg water per kg of food consumed, whereas deer fed a dry pellet ration consumed

2.9 kg water/kg food.

Mammalian water requirements also vary with age. Young animals (from birth to 6 months of age) typically need more water than do older individuals, because water turnover is higher and water is not stored in fat and other body tissues. Davis et al. (1978) found that burros from 1.6 to 2.4 months of age had 28% higher water turnover than did 4 month-old burros. In mule deer, fawns have a greater proportion of water in their body mass and a higher metabolic rate than do adult deer, making them more susceptible to dehydration (Short 1981).

Water is essential for reproduction in mammals. Availability of free water has been found to affect reproduction in a number of species. For example, female mountain gazelles (*Gazella gazella*) and Dorcas gazelles that have access to free water reproduce at a younger age, produce young throughout the year, and have higher reproductive success (Baharav 1983).

Water is also important to pregnant and lactating female mammals. Milk is composed largely of water, consequently female mammals experience increased water requirements during lactation. In the Sonoran Desert, water turnover rates were 44% higher for lactating, compared to nonlactating female ringtails (Chevalier 1984). Similarly, Farrell and Christian (1987) reported that lactating porcupines (*Erithizon dorsatum*) consumed 15% more water than non-lactating females. Female mule deer also exhibit significant increases in water requirements during late gestation and lactation (Short 1981). Camels can catabolize body fat during water shortages to obtain water needed to produce milk during lactation (Schmidt-Nielsen 1964).

Availability of water also affects food intake. When some mammals become dehydrated they consume less food, and may stop feeding altogether. Lautier et al. (1988) found that white-tailed deer with restricted access to water consumed less forage and lost body mass compared to deer provided with water ad libitum. One deer refused to eat after 4 days of water restriction. In contrast, other mammals, such as the camel, will continue to eat even when dehydrated (Schmidt-Nielsen et al. 1956).

Sources Of Water

Animals living in arid environments can obtain water from 3 primary sources: free water, pre-formed water, and metabolic water. Free water is that which is directly available to an animal in a liquid state. Animals in arid environments can obtain free water from a number of sources, including rivers, streams, lakes, ponds, springs, seeps, artificial water developments, ephemeral pools, snow, and dew. Pre-formed water is contained within succulent plant and animal tissues, and is available to animals that consume these items. Metabolic water is produced by the breakdown of carbohydrates contained in seeds and plant parts.

Adaptations To Arid Environments

Many studies have been conducted on water conservation adaptations of animals found in arid zones of the southwestern United States, Africa, the Middle-East, Asia, and Australia. Mammals living in these areas have evolved mechanisms that allow them to survive despite limited availability of free water. These mechanisms fall into 3 general categories: physiological adaptations, behavioral adaptations, and utilization of non-free water sources.

Physiological Adaptations

Many desert mammals have high tolerances for dehydration and are able to rapidly rehydrate desiccated body tissues. Schmidt-Nielsen et al. (1956) found that camels can withstand high levels of desiccation (water loss equal to 30% of body mass) and can drink enough water in 10 minutes to achieve rehydration. Turner (1979) reported that desert bighorn sheep can lose 48% of blood plasma volume during dehydration and then replace 50% of the lost volume within 4 hours of rehydration. Mohamed et al. (1988) indicated that Dorcas gazelle replaced 85-100% of lost water within several hours after rehydration.

Control of water loss via excretion is 1 of the most important water-conservation mechanisms of arid-adapted mammals. Physiological adaptations that increase urine concentration and reduce water loss are found in a variety of desert species, including the camel (Schmidt-Nielsen et al. 1956), collared peccary (Zervanos and Hadley 1973), and many North American rodents (Schmidt-Nielsen 1964). Increased efficiency is facilitated by specialized kidneys, elongated renal papillae, and other excretory system modifications.

Desert mammals also conserve water by altering body temperatures. Some species, such as camels (Schmidt-Nielsen et al. 1957), oryx (Taylor 1969b), and hartebeest (*Alcelaphus buselaphus cockii*) (Finch and Robertshaw 1979) exhibit an increase in body temperature (hyperthermia) when under water and/or temperature stress. Hyperthermia reduces the amount of water needed for cooling and also reduces heat gain from the surrounding environment. Other species, such as the eland, conserve water by reducing body temperature at night, thereby decreasing respiratory and water turnover rates (Taylor 1969a), while other species, such as lagomorphs, use heat loading as a physiological adaptation (Schmidt-Nielsen 1964).

Behavioral Adaptations

Many arid-adapted mammals exhibit behavioral adaptations that minimize water loss. One of the most common strategies is restricting activity to nocturnal periods when temperatures are lower or humidity is higher, thus reducing water requirements. Many small mammals spend diurnal periods in underground burrows where temperature flux is greatly reduced, further reducing water loss (Hoffmeister 1986).

Some diurnal species minimize heat stress by reducing activity when ambient temperatures are high or by using microclimates with more favorable conditions. For example, the eland, which has a relatively high water requirement, reduces water loss by seeking shade and reducing activity during midday heat (Taylor 1969b). Desert mule deer move to water sources during periods of heat and drought, reduce activity during high ambient temperatures (Leopold and Krausman 1987), and also exhibit increased nocturnal activity patterns (Hayes and Krausman 1993). Small mammal species that are not physiologically well-adapted to arid deserts survive in these areas by confining their activities to more mesic microhabitats (Mares 1983).

Utilization of Non-Free Water Sources

Utilization of pre-formed and metabolic water is a common strategy of desert-adapted birds and mammals. Herbivorous animals can obtain pre-formed water by consuming succulent fungi and plant parts. Pre-formed sources of water vary in their water content: mushrooms contain up to 95% water (by weight), berries and fruits 80%, succulent leaves 70%, and mature twigs $<45\%$ (Short 1981). Carnivorous species obtain pre-formed water from the body tissues of their prey. Metabolic water is produced in the digestive tract from the breakdown of carbohydrates in seeds and plant parts.

Zervanos and Day (1977) suggested that free-ranging collared peccaries in the Sonoran Desert met their water requirements by consuming cacti pads, which had a moisture content of 77-78%. Taylor (1969b) believed that African eland and oryx obtained nearly all required water from their food. Nagy and Knight (1994) concluded that African springbok can survive without water during the dry season by selecting forage plants containing ≥67% water. Golightly and Ohmart (1984) concluded that coyotes *(Canis latrans)* used pre-formed water, and consumed more prey when free water was unavailable. Metabolic water is particularly important to granivorous mammals in very arid habitats. For example, numerous rodents exist entirely on metabolic and pre-formed water, and apparently do not use free water even when it is available (Mares 1983).

EFFECTS OF WATER DEVELOPMENTS ON WILDLIFE

The underlying assumption of water development programs has been that water was a major factor limiting reproduction, survival, and distribution of many wildlife species. In theory, once this limiting factor has been alleviated, wildlife populations should respond through some combination of expanded distribution, increased productivity, reduced mortality, increased fitness, or reduced movements. Water developments intended to benefit game animals also may affect other wildlife species.

Desert Bighorn Sheep

Water development has been a primary focus of management activities for desert bighorn sheep in the Southwest (McCarty and Bailey 1994, Krausman and Etchberger 1996). Two studies have evaluated the effects of water availability on desert bighorn populations. Leslie and Douglas (1979) demonstrated that sheep in the River Mountains, Nevada increased

with the availability of artificial water sources, and Douglas (1988) reported sheep populations in Death Valley declined in response to erratic and inadequate natural water resources.

Desert bighorn sheep distributions have been correlated with proximity to water. McCarty and Bailey (1994) reviewed 8 studies in the Southwest (i.e., Leslie and Douglas 1979; Sandoval 1980; Hansen 1982; Bates and Workman 1983; Elenowitz 1983; Cunningham and Ohmart 1986; and Wakeling and Miller 1989, 1990) which listed the average distance of individual desert bighorn sheep from water as ranging from 1,320 to 10,560 ft (400 to 3,200 m). Wakeling and Miller (1989) found that desert bighorn sheep in the Superstition Mountains, Arizona preferred to bed within 1,320 ft (400 m) of water and that numbers of bedding sites decreased with increasing distances from water. They noted that water sources were relatively common and that this mountain range may not represent a typical situation. Excluding Wakeling and Miller (1989, 1990), average sheep distances from water ranged from 2,640 to 10,560 ft (800 to 3,200 m).

Desert bighorn sheep readily use free-standing water when it is available. However, controversy exists as to whether such water is required by sheep populations and whether they benefit from its presence (Broyles 1995, Krausman and Etchberger 1996). At least 2 desert bighorn sheep populations appear to exist in the apparent absence of free standing water (Watts 1979, Krausman et al. 1985, Alderman et al. 1989). Krausman and Leopold (1986) also reported that areas used by sheep in the Harquahala Mountains, Arizona were 3 times farther from free-standing water than those areas not used by sheep.

Krausman and Etchberger (1995) compared desert bighorn movements and habitat use during and after construction of the Hayden-Rhodes Aqueduct (HRA) and several associated

water catchments in central Arizona. Bighorn home-range sizes and use of vegetation associations did not differ and sheep were not attracted to the new water catchments. They concluded that water was not a significant limiting factor on desert bighorn in this area. A related study indicated that sheep within the Little Harquahala Mountains met their water requirements from pre-formed moisture in succulent vegetation such as barrel cacti (*Ferocactus* spp.) (Warrick and Krausman 1989).

Elk

Cow elk remain relatively close to water during lactation. Miller (1974), Marcum (1975), Thomas et al. (1976), and Skovlin (1982) indicated that lactating elk have a seasonal dependency on water. Jeffrey (1963) indicated that lactating elk in Utah preferred areas within <1,769 ft (536 m) from water, while Mackie (1970) in Montana, and Nelson and Burnell (1975) in central Washington found that elk distribution during a dry summer was limited to areas <2,657 ft (805 m) from water. McCorquodale et al. (1986) also reported that the distribution of natural springs was an important determinant of habitat use by lactating cow elk in Washington, but that bull elk distribution was less constrained by free water.

Proximity to water also affects habitat use by elk in the Southwest. On the Sitgreaves National Forest, Arizona, Delgiudice and Rudiek (1984) found that elk preferred habitats within 1,326 ft (402 m) of permanent water during early spring and within 2,653 ft (804 m) during late spring-summer. The lower elk concentrations within the 1,326 ft (402 m) areas during late spring-summer probably were attributable to the presence of cattle, increased precipitation during July and August, and coincident forage recovery. In contrast, Brown (1994) described elk calving habitat in Arizona as areas within 0.25 to 0.5 mi (0.4 to 0.8 km)

of standing water. Brown (1994) noted that his results differed from those of Delgiudice and Rudiek (1984), which was attributed to the fact that he had measured distances from mid-day bed sites when elk were not seeking water. Preliminary results of a study in New Mexico using global positioning system radio collars indicated that 75% of elk locations were within 1 mi (1.6 km) of surface water (Biggs et al. 1997). Only 10% of the elk locations were greater than 2.0 mi (3.2 km) from water.

Mule and White-tailed Deer

Some experiments have been conducted to directly measure the effects of water development on deer populations. Wood et al. (1970) studied desert mule deer populations in southeastern New Mexico before and after water development. They found that habitat use by desert mule deer decreased with increasing distance from water. In 1 area, as water catchments were added, deer densities increased from 1.6 to 13.0 deer per mi^2 (0.6 to 5.0 deer/km^2) over a 5-year period. In another pasture, deer densities increased from 14.7 to 19.2 deer/mi^2 (5.7 to 7.4 deer/km^2) during the first 2 years when additional water was available. As the number of water sources declined during the third and fourth years, deer densities declined to 9.4 deer/mi^2 (3.6 deer/km^2). During the fifth year of study, 28 water catchments were built and deer densities increased from 9.4 to 22.1 deer/mi^2 (3.6 to 8.5 deer/km^2). These authors concluded that there was a direct relationship between the number of permanent water sources and deer numbers.

Correlative studies also support the notion that availability of water affects deer populations in arid habitats. deVos and Clarkson (1990) reported that desert mule deer harvests and deer hunter density were positively correlated with the numbers of water

catchment units added to 2 southwestern Arizona game management units over an 11-year period. They suggested that the deer herd had increased in response to the increased distribution and availability of water.

A number of observational studies have reported that deer use water during at least some portions of the year. Results of these studies also indicate that deer movements and habitat use in arid habitats are affected by the availability of free water.

Swank (1958) indicated that in the southern half of Arizona, dead deer could be found during any season, but serious die-offs occurred during June when vegetation was dry and deer were crowded around water holes. Swank (1958:50) stated that "Insufficient free water is indirectly a cause of mortality. As previously stated, during May and June and again in the fall deer are forced to congregate in the vicinity of permanent water. Livestock also congregate in these areas at this time. The excessive periodic pressure depletes forage in these areas, and before long the food supply falls below the demand. The inevitable die-off occurs."

Hazam and Krausman (1988) reported that in Arizona, nonmigratory desert mule deer consumed from 0.4 to 1.6 gallons (1.5 to 6.0 L) of water per catchment visit and that females drank more than males during late summer. They hypothesized that the greater quantity of water consumed by females was related to lactation requirements of females that fawned during July and August. Ordway and Krausman (1986) found that male and female desert mule deer in southern Arizona occurred closer to artificial water during early and late summer, and farther from artificial water during winter and spring.

Rautenstrauch and Krausman (1989) reported that during the summer dry season in southwest Arizona, desert mule deer either migrated to areas with permanent water, or

restricted their movements to portions of home ranges containing permanent water. This deer herd had large seasonal home ranges in comparison to other migratory deer herds; migratory females averaged 12, 24, 19, and 12 square mi (30, 62, 48, and 30 km^2) during winter, spring, summer dry, and summer wet seasons, respectively. They concluded that deer in this area moved to summer-dry-season home ranges to obtain water, and speculated that deer concentrations near water sources during the dry season could decrease forage availability, making it advantageous for deer to migrate to other portions of their range when water becomes available. They also surmised that because water catchments have been developed in most desert mule deer habitats, few, if any, other mule deer populations now migrate to obtain water.

Hervert and Krausman (1986) monitored watering frequency of desert mule deer in 2 Arizona study areas. They found that adult females came to water once per night when ambient temperatures were high and consumed an average of 1.4 gallons (5.1 L) per visit, but that males were not predictable in their use of water. They experimentally removed access to water catchments for 3 adult females during summer 1993. All 3 females left their established home ranges and used alternative water sources in areas with little palatable forage, but returned to their home ranges within 1 hour after drinking. They concluded that the 3 deer were at least behaviorally dependent on free-standing water. Deer did not use water catchments during wet winter and spring months, and either used alternative water sources or acquired enough water from forage. A number of other studies have demonstrated changes in habitat use in response to water availability (Clark 1953, Hanson and McCulloch 1955, Johnson 1962, Wood et al. 1970, Rodgers et al. 1978, Bellantoni et al. 1993).

Boroski and Mossman (1996) studied the spatial distribution of mule deer in 2 study areas in California. Distribution was influenced by deer use of water, but when water needs were met, deer distribution was probably influenced by other factors. The distance deer were located from water was influenced by variation among individual deer within regions, time of year (e.g., shortest distance in June and greatest distance in October), and whether or not female deer had fawns. Deer distance from water during summer was negatively correlated with the density of water sources. They concluded that the their results supported a habitat capability model suggesting that water sources be spaced no more than 1.9 mi (3.2 km) apart.

Maghini and Smith (1990) compared water use and diurnal seasonal home ranges of Coues white-tailed deer in southeastern Arizona between 2 years; during 1988, developed water sources were "scarce", while in 1989, water sources were "abundant". They found no statistical differences in diurnal hot-dry seasonal home ranges or hot-wet seasonal home ranges between years, and concluded that water was not the only factor determining home range size. Deer visited water sources more frequently during hot-dry than hot-wet seasons. They suggested that movements of deer from established ranges to distant water sources demonstrated a "need" for free-standing water. However, Anthony (1976) reported that mule deer and Coues white-tailed deer in south-central Arizona had larger movement patterns during a 1-year drought.

In desert areas, the distribution of white-tailed deer is tied closely to the occurrence of free standing water (Henry and Sowls 1980, Krausman and Ables 1981, Ockenfels et al. 1991); areas without free standing water receive little or no use by white-tailed deer. Ockenfels et al. (1991) further indicated that Coues white-tailed deer in Arizona had a strong

dependence on human-made water sources. Deer strongly selected areas within a 1,320 foot (400 m) radius of water, whereas areas >3,960 ft (1,200 m) from water were avoided.

Both Barsch (1977) and Ockenfels et al. (1991) found greater use of foraging areas near permanent water. Verme and Ullrey (1984) found that use of free standing water was inversely related to forage moisture content. Ockenfels et al. (1991) suggested that the availability of free standing water could make the difference between poor fawn survival at birth, or good recruitment into the population when forage moisture was low.

Krausman (1978) studied diets of white-tailed and desert mule deer in Big Bend National Park, Texas. On ranges occupied only by mule deer, succulent plants made up the largest portion of the diet, whereas on ranges occupied only by white-tailed deer, browse species comprised the bulk of the diet. He concluded that although the carbohydrates contained in succulents were important to both deer species, pre-formed water content may be more critical to white-tailed deer, especially when free standing water was not available.

Pronghorn

Yoakum (1994) reported that apparently high density pronghorn populations were associated with abundant, available drinking water, while arid habitats with few permanent water sites supported low pronghorn densities. Beale and Smith (1970) found that water consumption by pronghorn in western Utah varied inversely with quantity and succulence of preferred forage species. When forbs were present and water content was >75%, antelope did not drink water, but when moisture was low (e.g., 39%) water consumption increased (Yoakum 1994). In a review of pronghorn literature, Yoakum (1994) reported that captive pronghorn deprived of water lost weight, were less active, had limited mobility, decreased

their forage intake, and used shade more often. He also reported that the availability of free water appeared to be related to fawn production, survival, and population densities.

Pronghorn may require free water during lactation. Ticer and Miller (1994) reported that in central Arizona, neonate pronghorn fawns selected bed sites within 1,320 to 2,640 ft (400 to 800 m) of water and avoided areas >3,960 ft (>1,200 m) from water. All other areas were used in proportion to availability. They concluded that fawn selection of bed sites with respect to water actually reflected water requirements of lactating adult females. Similar findings were reported by Barrett (1981, 1984) for pronghorn in Alberta.

Ockenfels et al. (1994) determined that both female and male pronghorn avoided the first 1,320 ft (400 m) surrounding water sources. However, all pronghorn locations were within 1 mi (1.6 km) of water because the study area was "well watered." They attributed the apparent avoidance around water sources to concentrations of livestock that denuded vegetation surrounding the water source. They concluded that water was particularly important to pronghorn survival and recruitment in the Southwest.

Clemente et al. (1995) reported on the movements of pronghorn in the Chihuahuan Desert, New Mexico. They found that the year-round average distance to the closest water source averaged 8,801 ft (2,667 m), and that yearlings remained closer to water than adults, apparently because of greater water needs. However, in the Red Desert of Wyoming, Deblinger and Alldredge (1991) found that although more pronghorn were found in locations with free water, pronghorn distribution did not change when free water was available.

One pronghorn subspecies of special concern is the Sonoran pronghorn (*Antilocapra americana sonoriensis*) which is currently federally listed as endangered (Thompson-Olais

1994). The loss of perennial water in the Gila River and the Rio Sonoyta was listed by Wright and deVos (1986) as one of several factors which contributed to the decline of Sonoran pronghorn. Wright and deVos (1986) found that 10 radiocollared Sonoran pronghorn were located closer to water than what would have been expected due to chance. Observations of tracks and pronghorn around potholes and water sources, as well as seasonal proximity of radiocollared pronghorn to water sources suggested that Sonoran pronghorn were opportunistic drinkers. However, Hughes and Smith (1990) found no differences in average pronghorn distances to water during summer nor did they find any sign of pronghorn water use. Cutler (1996) also found no evidence of pronghorn use of 2 artificial water developments in southwestern Arizona. Thompson-Olais (1994) indicated that the degree to which Sonoran pronghorn utilize permanent free standing water was probably the least understood of the species' habitat requirements. Recent studies indicate that at least a portion of the Sonoran pronghorn population frequents water sources on a regular basis (Hervert 1996). Hervert (1996) also reported that radiocollared pronghorn have been observed making long distance movements to sources of free standing water, and that herds which utilize free standing water are larger than those which do not use free standing water.

Mammalian Predators

The literature is contradictory concerning the needs of carnivorous mammals for drinking water. Numerous studies report predators drinking water when it is available (e.g., Clarke and Berry 1992, Green et al. 1984, Miller and Stebbins 1964, Egoscue 1956, and Chevalier 1984). Relatively few studies, however, address the need for free water among carnivores for survival or reproduction. Free water apparently is unnecessary for survival of

ringtails (Chevalier 1984), kit foxes (Golightly and Omart 1984), and spotted hyaenas (Green et al. 1984) in hot arid climates, but is of unknown importance to coyotes (Golightly and Omart 1984) and free-ranging African lions (*Panthera leo*) (Clarke and Berry 1992; Green et al. 1984).

Many carnivorous and omnivorous species appear capable of acquiring pre-formed or metabolic water from succulence in vegetation or prey (Chevalier 1984; Schmidt-Nielsen 1964). Schmidt-Nielsen (1964) reported that most carnivores have the ability to eat food with water content sufficient to meet all needs, including excretion of urea from protein metabolism, provided that such water was not needed for heat regulation. He also provided evidence that dogs could survive without drinking, if their diet consisted of rabbits, and cats could survive without drinking, if their diet consisted of fish and beef. He pointed out, however, that water requirements of wild desert carnivores had not been studied in detail. McIvor et al. (1994) suggested that water developments may benefit predators by increasing their health and reproductive rates, and by concentrating and supporting prey species.

Relatively few studies have directly addressed the effects of water development on the distribution of mammalian predators. Smith and Henry (1985) found no significant difference between predator use of 14.2-ac (5.8 ha) plots around 6 water units and 5 unwatered control plots in central Arizona. Cutler (1996) reported that coyotes, bobcat (*Felis rufus*), and mountain lions (*Felis concolor*) used free standing water at Jose Juan Tank in southwestern Arizona, while Schmidt and DeStefano (1996) found that predator sign, but not prey sign, was more abundant at watered compared to non-watered sites in southern Arizona. Schmidt and DeStefano (1996) speculated that predators were attracted to water sites either to drink or to

make kills.

Several studies have provided descriptions of predators killing or ambushing prey species at natural waters or water catchments in the Southwest (Monson 1964, Cunningham and deVos 1992, Krausman and Etchberger 1993). Some African studies suggest that predators congregate at water holes because of the improved chances of capturing prey (Bourliere 1963, Elliot et al. 1977). Senzota and Mtahko (1990) found no significant difference in the numbers of zebra (*Equus burchelli*), wildebeest (*Connochaetes taurinus*), or buffalo (*Syncerus caffer*) skulls found within 5 330 foot (100 m) wide transects within 825 ft (250 m) of a dam when compared to those found 825 to 1,650 ft (250 to 500 m) from the dam. Fewer animals were killed within the immediate vicinity of water, but the concentration of kills was higher and consequently, predation risk also may have been higher.

SECONDARY EFFECTS OF WATER DEVELOPMENTS

Several studies have reported ungulate mortalities at water developments. Baber (1983) reported that over a 5-day period in 1981, 2 adult and 1 fawn mule deer suffered mortality as a result of being entrapped in mud. He cautioned that potential hazards exist at earthen dams or at reservoirs where siltation is a problem. Mensch (1969) found 34 desert bighorn sheep carcasses in a "natural trap tank" in California. Additional losses were prevented by constructing an escape ramp. In Arizona, a few artificial water sources have trapped big game animals and resulted in mortality due to drowning or starvation (AGFD, unpub. data). For example, in 1996, 4 such traps were found on the Kofa National Wildlife Refuge. These traps were associated with the deaths of 18 desert bighorn sheep and 6 mule deer. Conversely, there are reports of instances where various species of ungulates denied access to artificial water

sources have suffered mortality (Allen 1980).

Forage quantity and quality

Krausman et al. (1985) stated "The addition of water to ranges may improve the habitat quality but unless water is the limiting factor the development of water may be an expense which is more detrimental than beneficial to sheep." Their principal concern was that in fair or marginal habitats, the addition of water might cause competition among several species of ungulates and excessive use of forage. Although we found no information from the United States addressing this issue, such studies have been conducted on the African continent.

Localized heavy use of artificial water developments by cattle affected soil mineral and nutrient levels near water holes in eastern Botswana (Tolsma et al. 1987). Heavy use by wild ungulates resulted in overgrazing and trampling in Tsavo National Park (Ayeni 1975). Large trees were damaged, leading to increases in brush cover in the Kalahari Desert and Kruger National Park (Child et al. 1971, Ayeni 1977, Thrash et al. 1991). Senzota and Mtahko (1990) measured percent grass cover around the Mwanambogo Dam in Tanzania to determine if ungulate concentrations affected available forage. They found significantly less grass cover within 330 ft (100 m) of the dam, but no significant differences from 333 to 1,650 ft (101 to 229 m) from the dam site. Impact from trampling was more significant than that of grazing because ungulates did not remain at watering sites. Child et al. (1971) reported that in the Kalahari Desert there was significantly less grass at 152 and 756 ft (46 and 229 m) than at 2,640 and 5,280 ft (800 and 1600 m) from a water hole. Knight (1995) reported that in the Kalahari Desert during 1995, provision of artificial water holes exacerbated the impacts of the dry season on ungulates and ostrich (*Struthio camelus*). The water holes attracted and

concentrated animals on summer season dry ranges during a dry winter; he suggested that the increased competition and poorer quality forage resulted in the starvation of many animals.

Although ungulate densities in the aforementioned studies were not described, we suggest that numbers of animals were considerably higher than those likely to be encountered in the Southwest. Nevertheless, on a relative scale there may be a potential for increased competition and reduced forage close to water development sites in the Southwest.

Water Quality

Broyles (1995) suggested that, on occasion, artificial waters in the desert may be harmful to wildlife due to poor water quality or disease and parasite transmission. Available literature suggests that enhancement of natural rock pools can increase sedimentation and could result in poor water quality. Kubly (1990) studied the limnological features of several rock pools (tinajas) in central and south-central Arizona and found that such pools could become stagnant, and could contain potentially noxious substances such as blue green algae, bacteria, hydrogen sulfide, and ammonia. He expressed concern that the engineering modifications made to deepen the rock pools could exacerbate these potential problems and increase siltation. deVos and Clarkson (1990) also voiced concern about sedimentation problems and noted that several dams had been torn down by AGFD personnel because of these problems. They suggested several modifications to reduce such effects. Schmidt and DeStefano (1996) reported high hydrogen sulfide concentrations at several artificial water developments during July and August 1995 and 1996 in southern Arizona. Whether such concentrations could harm wildlife has not been determined.

During summer 1995, at least 45 desert bighorn sheep in the Old Dad Mountains,

California, died from botulism poisoning (Swift 1996). This was the first documented major die-off associated with an artificial water development, however, the die-off was actually caused by sheep being denied access to water. The mortalities appear to have occurred when drinkers went dry. Sheep managed to remove the tank lid, several sheep fell in the tank and drowned, and the carcasses provided a substrate for growth of *C. botulinum* and production of botulinum toxin. deVos and Clarkson (1990) speculated that occasional, unexplained local mortalities (Monson 1964, Witham et al. 1982) also may be attributable to result of water quality or disease outbreaks.

CONCLUSIONS

Water is an essential physiological requirement for all wildlife. Water needs vary among species, as do their strategies for meeting daily and seasonal water needs. Some species can exist entirely on metabolic and pre-formed water obtained from food items, while others require intermittent or regular access to sources of free water. A wide variety of wildlife species will use free water when it is available, particularly during hot and dry summer months. Evidence strongly suggests that availability of free water plays an important role in the distribution, movement, habitat use, reproduction, or survival of wildlife.

Water is an essential component of wildlife habitat, but our understanding of the benefits and impacts of artificial water developments is incomplete because there have been few experiments that test effects of water developments on wildlife populations. Furthermore, broad inferences often cannot be made from these experiments because of design limitations. Most experiments were of short duration, were restricted to a small number of species and a small geographic area, had minimal replication, and may have been confounded by weather, climatic extremes, and other factors. Consequently, much of what we know about the effects

of water developments on wildlife has been derived from anecdotal observations and correlative or descriptive (non-experimental) studies often intended to answer other questions. In addition, a number of studies appeared to have contradictory results. Because of the aforementioned confounding factors, these apparent contradictions do not necessarily negate the findings of individual studies. Rather, they emphasize the need for well-designed, long-term experimental studies to address questions concerning the impacts of water developments on wildlife populations and habitats in the Southwest.

The preponderance of scientific evidence we found in this review indicates that wildlife water developments in the Southwest have not had a demonstrated negative impact on native flora and fauna, and that some wildlife species have benefitted from increased availability of free water. In particular, mule deer, white-tailed deer, and elk distribution and or population performance have likely been enhanced by water developments. Desert bighorn sheep appear to be have benefitted from water developments in some, but not all areas. Other species were either unaffected by water developments or were attracted to them during dry periods.

We found some evidence of increased predator occurrence in response to water development in the Southwest. However, we found only 1 African study examining whether water developments act as predation sinks for species expected to benefit from water development.

RECOMMENDATIONS

Research is needed to address the information gaps highlighted by this technical review. Most of the questions concerning the effects of water developments on wildlife can only be answered with well-designed research. To avoid limitations encountered by previous studies,

and to test clear cause-and-effect relationships, much of the proposed research will need to be long-term (i.e., 10 years or more in duration) and will require direct experimental manipulation of artificial water sources.

We identified 3 key research needs, which are listed below:

(1) Effects of water developments on population performance, habitat components, and/or habitat use of wildlife species, as well as effects on plant communities and insects;

(2) Effects of water developments on mammalian predator distribution, predator abundance, and predation rates; and

(3) Water quality in artificial versus natural wildlife water sources, including the potential for disease transmission.

ACKNOWLEDGMENTS

Critical reviews of this document were provided by B. Broyles, V. C. Bleich, and P. R. Krausman. G. Carmichael, V. Dickinson, E. Gardner, J. Gunn, R. Haughey, J. Hervert, and R. Lee contributed to various aspects of this review.

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HABITAT USE OF DESERT BIGHORN SHEEP NEAR PERENNIAL WATER SOURCES IN THE SILVER BELL MOUNTAINS, ARIZONA.

KIRBY D. BRISTOW

Abstract – I investigated habitat selection of desert bighorn sheep (*Ovis canadensis*) relative to the location of perennial water sources in the Silver Bell and West Silver Bell mountains. Seven of the 13 perennial water sources within the study area were wildlife water developments created for desert bighorn sheep. I collected 1070 relocations of radio-instrumented (marked) desert bighorn sheep between September 1993 and February 1996, and recorded the distance to nearest water source for each. Throughout the study, radio-instrumented desert bighorn sheep selected habitat ≤2 km of perennial water sources. I found radio-instrumented desert bighorn sheep ≤2 km of perennial water sources 95% of the time. However, the study area was well watered and a large portion of the mountainous habitat was ≤2 km of perennial water sources. When desert bighorn sheep were ≤2 km of perennial water they selected for areas ≤900 m and avoided areas ≥1100 m from perennial water sources. Desert bighorn sheep used habitat closer to perennial water during the summer and fall (May-Nov), and ewes selected habitat closer to perennial water than rams. Among ewe groups, in the summer, distance to escape terrain was shorter than distance to perennial water. I observed desert bighorn sheep drinking free water only occasionally, and only during the summer. Except during summer months, habitat selection seemed to be influenced more by topography than water availability.

INTRODUCTION

Desert bighorn sheep inhabit some of the most arid areas of North America. While desert bighorn sheep are well adapted to dry climates, they have been found to be at least partially dependent upon free water (Turner 1973). Desert bighorn sheep are better able to metabolize water from their food than are most North American ungulates, yet this metabolic water accounts for a small fraction of their total water needs (Turner 1970). While Desert bighorn sheep may have to drink water less frequently than deer or other desert ungulates, they will restrict habitat use and movement patterns to areas near water during dry periods (Halloran and Deming 1958, Blong and Pollard 1968, Wilson 1971).

As human development expanded into desert bighorn sheep ranges in the western United States, increasing domestic demand for water reduced its availability to wildlife. Permanent usurpation (capping springs) and restricted access due to habitat fragmentation reduced the quantity and altered distribution of water sources available to desert bighorn sheep. In response to this apparent need for increased water availability, wildlife managers in Arizona began developing water holes to benefit desert bighorn sheep in 1939 (Broyles 1997). While desert bighorn sheep have been found to use these developments, (Halloran and Deming 1958, Campbell and Remington 1979), recent questions have been raised about the impacts these developments have had on wildlife populations and distributions (Broyles 1995).

Desert bighorn sheep use of water has been well documented (Halloran and Deming 1958, Koplin 1960, Turner 1973). Yet some populations exist in areas without permanent water (Alderman et al. 1989, Lee 1993), and Krausman and Etchberger (1995) found that desert bighorn sheep were not attracted to water catchments. While desert bighorn sheep need free water at least seasonally (Turner 1970, Turner 1973), the necessity and relative importance of permanent water sources relative to habitat selection is unclear. I examine how the placement of water developments impact habitat use patterns, and attempted to determine the relative importance of perennial water sources to desert bighorn sheep habitat selection.

METHODS

Study Site

The Silver Bell study area (SBSA) consisted of an interconnected mountain complex comprised of the Silver Bell and West Silver Bell mountains (Fig. 1). The Silver Bell and West Silver Bell mountains are part of a series of low desert mountain ranges in south central Arizona. The SBSA encompassed 227 km^2 and included all areas of broken terrain and surrounding hills that are contiguous to this mountain complex. Elevations within SBSA ranged from approximately 500 m at the lowest elevations to 1,290 m at Silver Bell Peak.

Four vegetation communities occurred within SBSA. A creosote (*Larrea tridentata*)-bursage (*Ambrosia deltoidea*) community dominated the lowest elevations. The hillsides were composed primarily of a palo verde (*Cercidium* spp.)-mixed cacti community. This community was dominated by foothill palo verde (*C. microphyllum*), saguaro (*Carnegiea gigantea*), and various prickly pear and cholla cacti (*Opuntia* spp.) (Turner and Brown 1982). A desert riparian community occurred along major washes and drainages. This community was dominated by palo verde, ironwood (*Olneya tesota*), mesquite (*Prosopis velutina*), and acacia (*Acacia* spp.) (Turner and Brown 1982). Jojoba (*Simmondsia chinensis*)-mixed scrub, a chaparral-like community dominated by jojoba, occurred at some of the upper elevation sites (Turner and Brown 1982).

Livestock grazing and mining were the primary land uses within SBSA. Most grazing occurred on BLM and State Land Department allotments. Livestock were concentrated around water sources located at lower elevations. Much of the SBSA had been impacted by prior mining activity. Shafts, adits, mine dumps, and pits are scattered throughout SBSA, with the greatest concentration being at and near the ASARCO-owned Silver Bell Mine near Silver Bell Peak (Fig. 1).

There were 7 wildlife water developments within SBSA during this study. These developments were constructed between 1965 and 1987, and designed to provide a perennial water source for desert bighorn sheep. Each development consisted of; a water collection apron made of fiberglass, tin, or concrete, a holding tank of 2,500-75,00 gallon capacity, and a drinking trough. Each summer AGFD personnel haul water to refill holding tanks in danger of drying up. Each water development contained free water available to bighorn sheep throughout this study. Additionally, there were 6 alternative water sources (springs, tinajas etc.) that provided perennial water for desert bighorn sheep throughout SBSA. Livestock water catchments within SBSA were located in lower flat terrain and often surrounded by fences and dense brush making them less attractive to desert bighorn sheep. I found no evidence of desert bighorn sheep use of livestock water catchments within SBSA and therefore excluded them from my analysis.

Duration of study

The study lasted 28 months between September 1993 and February 1996. I divided each year into 4 seasons based upon rainfall patterns and water availability. Annual precipitation at the ASARCO Silver Bell Mine averaged 31.8 cm since 1956. Rainfall pattern was bimodal with peaks in fall (Aug 3-Nov 1) and spring (Feb 1-May 3). Summer (May 4-Aug 2) is the hottest, driest period and mean summer temperatures were commonly in excess of 38 C. Winter (Nov 2-Jan 31) daytime high temperatures ranged from 15 to 20 C (Sellers and Hill 1974).

There were 13-17 radiocollared (marked) desert bighorn sheep within SBSA throughout the study. I visually located each marked desert bighorn sheep from the ground ≥30 times annually. I separated locations of individual marked animals by ≥ 24 hours to avoid auto-correlation of consecutive locations (Swihart and Slade 1985). I plotted all locations on U.S. Geological Survey (USGS) 7.5′ topographical maps, and recorded Universal Transverse Mercator (UTM) coordinates for each.

For each ground location I recorded; sex and age class, slope, distance to escape terrain, and distance to perennial water. I classified each desert bighorn sheep observed into age and sex categories following Geist (1971). I classified each group of desert bighorn sheep that I observed as rams (all male), mixed (males and females), or ewes (all females including those with lambs and yearlings). I measured percent slope, and estimated distances to escape terrain and perennial water using USGS 7.5′ topographical maps. I defined escape terrain as rugged, rocky areas >60% slope (Holl 1982). I located perennial water sources within SBSA using USGS 7.5′ topographical maps and through ground surveys and interviews with area ranchers, miners, and land managers. I considered a water source perennial if it contained free water throughout the driest months (May-July).

I used chi-square goodness-of-fit to determine if ewes and rams used slope and distance to water classes in proportion to their availability. If use differed from availability, I calculated Bonferroni confidence intervals (Neu et al. 1974). If the percent area available within a particular habitat parameter class was outside the Bonferroni confidence interval, then I calculated Jacobs' *D* (Jacobs 1974) to determine magnitude of selection. I used The Geographic Information Systems (GIS) slope cover created by Bristow et al. (1996) to establish availability of slope classes and created 100m contour buffers around all perennial water sources to establish availability of habitat within distance to water classes. I compared distance to water among seasons and group composition classes using Kruskal-Wallis ANOVA (Zar 1984). I also compared distance to water between group composition classes using a Mann-Whitney *U* test (Zar 1984). For all ewe locations I compared distance to escape terrain to distance to perennial water using a Mann-Whitney *U* test.

I delineated 3 study area subunits based on distinct areas of desert bighorn sheep use determined from observations of marked ewes (Fig. 1). The Silver Bell Peak subunit (SBP) contained the largest amount of desert bighorn sheep habitat as well as the most perennial water sources. Perennial water sources within the Ragged Top Peak subunit (RTP) were closest to rugged steep topography. The West Silver Bell subunit (WSB) contained the least high quality desert bighorn sheep habitat and perennial waters were located farther from steep rugged topography (Bristow et al. 1996). I compared use of distance to water classes among ewe groups which included groups of ewes and mixed groups, within the 3 subunits. I observed no interchange of marked ewes among the 3 subunits. I used chi-square goodness-of-fit, Bonferroni

confidence intervals, and Jacobs' D to test for selection within slope, and distance to permanent water classes by ewe groups within different study area subunits.

Bristow et al. (1996) found that ewes exhibited the strongest selection relative to habitat parameters. To establish relative importance of proximity to water and topography I compared use of distance to water classes (400 m buffers) and slope classes among ewes by contrasting selection coefficients for each parameter.

RESULTS

Throughout SBSA desert bighorn sheep selected areas ≤1 km of perennial water sources (X^2 = 2,013.9, 6 df, $P < 0.001$, Jacobs' $D = 0.81$). Desert bighorn sheep were located ≤2 km of perennial water 95% of the time. When desert bighorn sheep were ≤2 km of perennial water they selected for areas ≤900 m and avoided areas ≥1100 m from perennial water sources (Table 1). Distance to perennial water was shortest in summer and fall (median = 760 m and 720 m respectively) and greatest in winter and spring (median = 830 m and 830 m respectively, $KW\ X^2$ = 18.76, 3 df, $P < 0.001$). Distance to perennial water was shortest for ewes and mixed groups (median = 710 m and 660 m respectively) and greatest for rams (median = 1,160 m, $KW\ X^2$ = 103.42, 2 df, $P < 0.001$). Distance to water was not significantly different between ewes and mixed groups (U = 5,124.0 $P < 0.001$), therefore I combined these group composition classes for subsequent analysis. Selection coefficients for distance to water classes were more divergent for ewe groups than rams (Table 2).

Within the RTP, SBP, and WSB subunits ewe groups selected areas ≤1 km of perennial water. In SBP and WSB subunits, where water sources were farther from steep terrain (Fig. 2), selection coefficients were not as divergent relative to distance to perennial water sources (Table 3). Among ewe groups, in the summer, distance to escape terrain was significantly shorter than distance to perennial water (U = 203.0, P <0.001).

Desert bighorn sheep use of slope classes >20% differed from availability (X^2 = 5,090, 4 df, $P < 0.001$). Selection coefficients were greatest for slope classes >80% (Jacobs $D = 0.95$). Ewes selected all slope classes >20% while Rams selected slope classes ≥20% and ≤60% (Table 4). Ewes exhibited strong selection for slope classes >40%, >60%, and >80% (Table 4). Among ewe groups selection coefficients were more divergent for slope than distance to water classes (Fig. 3).

CONCLUSION

Throughout SBSA desert bighorn sheep selected areas near perennial water. Ewes showed a stronger selection for areas near water than rams. Lactating ewes have the greatest need for free water and, thus, should spend more time near water sources (Welles and Welles 1961, Turner 1973). Within the SBP and RTP subunits, ewes exhibited strong selection for areas near perennial water sources. However, selection for proximity to water was not as strong in WSB. One factor that could have contributed to the lower selection for areas near perennial water within WSB could be that the water sources within WSB were located at lower elevations and farther from steep habitats than in other subunits. Bleich (1993) found that suitable terrain

constrains the use of water by desert bighorn sheep ewes. Thus, the proximity of desert bighorn sheep locations to water could be a function of the proximity of water sources to steep terrain.

Distribution of water sources may effect desert bighorn sheep habitat use during the hot dry summer months (Monson 1958, Wilson 1971). However, I found desert bighorn sheep used areas closest to perennial water during the fall when rainfall provides more free water. This indicates that other factors may be involved in the high use of these areas by desert bighorn sheep. Ewes exhibited a stronger selection for steep slopes than proximity to water, and distance to escape terrain was shorter than distance to water, suggesting that topography may be more important than water availability relative to desert bighorn sheep habitat use.

The high degree of selection for areas near perennial water within the RTP and SBP subunits could be due to an auto-correlation of water sources and steep habitat. According to criteria from Ebert and Douglas (1994), the entire SBSA is well watered as the entire area is ≤6 km from perennial water and many of these perennial water sources were near steep terrain (Fig. 2). A majority of the perennial water sources that I recorded were located in proximity to areas of high desert bighorn sheep use. I excluded all water sources (livestock catchments) that I had determined were not visited by desert bighorn sheep. I made this determination based upon observations, presence of spoor, topography and vegetation density. The exclusion of water sources that are probably not visited by desert bighorn sheep would restrict water availability to areas of high desert bighorn sheep use. This would tend to increase selection coefficients for areas close to recorded perennial water. However, if habitat factors such as topography and vegetation density preclude desert bighorn sheep use of a particular water source, then that water source should be unavailable to desert bighorn sheep, and therefore, excluded from any use-availability equations.

Water availability can be affected by mining as large amounts of water are needed for mineral leaching, dust abatement, and other uses (MacCallum and Geist 1992). The Silver Bell mine property contained several kilometers of steel pipe used to transport water. Leaks in these pipes provided water for desert bighorn sheep at several sites at the mine. I found that desert bighorn sheep used water that had accumulated near standing pipes used to fill water trucks on the main haul road of the Silver Bell mine. However, since human activity levels were higher in these areas sheep may have spent less time near these water sources in SBP. Campbell and Remington (1981) found that construction activities near water sources caused bighorn sheep to alter their water use patterns. In spite of their sensitivity to human activities, I often witnessed desert bighorn sheep using these water sources sometimes within 100 m of mine personnel and operating equipment.

I found desert bighorn sheep using the wildlife water development on Ragged Top Peak quite frequently during summer months. During a 2-3 week period during the driest period of each summer I consistently found desert bighorn sheep of both sexes bedded within 50 m of the water trough, often bedded in the shade of the fiberglass holding tanks. Each year these locations represented the first instance when adult rams (Class II-IV) were observed with ewes. These watering holes may serve a social function by providing a meeting place for the rams and ewes that have been largely segregated since lambing began the previous winter. Habitats that serve a social function may be more important relative to the long term viability of a population (Festa-Bianchet 1986). Clearly these water sources are important during these periods.

It is unclear to what extent water availability plays in the habitat use of the desert bighorn sheep of the Silver Bell Mountains. Proximity to water seems to be an important factor during

the summer but may be less important than topography or vegetation at other times of the year. This study did not provide a conclusive answer to the question of the impact of water availability on habitat selection of desert bighorn sheep. A more useful approach may be to compare changes in habitat use patterns of desert bighorn sheep in response to manipulations of water availability. This approach would require either restricting or increasing water availability within the range of a population of desert bighorn sheep in which the habitat use patterns are known. Given the relatively conservative habitat use and dispersal behaviors of desert bighorn sheep (Geist 1967), it may require several years for a measurable effect to be detected, however this may be the only way to establish the relative importance of habitat components that are closely linked together.

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Table 1. Distances of desert bighorn sheep locations from identified water sources compared with percent area within isometric distance buffers ≤2 km of perennial water sources within the Silver Bell study area, southern Arizona, 1993-96.

Distance Class [a]	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D [b]
0 - 1	24	2.3	0.4	4.1	1.1 - 3.5	+0.71
1 - 2	80	7.9	1.1	11.2	5.7 - 10.0	+0.77
2 - 3	93	9.1	2.0	20.3	6.8 - 11.4	+0.66
3 - 4	87	8.6	2.7	27.5	6.4 - 10.8	+0.55
4 - 5	60	5.9	3.4	34.6	4.0 - 7.8	+0.28
5 - 6	72	7.1	3.9	39.7	5.1 - 9.1	+0.31
6 - 7	81	8.0	4.5	45.8	5.9 - 10.1	+0.30
7 - 8	107	10.5	5.0	50.9	8.1 - 12.9	+0.38
8 - 9	90	8.8	5.5	55.9	6.6 - 11.0	+0.25
9 - 10	72	7.1	6.0	61.0	5.1 - 9.1	
10 - 11	61	6.0	6.4	65.1	4.1 - 7.9	
11 - 12	49	4.8	6.7	68.1	3.1 - 6.5	-0.18
12 - 13	41	4.0	6.8	69.1	2.5 - 5.5	-0.27
13 - 14	26	2.5	6.5	66.1	1.3 - 3.7	-0.46
14 - 15	18	1.8	6.8	69.1	0.8 - 2.8	-0.60
15 - 16	19	1.9	6.7	68.1	0.8 - 3.0	-0.58
16 - 17	12	1.2	6.5	66.1	0.3 - 2.1	-0.70
17 - 18	14	1.4	6.4	65.1	0.5 - 2.3	-0.66
18 - 19	3	0.3	6.3	64.1	-0.1 - 0.7	-0.81
19 - 20	8	0.8	6.4	65.1	0.1 - 1.5	-0.79

[a] Distance to perennial water x 100 m.

[b] Use differed from availability (X^2 = 1,372.2, 19 df, $P < 0.001$, n = 1070). Jacob's D indicates direction and magnitude of avoidance or selection.

Table 2. Distances of ram and ewe group locations from identified water sources compared with percent area within isometric distance buffers ≤2 km of water sources within the Silver Bell study area, southern Arizona, 1993-96.

Sex	Distance Class [a]	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D [b]
Rams	0 - 4	42	15.7	6.2	16.6	10.5 - 20.9	+0.48
	4 - 8	58	21.7	16.8	44.9	15.8 - 27.6	
	8 - 12	86	32.2	24.6	65.7	25.5 - 38.9	+0.19
	12 - 16	52	19.5	26.8	71.5	13.9 - 25.1	-0.20
	16 - 20	29	10.9	25.6	68.3	6.5 - 15.3	-0.48
Ewes	0 - 4	242	32.3	6.2	46.5	28.3 - 36.3	+0.76
	4 - 8	262	34.9	16.8	126.0	30.8 - 39.0	+0.45
	8 - 12	186	24.8	24.6	184.5	21.1 - 28.5	
	12 - 16	52	6.9	26.8	201.0	4.7 - 9.1	-0.66
	16 - 20	8	1.1	25.6	192.0	0.2 - 2.0	-0.94

[a] Distance to perennial water x 100 m.

[b] Use differed from availability for rams (X^2 = 76.9, 4 df, $P < 0.001$, n = 267), and ewe groups (X^2 = 1,255.5, 4 df, $P < 0.001$, n = 750). Jacob's D indicates direction and magnitude of avoidance or selection.

Table 3. Distances of ewe group locations from identified water sources compared with percent area within isometric distance buffers from water sources within the Ragged Top Peak (RTP), Silver Bell Peak (SBP), and West Silver Bell (WSB) subunits of the Silver Bell study area, southern Arizona, 1993-96.

Subunit	Distance Class	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D^a
RTP	0 - 1 km	315	83.3	13.8	52.2	78.8 - 87.8	+0.94
	1 - 2 km	62	16.4	39.1	147.8	12.0 - 20.8	-0.53
	2 - 3 km	1	0.3	30.2	114.1	-0.4 - 1.0	-0.99
	3 - 4 km	0	0.0	16.7	63.2	0 - 0	-1.0
	4 - 5 km	0	0.0	0.2	0.7	0 - 0	-1.0
SBP	0 - 1 km	227	66.6	39.0	133.0	60.9 - 72.3	+0.51
	1 - 2 km	114	33.4	40.2	137.1	27.7 - 39.1	-0.15
	2 - 3 km	0	0.0	17.2	58.6	0 - 0	-1.0
	3 - 4 km	0	0.0	3.6	12.3	0 - 0	-1.0
WSB	0 - 1 km	23	41.8	7.8	4.3	25.5 - 58.1	+0.79
	1 - 2 km	28	50.9	23.2	12.8	34.4 - 67.4	+0.55
	2 - 3 km	2	3.6	30.0	16.5	-2.6 - 9.8	-0.84
	3 - 4 km	0	0.0	25.1	13.8	0 - 0	-1.0
	4 - 5 km	2	3.6	9.7	5.3	-2.6 - 9.8	-0.48
	5 - 6 km	0	0.0	3.8	2.1	0 - 0	-1.0
	>6 km	0	0.0	0.4	0.2	0 - 0	-1.0

[a] Use differed from availability for RTP (X^2 = 1,548.9, 3 df, $P < 0.001$, n = 378), SBP (X^2 = 141.2, 3 df, $P < 0.001$, n = 341), and WSB (X^2 = 130.0, 4 df, $P < 0.001$, n = 55). Jacob's D indicates direction and magnitude of avoidance or selection.

Table 4. Use of slope classes by rams and ewes compared with slope class availability, Silver Bell study area, southern Arizona, 1993-96.

Sex	Slope Class	No. of locations	% of locations	% of area	No. of locations expected	Bonferroni 90% CI	Jacobs' D^a
Rams	0-20%	125	46.8	87.1	232.5	38.3 - 55.3	- 0.77
	21-40%	98	36.7	10.0	26.7	28.4 - 44.8	+ 0.68
	41-60%	35	13.1	2.4	6.4	7.6 - 19.2	+ 0.73
	61-80%	9	3.4	0.4	1.1	0.2 - 6.2	
	>80%	0	0.0	0.1	0.3	0 - 0	- 1.0
Ewes	0-20%	192	25.6	87.1	653.3	18.5 - 32.7	- 0.90
	21-40%	248	33.1	10.0	75.0	25.3 - 40.7	+ 0.63
	41-60%	211	28.1	2.4	18.0	20.7 - 35.5	+ 0.88
	61-80%	44	5.9	0.4	3.0	2.0 - 9.8	+ 0.88
	>80%	55	7.3	0.1	0.7	3.1 - 11.7	+ 0.98

[a] Use differed from availability for rams ($X^2 = 299.6$, 4 df, $P < 0.001$, $n = 267$) and ewes ($X^2 = 3,126.5$, 4 df, $P < 0.001$, $n = 750$). Jacobs' D indicates direction and magnitude of avoidance or selection.

Figure 1. Silver Bell desert bighorn sheep study area and subunits, Southern Arizona, 1993-96.

Figure 2. Location of recorded perennial water sources within the Silver Bell study area, southern Arizona, 1993-96.

Figure 3. Habitat selection coefficients (Jacobs' *D*) for slope and distance to perennial water classes among ewe groups, Silver Bell study area, southern Arizona, 1993-96.

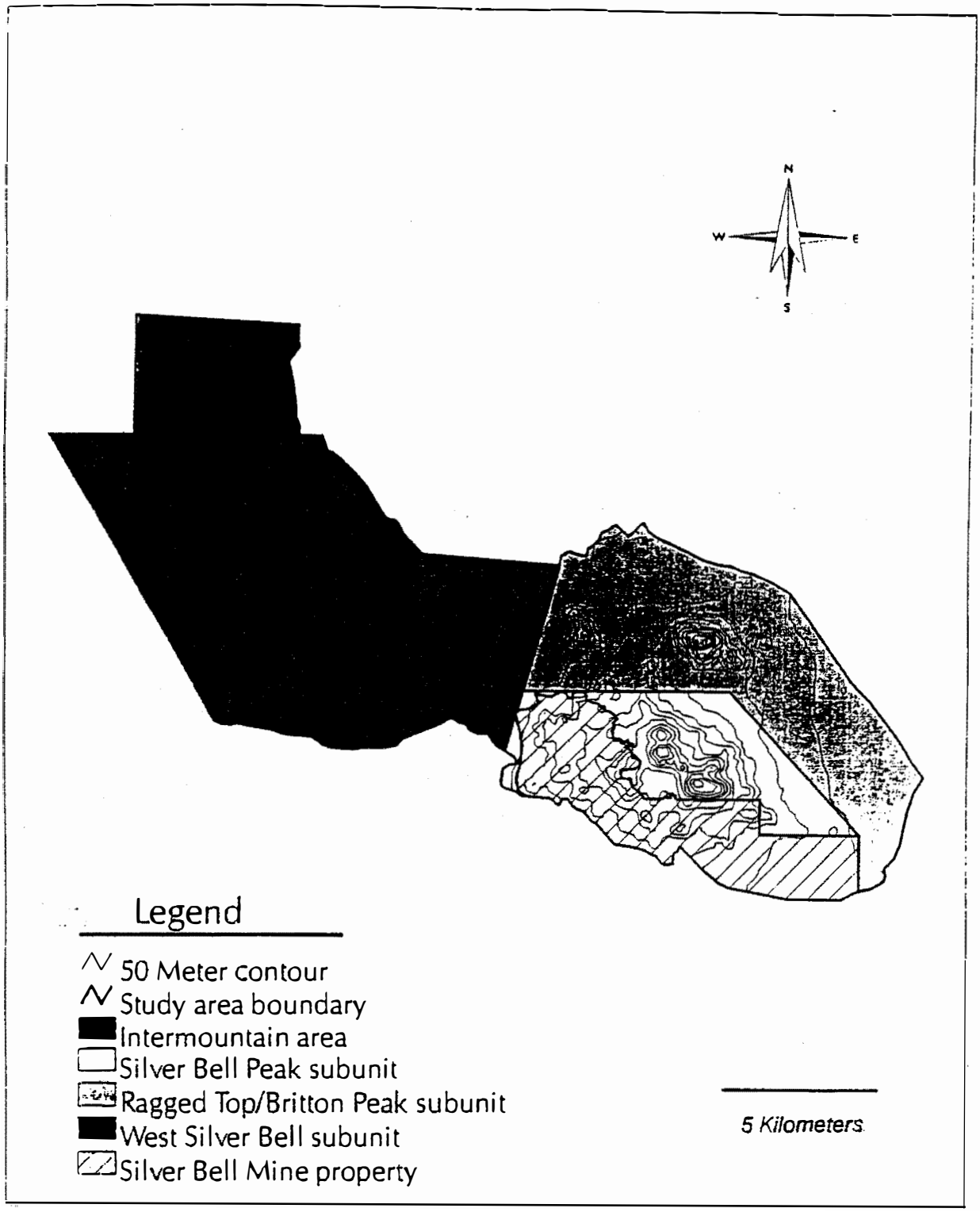
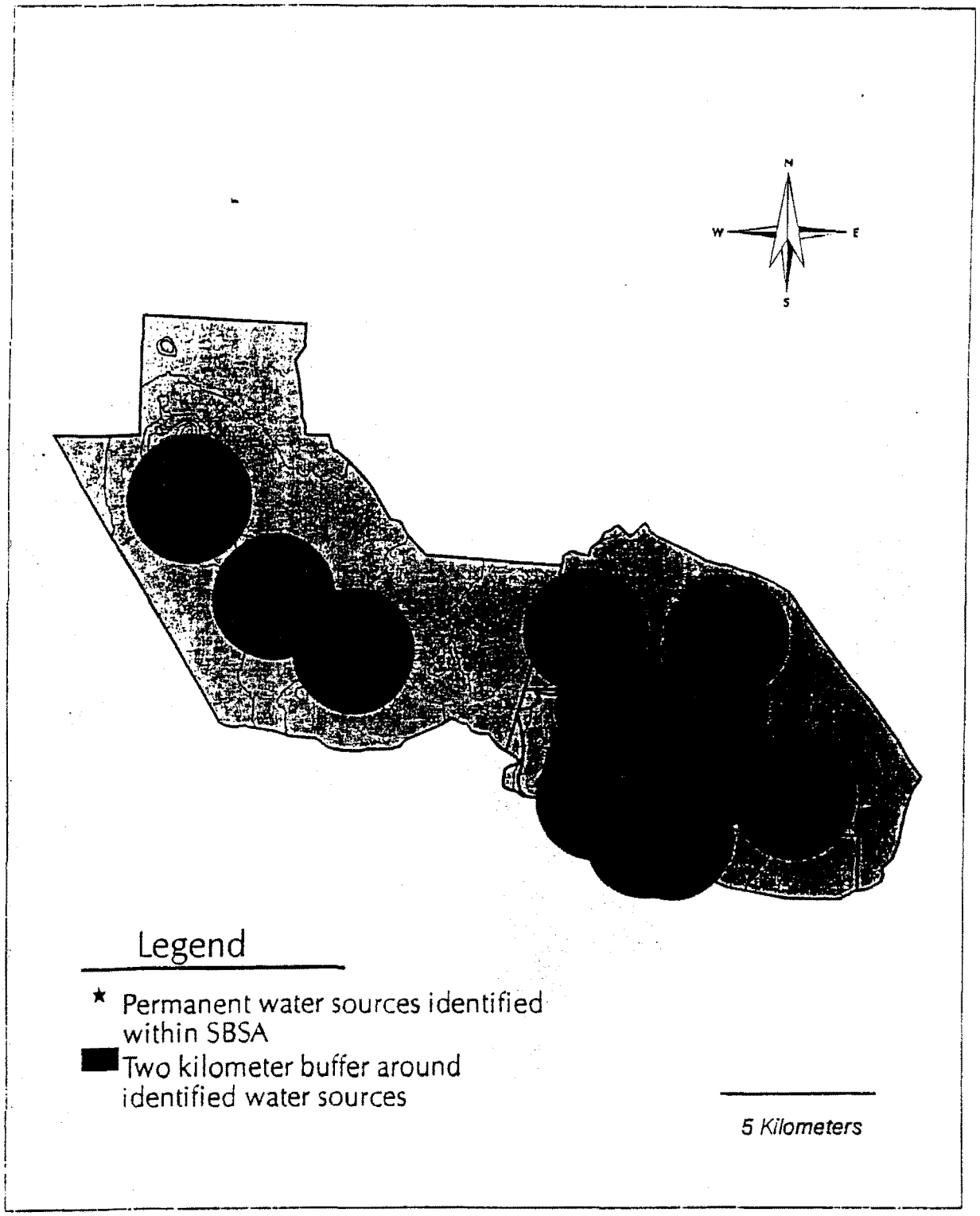


Figure 1. Silver Bell desert bighorn sheep study area and subunits, Southern Arizona, 1993-96.



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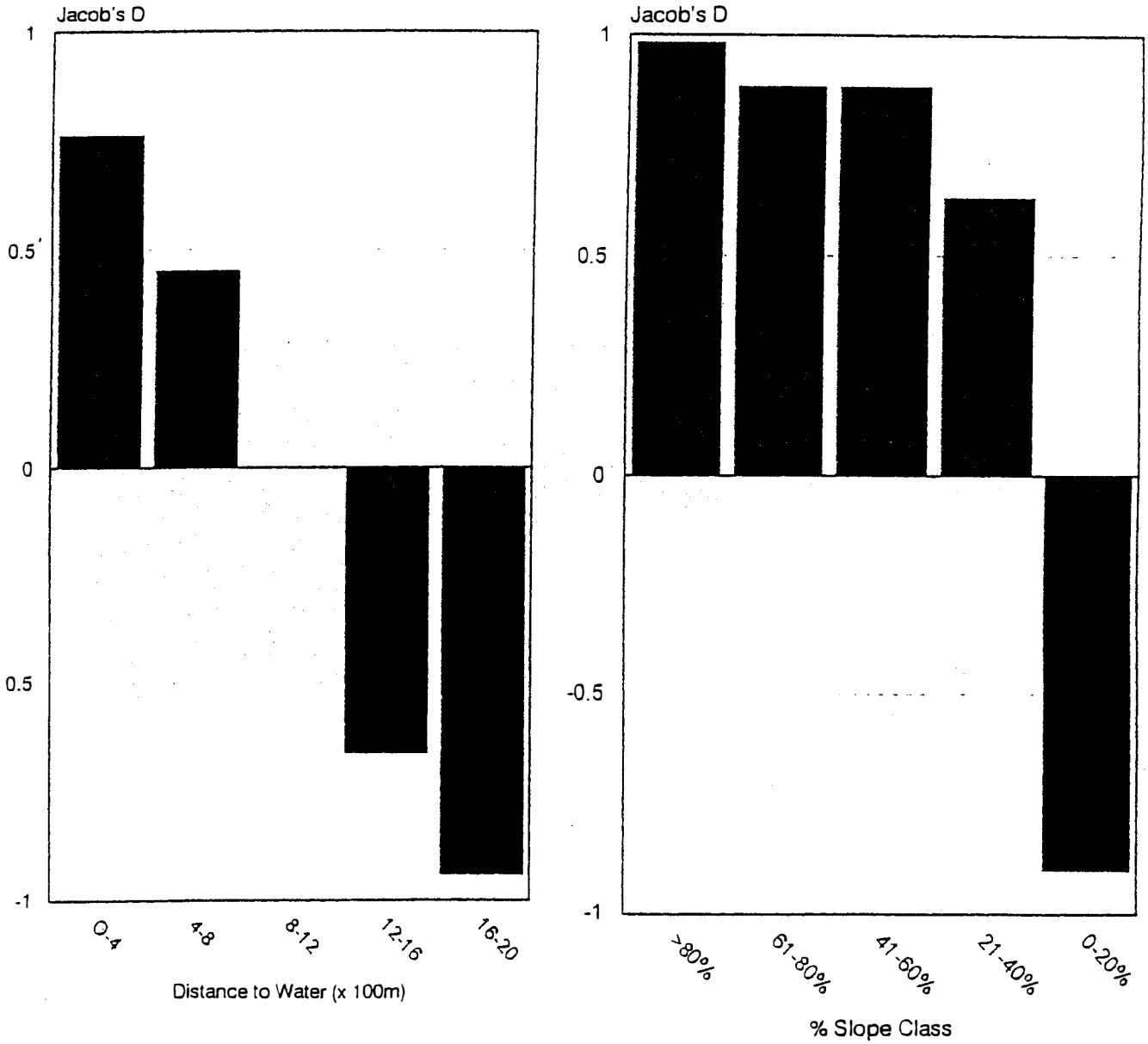

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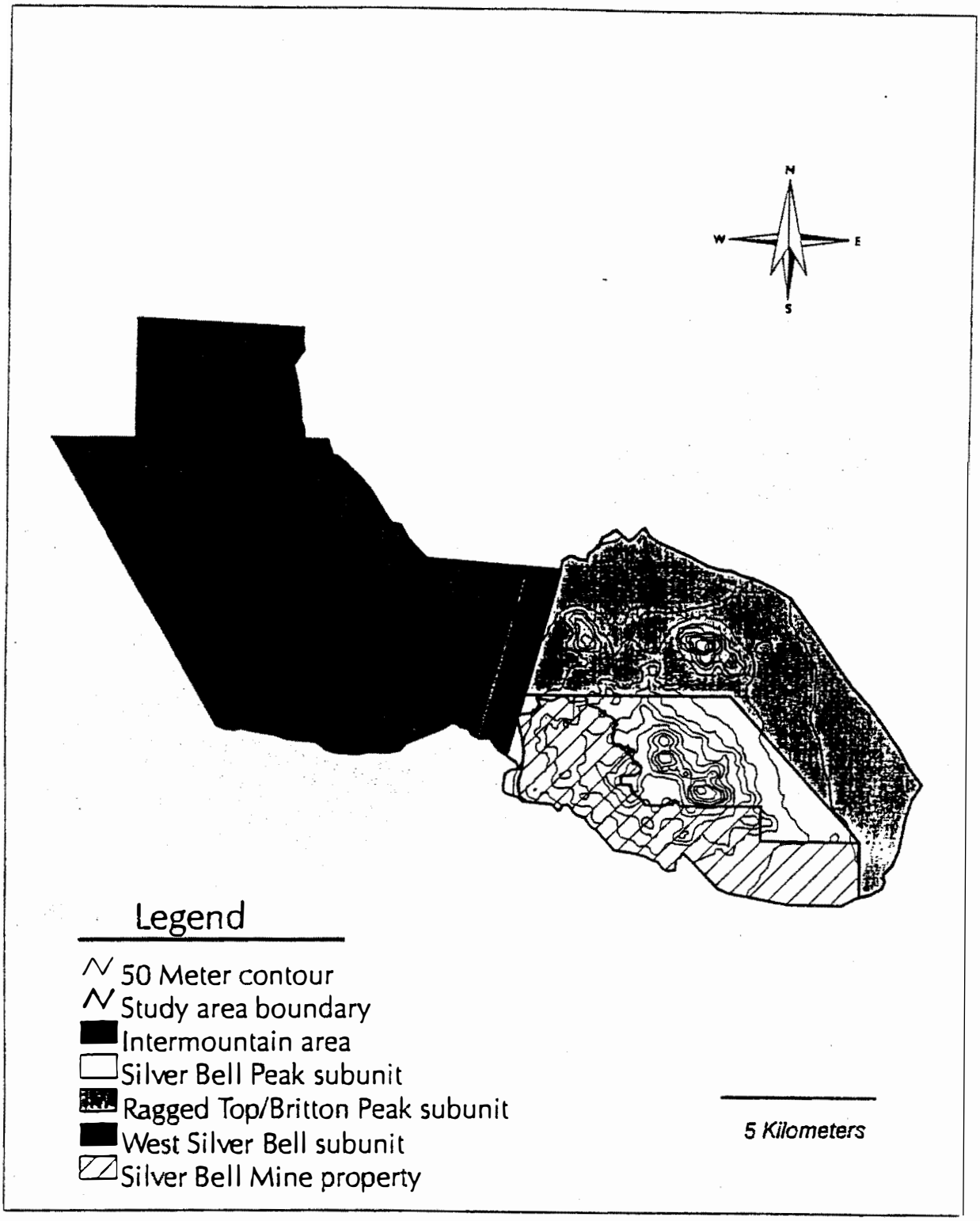
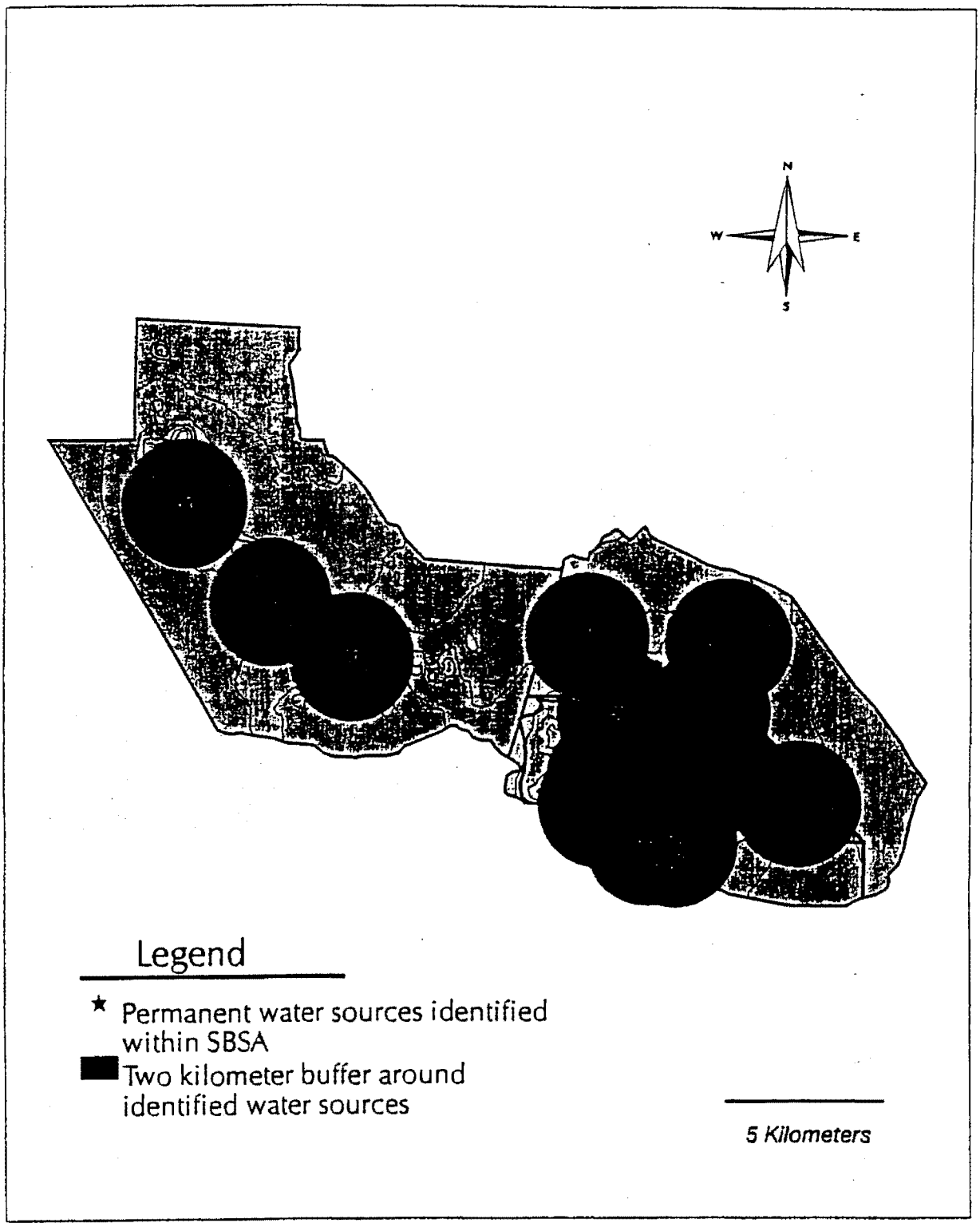


Figure 1. Silver Bell desert bighorn sheep study area and subunits, Southern Arizona, 1993-96.



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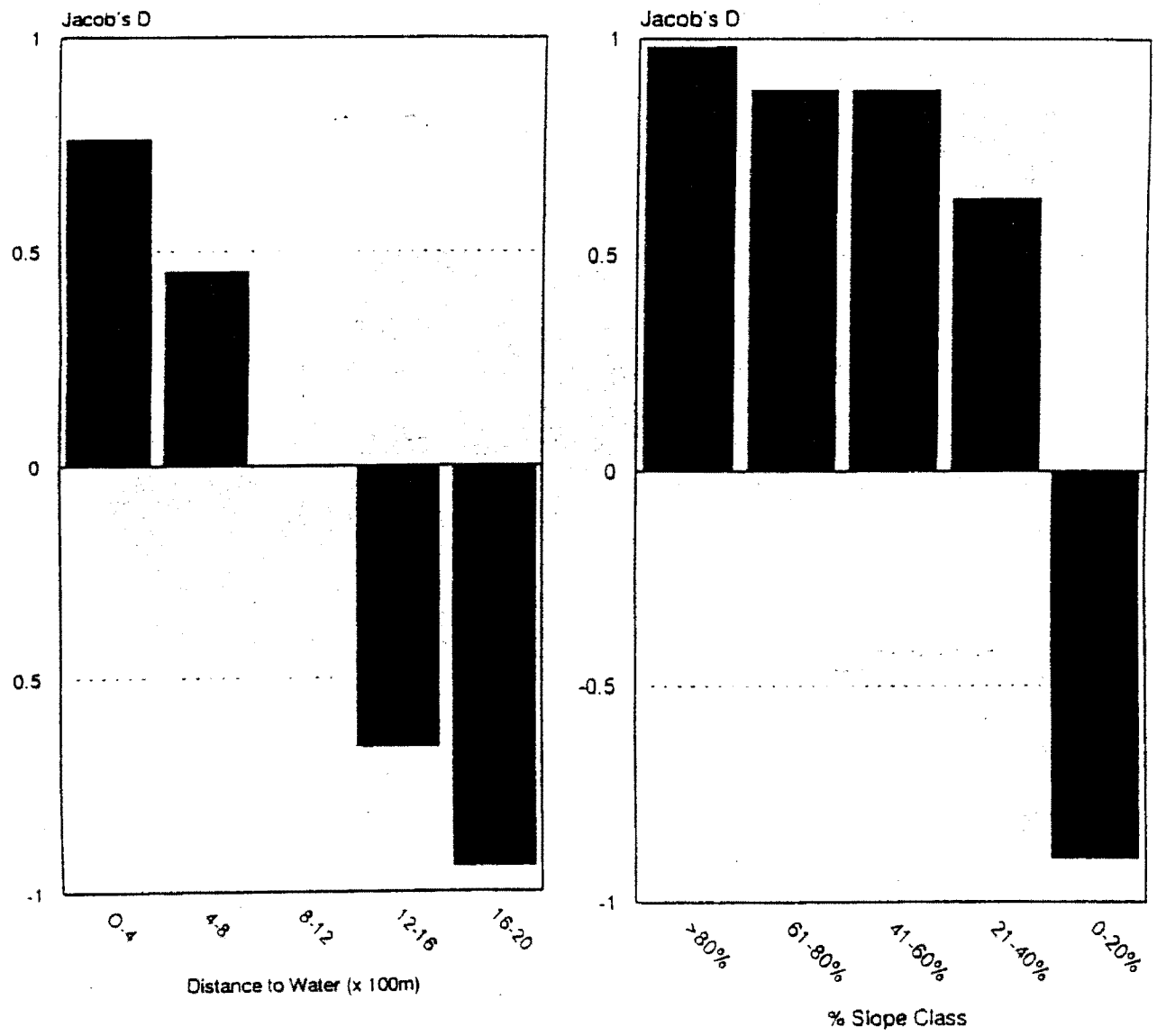

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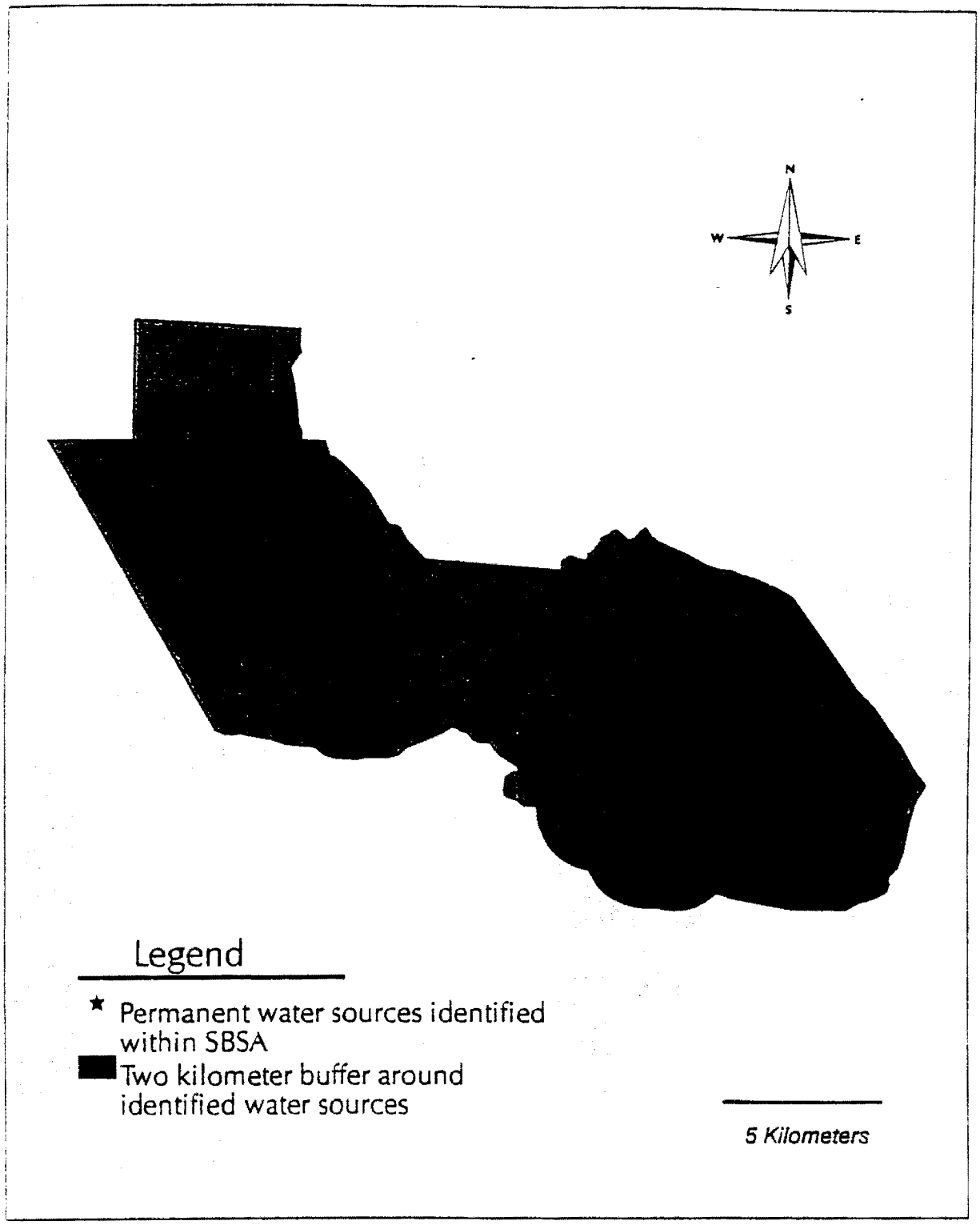
N
W
E
S
Legend
Permanent water sources identified within SBSA
Two kilometer buffer around identified water sources
5 Kilometers

PRELIMINARY INVESTIGATIONS OF SONORAN PRONGHORN USE OF FREE STANDING WATER.

JOHN HERVERT, Arizona Game and Fish Department, 9140 E. Co. 10 1/2 St. Yuma, Arizona 85365.

ROBERT S. HENRY, Arizona Game and Fish Department, 9140 E. Co. 10 1/2 St. Yuma, Arizona 85365.

MARK T. BROWN, Arizona Game and Fish Department, 9140 E. Co. 10 1/2 St. Yuma, Arizona 85365.

Abstract: Sonoran pronghorn (*Antilocapra americana sonoriensis*) use of water sources was monitored with a combination of cameras, direct observation, and radio receiver-data logger systems. A bomb crater filled with water on the Barry M. Goldwater Air Force Range in 1995. As many as 15 Sonoran pronghorn used the source of water on a daily basis from 24 June through 14 July, 1995. Sonoran pronghorn visited the water source during daylight hours. Coyote and pronghorn encounters were recorded. Predation of Sonoran pronghorn was not documented. Adult pronghorn appeared to dominate single coyotes in open habitats immediately adjacent to the bomb crater. The source of water was allowed to go dry and the responses of two radio collared female pronghorn were documented. Group size decreased and the animals dispersed (pronghorn #14 moved 30.6 km, pronghorn #22 moved 56.2 km) to the southeast within two weeks of the crater going dry. Free-standing water in the bomb crater appeared to influence the distribution and group size of Sonoran pronghorn during the summer of 1995. Other water sources were monitored, but visitation by pronghorn was not detected.

INTRODUCTION

Few studies have been conducted with the Sonoran pronghorn (*Antilocapra americana sonoriensis*) in part because of low density, endangered status, and restricted access to the Barry M. Goldwater Air Force Range (BMGAFR). The Sonoran pronghorn was listed as an endangered subspecies in 1967. Low numbers of pronghorn (164 estimated in 1996, Hervert et al. 1997) inhabit 10,117 km^2 of habitat, thereby making field study difficult. Logistical problems plague any attempt to gather sufficient data in the field on Sonoran pronghorn.

Sonoran pronghorn use of free-standing water has been largely undetected by previous investigators (Monson 1968, Wright and deVos 1986, Hughes and Smith 1990, Cutler 1997). The literature is mostly anecdotal in regards to water use. Prior to 1995, use of free-standing water by Sonoran pronghorn had been limited isolated observations and a photograph of a buck at Charlie Bell well. Recently, the management of wildlife through water development has

been questioned (Broyles 1995). The designation of portions of the Cabeza Prieta National Wildlife Refuge as wilderness has increased opposition among wilderness advocates to management activities. The Sonoran pronghorn Recovery Plan (1982) identifies a management option to "increase available water"(USF&WS 1982). Wildlife managers require reliable knowledge (Romesburg 1981) in order to make decisions regarding the use of water development as a recovery tool for Sonoran pronghorn.

Our investigation of Sonoran pronghorn use of free-standing water is designed to address the following hypotheses:

H_0 : Sonoran pronghorn do not use available free-standing water. H_1 : Sonoran pronghorn use available free standing water. H_0 : Water developments are used by Sonoran pronghorn independent of design configuration or habitat variables. H_1 : Sonoran pronghorn use of water developments is dependant on design configuration or habitat related variables. H_0 : Sonoran pronghorn group size, habitat use, and distribution is not influenced by use of free-standing water. H_1 : Sonoran pronghorn group size increases, habitat use, and distribution is influenced by use of free-standing water.

STUDY AREA

The Barry M. Goldwater Air Force Range (including the Cabeza Prieta National Wildlife Refuge) and Organ Pipe Cactus National Monument serve as the study area (Figure 1). Vegetation associations include the Lower Colorado River Valley and the Arizona Upland subdivions of the Sonoran desertscrub vegetation community (Brown 1994).

High Explosive Hill (H.E. Hill) is located in the South Tactical Range and is used as a target for high explosive bombs. A large bomb crater (H.E. Hill tank) collects water and serves as an ephemeral source of water. The area around H.E. Hill is disturbed by military ordinance, resulting in an early successional stage plant community. Fire occasionally acts to remove woody perennial species and further impede plant succession. The area is generally open, and characterized by annual plant species.

METHODS

We relied upon radio-collared pronghorn (n=16 1995, n=8 1996, n=7 1997) for the majority of our data collection and monitoring effort. Hervert and Krausman (1985) used a receiver-scanner unit to detect mule deer use of water developments. We modified this system to include a data logger thereby increasing the interval between maintenance visits from two days to three weeks. Radio frequencies were continuously scanned, and recorded if the subject walked within 50-75 meters of the receiver antenna. Trailmaster infrared monitors-35mm camera systems were placed on water sources as described by Cutler et al. (1996). Direct observations were made from hill top vantage points.

Fixed-wing aerial locations were gathered each week on all radio-collared pronghorn. Pronghorn observed during aerial flights were counted, classified as to sex and age (adult-juvenile), and assigned a habitat association with the aid of image stabilized binoculars. Fixed-winged aircraft maintained a minimum altitude of 305 meters. We used the habitat associations used by Wright and deVos (1986).

Duration of Study

Water developments were monitored during the months of May through August, 1995 and 1996.

RESULTS

Sonoran pronghorn (n=15) visited H.E. Hill tank on a daily basis from June 24, 1995, through July 14, 1995 (Figure 2). Two radio-collared female pronghorn and as many as 13 other unmarked pronghorn were observed drinking water during each of 3 days when direct observation was possible. Visits to water occurred primarily during the crepuscular hours. Trailmaster infrared monitors-35mm cameras also recorded pronghorn visitation of the water source. Film capacity limited the time interval the water source was monitored by the camera system.

Sonoran pronghorn observed using the water at H.E. Hill tank (from June 29, 1995 each week through July 15, 1995) were found in larger groups (mean = 11, n=3) than those observed elsewhere (mean = 3.0, n=12) in the study area and continued to use the broad valley habitat (creosote-bursage association) longer (Figure 3). One week after H.E. Hill tank went dry, pronghorn #14 and #22 abandoned the area. By July 30, 1995, #14 and #22 had moved southeasterly 30.6 km and 56.2 km, respectively (Figure 4). Average group size decreased to 1.5 for #14 and #22 during the two week period ending July 30, 1995. Group size appears to be influenced by use of free-standing water.

Sonoran pronghorn were observed interacting with coyotes in the vicinity of H.E. Hill tank. Pronghorn dominated each of two encounters observed directly. Each encounter consisted of pronghorn approaching a coyote, followed by the coyote leaving the area. Pronghorn also appeared to dominate in an encounter documented by an infrared triggered camera system. The first photograph recorded a retreating coyote and an advancing pronghorn near the water's edge. The second photograph recorded a pronghorn where the coyote had been before. Although four fawns were present in the group using the water source, no predation occurred within the period the water was monitored. Cutler (1997) stated the presence of coyotes may inhibit pronghorn use of a water hole. Our observations do not support this contention.

Monitoring efforts in 1995 and 1996 did not detect pronghorn use of Adobe Well, Cameron Tank, or Papago Well. Factors that may influence the use or nonuse of a water development require further

investigation (Table 1). Although other radio-equipped pronghorn did not appear to use water developments, we did not record any mortalities among this sample during the summer months. Use of available chain-fruit cholla (*Opuntia fulgida*) in the vicinity of these water sources apparently provides at least the minimum water requirements of adult pronghorn.

We investigated fawn mortality relative to time of year. The number of fawns reaching 100 days of age was high, indicating a growing population (Table 2). High juvenile mortality was noted during the dry summer months (July and August). Trainer et al. (1983) and Ockenfels et al. (1992) reported fawn predation primarily within the first 30 days of a fawn's life. Byers (1997) reported mortality of fawns within the first 45 days. We presume the influence of predation on Sonoran pronghorn fawns is greatest within the first 45 days and the late summer mortality noted in 1995 was due to environmental factors (dietary deficiency and/or water stress).

Juvenile pronghorn likely require higher amounts of water per body weight than do adults. Knox et al. (1969) reported higher (> 2x) water flux for 105 and 120 day old mule deer fawns compared with older (231-305 day old) fawns. Wesley et al. (1970) reported similar water flux trends for pronghorn fawns. They also noted a difference between the sexes, with males requiring less water. Of the surviving pronghorn fawns in 1995, all 5 were males, possibly reflecting a differential ability among the sexes to survive drought conditions. Factors influencing the mortality of fawns during the summer of 1995 have not been documented. In our opinion, the influence of drought related dietary stress, coupled with water stress, can not be discounted.

The influence of free-standing water on Sonoran pronghorn requires additional investigation. Chain-fruit cholla may supply the water needs of adult pronghorn, but may be insufficient or even unavailable to fawns. Chain-fruit cholla may be susceptible to browse line formation. Fawns would not be able to reach fruits still obtainable by adults during shortages. A severe drought in 1996 killed chain-fruit cholla plants in the Tule desert region of the Cabeza Prieta National Wildlife Refuge. The availability of fruits may be limiting the size of the population. In our opinion, it is likely Sonoran pronghorn are influenced by available chain-fruit cholla fruits.

Fox (1997) reported estimates of water (preformed and metabolic) intake for Sonoran pronghorn in two habitats using diet models, and compared these estimates to the predicted turnover rates using the Richmond et al. (1962) model. Fox concluded "some areas within the present range of Sonoran pronghorn were able to provide adequate forage and water for pronghorn throughout the year,..". Although our field investigations support this conclusion, caution should be applied to these results. Richmond's equation assumes thermoneutral conditions, and is meant to reflect water turnover under conditions that include water ad libitum. The water requirements of a Sonoran pronghorn subjected to 45 degree C temperatures would presumably be

dissimilar to those experiencing thermoneutral conditions. The minimum water requirements of either adult or juvenile Sonoran pronghorn are not known. Chain-fruit cholla provides low levels of protein and digestible energy, but is very high in preformed water content (Fox 1997). Consumption of chain-fruit cholla to meet pronghorn water demands may be at the expense of a diet higher in quality.

The movements of Sonoran pronghorn can be characterized as wandering in nature. The home range of Sonoran pronghorn is larger than mule deer (*Odocoileus hemionus crooki*) or bighorn sheep (*Ovis canadensis mexicana*) (Table 3). Pronghorn may require vast areas in order to meet a high energy demand while selecting relatively scarce habitats free of perennial vegetation as a strategy to avoid predation. It is not known how this behavior influences the patterns or lack of patterns pronghorn exhibit relative to water development use.

CONCLUSION

Sonoran pronghorn were documented drinking water from H.E. Hill tank. Pronghorn were not detected at several other water sources that were monitored. The configuration of the water source may influence whether it is used or not by pronghorn. Sonoran pronghorn used a water source characterized by open, level terrain, in the proximity of food resources and thermal cover. Other water developments lacking documented pronghorn use are characterized by more vegetative cover adjacent to the water source, the presence of mule deer, and the availability of chain fruit cholla.

Sonoran pronghorn distribution, habitat use and group size during the months of June and July, 1995 was influenced by H.E. Hill tank.

Additional research is needed relative to the influence free-standing water plays in the recovery of the subspecies. We propose to investigate the influence of free-standing water on the diet of Sonoran pronghorn. We intend to compare the relative composition of forage species (chain-fruit cholla versus other forage items) within the diet of Sonoran pronghorn pre and post free-standing water use. The water requirements of fawns should be investigated further. Fawns are the most vulnerable segment of the population and recovery of the subspecies depends to a large part on the survival of fawns.

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Table 1. Characteristics of water sources that were monitored for use by Sonoran pronghorn.

Name of water	Permanence	Openness	Soil disturbance[1]	>2km from Opfu[2]	Mule deer[3]	Metal structures
HE Hill		X	X			
Cameron Tank	X		X	X	X	
Adobe Well	X	X		X	X	X
Papago Well	X			X	X	X

[1] Soil disturbance that encourages the growth of annual plants
[2] Distance from habitat that contains *Opuntia fulgida*
[3] Mule deer are known to inhabit the area and drink from the water source

Table 2. Ratios of Sonoran pronghorn fawns to adult females during 1995.

Date	No. of Fawns	No. of Does	Ratio
6-24-95	11	25	0.44
7-14-95	11	22	0.50
8-6-95	6	16	0.38
8-18-95	3	16	0.19
9-24-95	8	44	0.18
11-5-95	10	47	0.21
12-10-95	5	39	0.13

Table 3. Comparison of annual home ranges of adult female Sonoran pronghorn to adult female desert bighorn sheep on the Cabeza Prieta National Wildlife Refuge and Barry M. Goldwater Air Force Range (Scott et al. 1990), and to adult female mule deer in the Belmont and Bighorn mountains, Arizona (Krausman 1985). Home ranges were calculated as 100% minimum convex polygons.

Species	Year	n	Mean home range (km^2)	Range
Sonoran pronghorn	1995	14	1043.7	148 - 2270
Bighorn sheep	1986-1987	10	22.0	7.3 - 48.3
Mule deer	1983	8	43.4	12.6 - 73.8

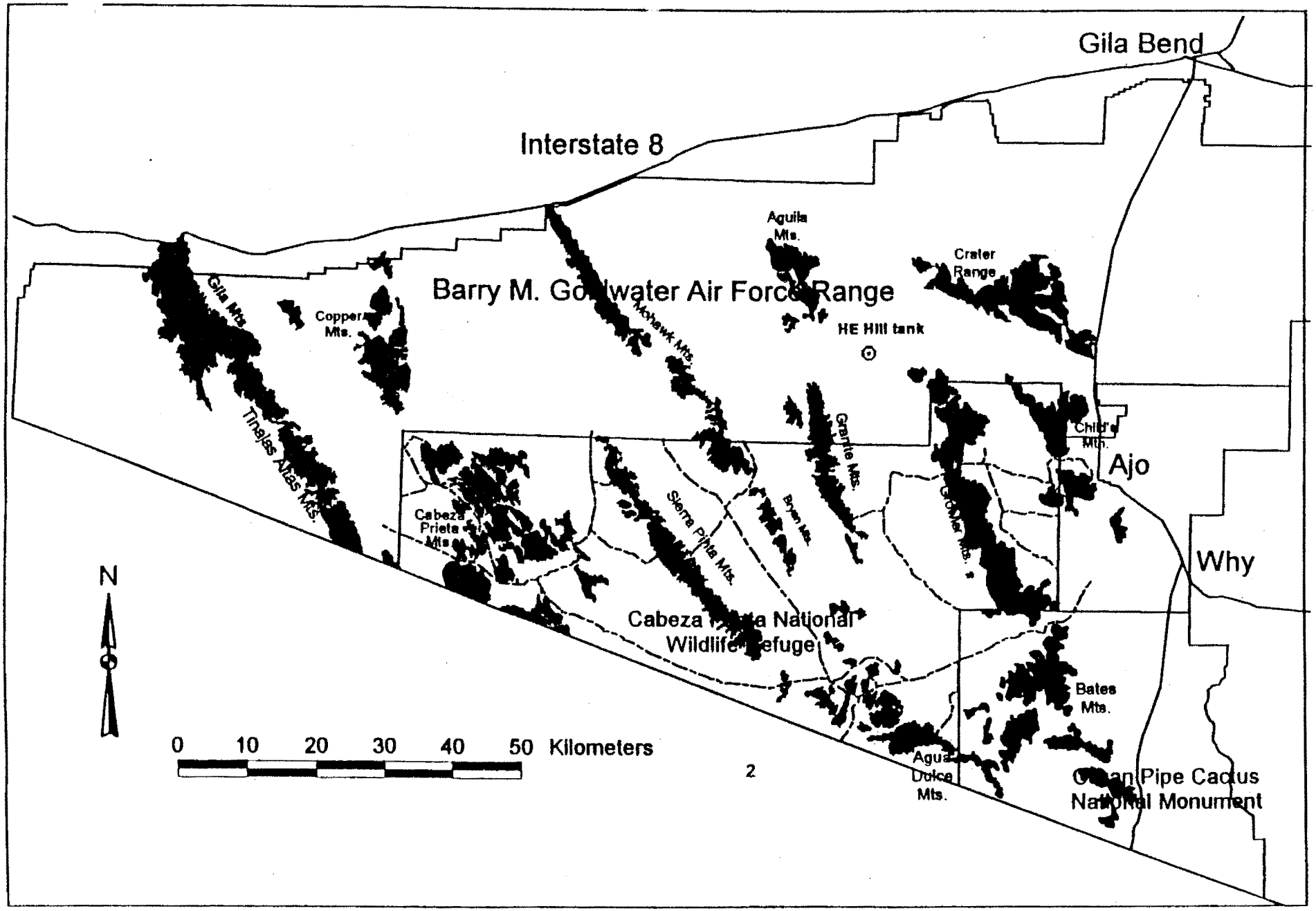

Fig 1. Study area for Sonoran pronghorn.

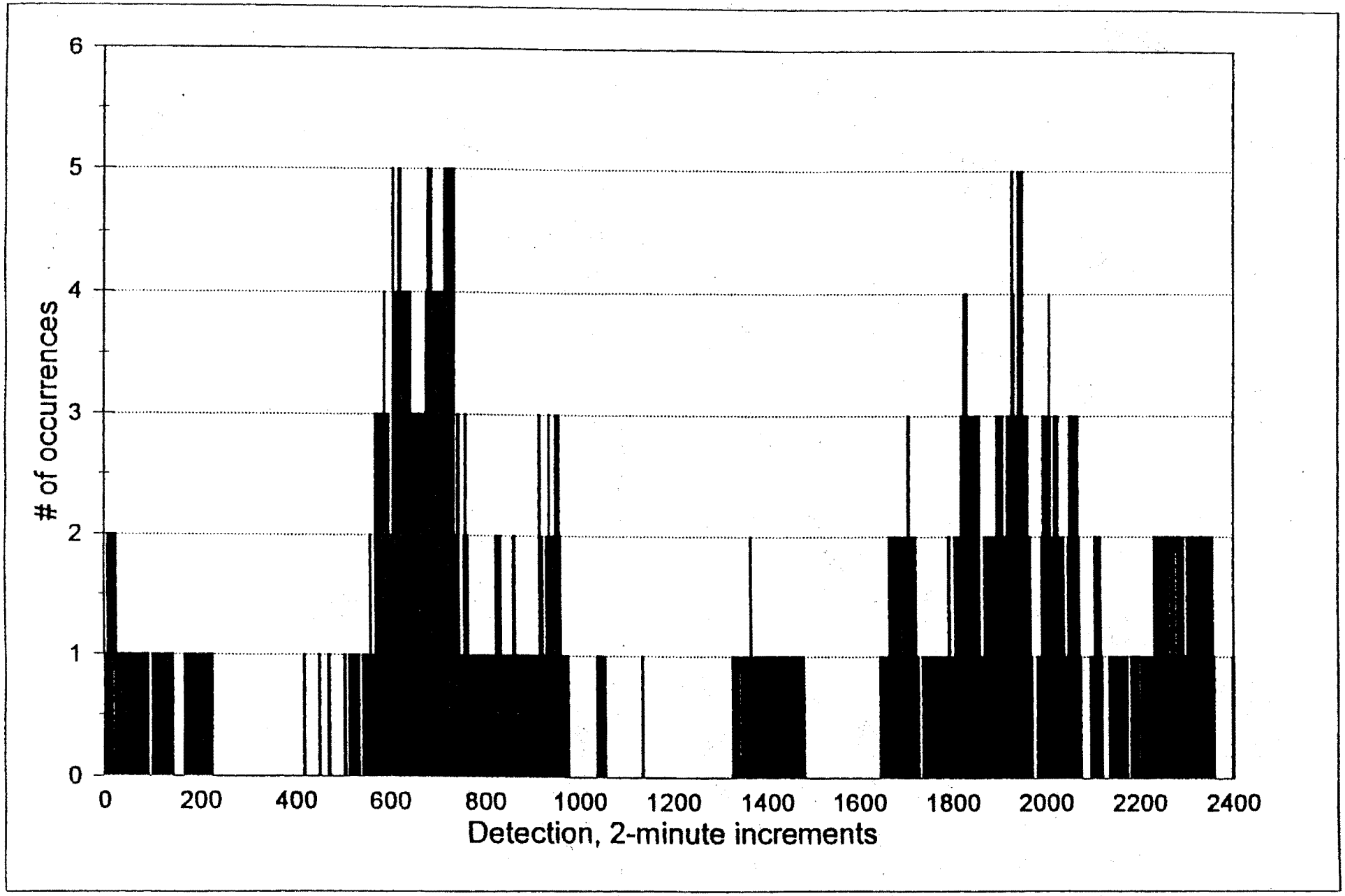

Fig. 2. Occurance of pronghorns 14 and 22, H.E. Hill.

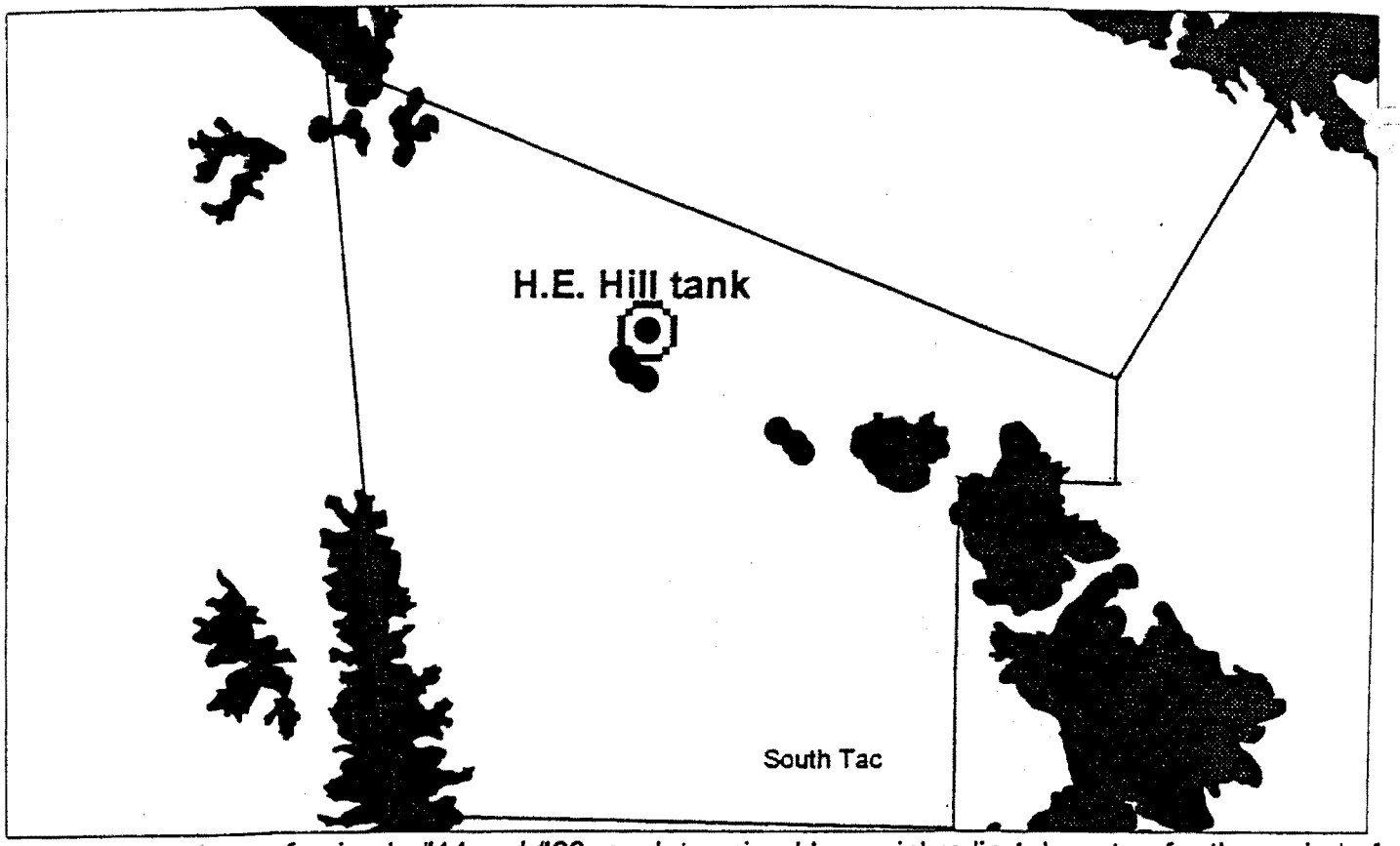

Fig. 3. Locations of animals #14 and #22, as determined by aerial radio telemetry, for the period of June 6 through July 14, 1995. Water was present in HE Hill tank during this period.

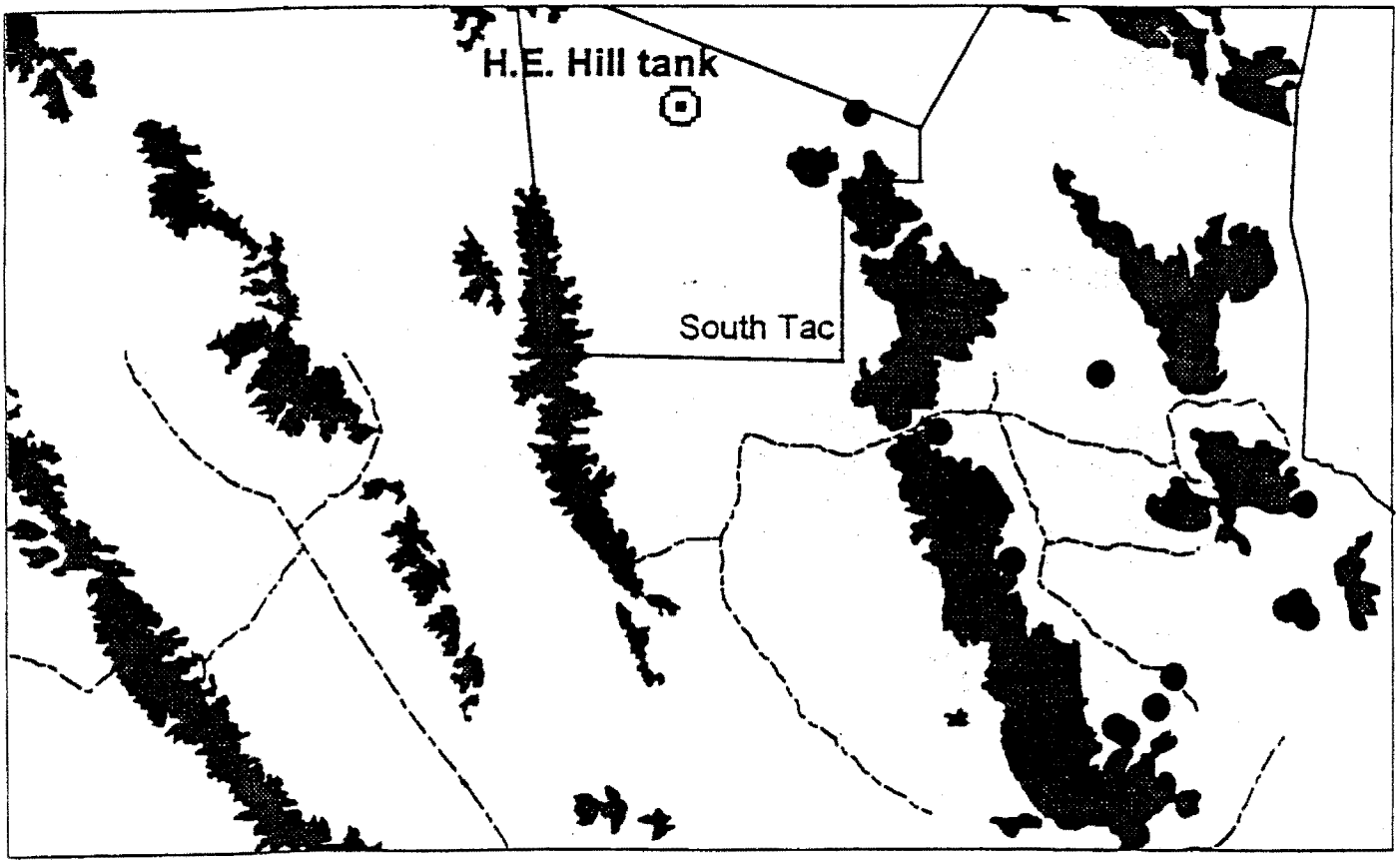

Fig. 4. Locations of animals #14 & #22, as determined by aerial radio telemetry, for the period of July 23 through August 27, 1995. Water was not present in He Hill tank during this period.

Water Developments and Desert Ungulates

Paul R. Krausman and Brian Czech[1]

Abstract – We examined the requirements and use of water by desert bighorn sheep (Ovis canadensis spp.), Sonoran pronghorn (Antilocapra americana sonoriensis), and desert mule deer (Odocoileus hemionus crooki). Desert bighorn sheep require 4% of their body weight in water/day, pronghorn require 1.8-2.6 L/29kg animal/day to 3.4-5.0 L/64kg animal day, and desert mule deer consumed 1.5-6.0 L/day during summer. All ungulates require water but their use of free standing water varies. Populations of sheep and deer use water catchments regularly (1.4 days/visit) to infrequently and Sonoran pronghorn have not been observed drinking from catchments. The importance of water catchments to productivity and recruitment of desert ungulates and their role in the animals habitat needs to be evaluated scientifically.

INTRODUCTION

Many biologists have claimed water as a limiting factor for ungulate populations in the desert Southwest (Bickle, 1969; Irvine, 1969; Simmons, 1969; Wood et al., 1970; Mahon, 1971; Wilson, 1971; Brownlee, 1979). Therefore, a major effort of wildlife management agencies has been the development of watering sources (Werner, 1984, 1985; Tsukamoto, and Stiver, 1990; Mouton and Lee, 1992). Describing the methods of water development has been a major literary undertaking (Halloran and Deming, 1958; Kennedy, 1958; Schadle, 1958; Mahon, 1971; Parry, 1972; Gray, 1974; Bleich et al., 1982; Brown and Johnson, 1983; Werner, 1984, 1985; Tsukamoto and Stiver, 1990). However, Broyles (1995) questioned the wisdom of providing artificial watering areas, and the results of water development have been mixed (Krausman and Etchberger, 1996).

Because of the costs involved (e.g., $20,000 to $50,000 for a typical bighorn [Ovis canadensis] water development [Mouton and Lee, 1992]), it is important for managers to have a firm knowledge of where and when water developments increase sustainable ungulate production. In this article, we: (1) review the literature on requirements and use of water by desert bighorn , Sonoran pronghorn (Antilocapra americana sonoriensis), and desert mule deer (Odocoileus hemionus crooki), (2) summarize general conclusions about the

[1] Professor and Research Associate, respectively, Wildlife and Fisheries Resources, School of Renewable Natural Resources, University of Arizona, Tucson, AZ 8521

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importance of water for desert ungulates, (3) identify research that would help managers to understand where and when water development is appropriate, and, (4) assess the management implications of our findings.

LITERATURE REVIEW

Desert Bighorn

Desert bighorn require 4% of their body mass in water/day (Turner, 1970), and often meet that requirement by consuming free-standing water (Gross, 1960; Graves, 1961; Welles and Welles, 1961; Crow, 1964; Douglas and White, 1979; Olech, 1979), especially during hot, dry periods (Monson, 1958; Wilson, 1971). The amount consumed (L/animal/water catchment visit) has been documented as 2.6 in the Black Gap Wildlife Management Area of Texas (Hailey, 1967), 3.8 in the Santa Rosa Mountains, California (Knudsen, 1963), and 4.8 to 9.4 at various sites in the Desert Game Range, Nevada (Koplin, 1960). In Knudsen's (1963) study area, bighorn watered $\leq$ once/3 days. Bradley (1963) proposed that water must be consumed at least every 2-3 weeks during hot and dry periods, but recommended that water be available every 2-3 days.

Most watering occurs between daybreak and noon (Koplin, 1960; Hansen, 1964), and late afternoon constitutes a secondary peak for drinking activity (Graves, 1961; Campbell and Remington, 1979). Almost no watering occurs at night, but nighttime movements to water have been documented (Hansen, 1964). Loitering at watering sites averages less than 12 minutes, and actual drinking time is about 3 minutes (Knudsen, 1963; Campbell and Remington, 1979).

Bighorn may also obtain water from succulent vegetation like fallen saguaro fruits (Halloran, 1949) and barrel cacti (Warrick and Krausman, 1989). Krausman et al. (1985) continuously monitored 2 ewes from 27 June through 7 July 1983 in the Little Harquahala Mountains, Arizona. The ewes did not drink free-standing water, survived, and gave birth to lambs. Populations survive on ranges perennially without free standing water in the Big Hatchet Mountains, New Mexico (Watts, 1979) and in the Little Harquahala Mountains, Arizona (Alderman et al., 1989). However, succulence is only 1 dietary factor that influences water budgets; low nutrition increases metabolic rates and respiratory tract evaporation (Turner, 1970).

Bighorn have adapted to arid conditions. The kidneys of bighorn sheep appear capable of concentrating urine to conserve water (Horst and Langworthy, 1971). Bighorn can produce dry feces (Turner, 1970). They pant and sweat to reduce heat loads (Simmons, 1969) and may migrate to higher elevations during hot, dry periods to avoid the hottest portions of their range (Koplin, 1960). Bighorn sheep use caves, overhangs, and other rocky topography for thermal

regulation, and often forage at night to avoid solar radiation (Simmons, 1969; Leslie and Douglas, 1979).

Natural water sources are preferred to artificial sources (Hailey, 1967, 1968). Tinajas (i.e., rock depressions) are particularly important, because they are often found in the type of terrain occupied by bighorn sheep (Brown and Johnson, 1983). However, tinajas can become death traps under certain conditions (Mensch, 1969). Access to water, natural or artificial, is negatively affected by human activities (Jorgensen, 1974; Graham, 1980; Campbell and Remington, 1981), but not necessarily with an effect on bighorn production (Leslie and Douglas, 1980). Burros (Equus assinus) also have a negative effect on water visitation (Weaver, 1973), and in extreme cases can foul the water with feces and urine, consume all of the water, or destroy the watering source (Weaver, 1959).

Water availability is a key factor influencing distribution and home range size (Wilson, 1971), and the presence of water has an effect on bighorn behavior and the use of other habitat components. For example, Merritt (1974) found that the largest bedding sites were found near water. In fact, water serves as a focal point for many activities, including feeding, resting, and courtship behavior (Simmons, 1969; Olech, 1979). Halloran and Deming (1958) proposed that free water is needed every 8 km. Blong and Pollard (1968) designated the optimum water distribution as 3.2 km.

Water requirements vary with age and gender. Gross (1960) postulated that lamb crops are dependent on free water. Douglas and Leslie (1986) found that autumn precipitation during gestation accounted for 87% of the variability in lamb survival. In the Santa Rosa Mountains, California, ewes, lambs, and yearlings stayed within 1.2 km of waterholes during July and August, while older rams ventured up to 4.8 km from water (Blong and Pollard, 1968). At the Cabeza Prieta Game Range in Arizona, ewes and juveniles stayed within 0.8 km of water, but rams were less restricted (Simmons 1969). In the River Mountains, Nevada, bighorn sheep were restricted to a 3.2 km radius around a permanent water source during summer, and throughout the year ewes inhabited areas closer to free water than rams (Leslie and Douglas, 1979).

Lack of water has been cited as a limiting factor or as a possible reason for declining bighorn populations (Jones et al., 1957; Mahon, 1971; Deforge et al., 1981; Douglas, 1988). Few studies have assessed the effectiveness of water developments, however. Krausman and Etchberger (1995) monitored 2 catchments in the Harquahala Mountains of Arizona. One was poorly designed and effectively nonfunctional, while the other was rarely used.

Bighorn water developments are difficult and expensive to construct, because bighorn habitat is steep, rocky, and remote. To be effective, water catchments should be located near foraging areas and shade, but should offer bighorn unobstructed vision (Simmons, 1969; Werner, 1989). They should be constructed within escape terrain (Leslie and Douglas, 1979), which is open and

steep.

Desert Mule Deer

Leopold (1933) and Anderson (1949) proposed that desert mule deer do not require free water, but deer movements in response to the loss or establishment of a water source have been documented (Clark, 1952; Hanson and McCulloch, 1955; Johnson, 1962; Evans, 1969; Rodgers et al., 1978; Hervert and Krausman, 1986; Bellantoni and Krausman, 1991). Rautenstrauch and Krausman (1989a) documented a population in King Valley, Arizona that migrated during the dry season to areas with permanent water sources. They provided evidence that deer are capable of detecting rainfall at long distances and moving to those areas. Hervert and Krausman (1986:674) proposed that "desert mule deer appear to be at least behaviorally dependent on free-standing water." Bickle (1969) asserted that water was the factor most influential on density and movements of deer on the Fort Stanton Range in New Mexico, and Wood et al. (1970) suspected the same. Brownlee (1979) thought that water was a limiting factor in much of the Trans-Pecos region of Texas, and Koerth, Jr. (1981) found that distance to water was an important factor in habitat selection by mule deer in the Texas panhandle. Deer require free-standing water, but their diurnal home ranges may not include free-standing water (Maghini and Smith, 1990).

Deer tend to be closer to water during the summer dry season (Ordway, 1985, Ordway and Krausman, 1986; Rautenstrauch and Krausman, 1989b). Krausman and Etchberger (1995) noted the same with does west of Phoenix, Arizona, although they found bucks farther from the nearest water catchment during summer than during other seasons. In the latter study, however, deer were always within 5 km of water. Krausman and Etchberger (1995) found that deer were closer to water at all seasons than random locations would be. McNab's (1963) hypothesis that animals in arid regions have larger home ranges than conspecifics in mesic regions appears to apply to mule deer (Rautenstrauch and Krausman, 1989a).

Deer tend to visit water sources once each day, usually around sunset or at night during the summer (Hazam and Krausman, 1988). During winter, they most commonly drink just before sunrise. In the Belmont and Picacho mountains, Arizona, about 38% of does watered during daylight hours (Hervert and Krausman, 1986).

Elder (1954) found that does in the Tucson Mountains, Arizona consumed 6.6 L/catchment visit during summer. Hervert and Krausman (1986) detected an average consumption of 5.1 L/visit from study areas in the Picacho and Belmont mountains, Arizona during summer. Does in late summer consumed the most. Hazam and Krausman (1988) found that deer in the Picacho Mountains consumed from 1.5 to 6 L water/catchment visit during summer, and the average consumption was 3.7 L. Females drank more (3.3 L in

early summer, 4.16 L in late summer) than males (2.7 L in early summer, 3.55 L in late summer).

Water requirements of mammals are inversely proportional to body size (Richmond et al., 1962), and Hervert and Krausman (1986) pointed out that bucks should require less water/body weight than does, and fawns should require the most. Hervert and Krausman (1986) reported that bucks were found farther from water than does during all months except July, and that does were more predictable in their watering habits than bucks, which visited water catchments once every 1-4 days. Deer may water more than once/day when under heat stress (Clark, 1952; Swank, 1958; Hervert and Krausman, 1986). Hervert and Krausman (1986) thought the lower frequency of buck visits to water in late summer compared to other seasons was due to the greater water requirements of does, which usually lactate in late summer (Short, 1981). Fox and Krausman (1994) found that does during fawning were not any closer to water than during the rest of the year in Maricopa County, Arizona, but fawning coincides with the monsoon season (mid-late summer), when there are many ephemeral pools of water and plants contain more moisture. On the other hand, the monsoon season during the study was unusually dry, and only 1 of 7 fawns monitored survived. Knox et al. (1969) found that water turnover rates lowered as mule deer fawns aged.

Many animals have a thermoneutral zone in which a change in ambient temperature causes no change in water demand (Taylor and Lyman, 1967; Schmidt-Nielsen, 1981). Hervert and Krausman (1986) estimated the thermoneutral zone of desert mule deer at 25 to 30 C°. When temperatures remained in that zone, deer in the Belmont Mountains of Arizona watered no more than once every 4 days. However, Hervert and Krausman (1986) listed a number of factors that complicate that estimation, including efficiency of evaporative heat loss, size of the animal, nutrition, relative humidity, and wind velocity. They also identified 38 C° as the maximum body temperature, above which evaporative cooling must occur for desert mule deer to survive.

Mule deer remain inactive during hot days to conserve water (Hervert and Krausman, 1986). They incorporate succulent vegetation (e.g., cacti fruits) in their diets to reduce their need for free water, especially during the dry season (Krausman et al., 1990) but perhaps in general (Short, 1977; Krausman, 1978; Sowell et al., 1985; Krausman et al., 1997).

Desert mule deer appear readily adaptable to the use of artificial water developments (Elder, 1954). However, when water is plentiful, they tend to use natural sources and obtain more of their water requirements through foraging (Hervert and Krausman, 1986). In the Picacho Mountains, Arizona, younger bucks used artificial catchments more frequently than older bucks, which used earthen stock ponds (Hazam and Krausman, 1988), but that may have been a function of other factors influencing distribution. Some artificial sources of water have negative and positive effects on deer populations. Thousands of deer

have drowned in water canals in the West (Busch et al., 1984; Rautenstrauch and Krausman, 1986, 1989b).

Sonoran Pronghorn

Sonoran pronghorn are among the rarest ungulates in North America (Yoakum et al., 1996), and little research on their water use and requirements has transpired. American pronghorn have been studied more. The distinction between Sonoran and American pronghorn appears less distinct than that among mule deer and bighorn subspecies, and almost all pronghorn range is relatively dry. We therefore supplemented our review with American pronghorn literature.

Pronghorn obtain water by drinking, foraging, and from oxidative metabolism (Yoakum, 1994; Fox, 1997). Deblinger and Alldredge (1991) found that pronghorn distributions in Wyoming did not change with the availability of free water, but Boyle and Alldredge (1984) noted that water content of pronghorn forage in Wyoming was inversely related to pronghorn distance from water and that pronghorn were found closest to free water during the dryest seasons. Beale and Smith (1970) found an inverse relationship between the use of free water and forage moisture content in Utah. When moisture content of forage was >75%, pronghorn did not drink water even when it was available.

Forage selection by Sonoran pronghorn appears to be influenced by water content (Hughes, 1991), but the only research that focused on the water requirements of Sonoran pronghorn was conducted by Fox (1997). She was concerned primarily with determining if pronghorn at the Cabeza Prieta National Wildlife Refuge in Arizona could meet their water requirements through consumption of forage. Site, season, and species affected the preformed water content of forage. However, pronghorn could not increase their consumption of preformed water by feeding at a specific time of day, as was often assumed, because preformed water content did not vary with time of day.

The water requirement model of Richmond et al. (1962) indicates that pronghorn require from 1.8L/29 kg animal/day to 3.4L/64 kg animal/day, while Robbins' (1993) model indicates that pronghorn require from 2.64L/29 kg animal/day to 4.97L/64 kg animal/day. (Smaller individuals require less water, but more water/body weight.) Fox (1997) estimated the amount of preformed water intake at from 1.4 to 6.9 L/animal/day, and metabolic water production at from 0.2 to 0.5 L/animal/day. However, she derived the low preformed water intake estimate (i.e., 1.4 L/animal/day) under the assumption that pronghorn do not select plants in proportions different from those available. She rejected that assumption and surmised that free water was not a limiting factor for pronghorn at one of her study sites, but that the forage at the other site did not contain enough preformed water to support pronghorn at any season.

Also at Cabeza Prieta, Cutler (1996) monitored the use of 2 water developments constructed specifically for pronghorn. She detected no use by pronghorn. Furthermore, the catchments were used by coyotes (Canis latrans) and therefore may have comprised a net detriment to pronghorn survival.

Summary

Researchers have found variable results and subsequently drawn variable conclusions about the importance of free water to desert ungulates. Some populations need free water, and some areas perennially host few or no ungulates presumably because of a lack of water. Many areas lack water and ungulates seasonally. On the other hand, there are strong theoretical grounds, and in the cases of bighorn and pronghorn, some empirical grounds for concluding that desert ungulates may survive without free water.

Most of the data summarized are straightforward, but care should be taken with data on ungulate distance from water. As Fox and Krausman (1994) pointed out, distances may be greater during the dry season because waters are fewer then. One would be remiss to conclude that greater distances during the dry season were evidence for a lack of dependence on free water.

The physiological adaptations of desert ungulates have allowed them to populate drier areas than their relatives from more mesic regions. Theoretically, they are evolving more pronounced adaptations, and may one day inhabit drier areas presently void of ungulates. Alternatively, the large mammalian structure may have physiological limits to water conservation that may have already been reached with the desert ungulates. Perhaps there is much remaining evolutionary potential to cope with water shortage behaviorally, but it is difficult to conceive how the desert ungulates could improve on their thermal regulation strategies, and they cannot devote all of their energy to thermal regulation or water conservation.

When free water is absent, and within the confines of animal physiology and behavior, plant community composition is the primary consideration in determining the capacity of a range to carry ungulates. When populations exist in areas perennially devoid of free water, the plant community must be providing ungulates with enough preformed water (supplemented by their metabolized water) to enable survival. However, the duration of such populations is questionable. For example, Watts (1979) pointed out that the population of bighorns in the Big Hatchet Mountains of New Mexico had declined from about 140 to 25 animals in the late 1950s and then fluctuated near the latter figure, which is inadequate to protect the genetic variability of the population (National Research Council, 1995). There may have been springs that provided water in the Big Hatchets prior to the population decline, or there may have been water developments that fell into disrepair.

In some dry areas where ungulates barely survive, they would perhaps

flourish with water. Too much water may be detrimental, however. Watering sources tend to promote overgrazing nearby, especially when cattle share the range. Water is also used by predators. If predators are more dependent on water than ungulates, then the addition of water may work to the net detriment of ungulates.

Ungulates do use artificial water developments (although there is no record of Sonoran pronghorn drinking from water developments), but they prefer natural sources. Studies designed to ascertain use of artificial catchments may be misleading, however, if it takes many years for ungulates to become habituated to artificial sources.

RESEARCH NEEDS

Broyles (1995) admonished the wildlife profession to scientifically assess water development for desert wildlife, so we can either provide more and better water sources or redirect our conservation efforts. However, that admonition was somewhat simplistic. Assessing water needs of ungulate populations is ultimately a local endeavor, and rules of thumb are of little value. Douglas and White (1979) provided a good example of applied, locally driven research. Their objectives were to determine the extent of bighorn movements in their study area and then to determine where an additional water development should be placed to enhance summer range for the study population. They provided a very specific recommendation on where to place the development and why.

There are certain themes, however, on which useful local studies should focus. Plant community composition is always important. Composition studies offer the advantage of providing information on preformed water availability and on nutrition. Fox (1997) provided a model for determining whether or not the vegetation of an area contains water sufficient for survival, and for simultaneously ascertaining nutritional weaknesses in a plant community.

It is important for managers to know how variable and predictable the water levels of free sources and of plant communities are. Variability operates at seasonal and longer terms, and longer terms have been neglected by researchers because the time frame required often exceeds funding commitments. In many areas, simple descriptive studies that show how water levels fluctuate over time would be very helpful, especially if they provide predictive power. The manager with a reason to believe that a water shortage is coming can prepare to take measures to alleviate the problem, including maintenance of temporary watering facilities. With thorough rainfall variability data, the manager can prevent the error of constructing a catchment and thinking it will perennially contain water when in fact it will be dry during the periods it will be needed the most.

In most cases in the Southwest, it is difficult to tell if water is the limiting factor. Managers are likely to proceed on the assumption that water

development will be helpful, or at worst will not hurt, especially if predators are controlled. However, if forage is the limiting factor, then providing water at the expense of forage will result in a population decline. More data are needed on the impact of ungulates on plant communities surrounding water developments. Studies to measure such impact are relatively easy to design; the experimental treatment is simply the construction of the water development, while the dependent variables are plant community parameters. Except in remote, rugged areas, periodic plant community assessments pose no great logistical challenge. As with many types of ungulate studies, however, the time frame required for meaningful results may be administratively prohibitive.

With the expense and time required by ungulate field studies, there is a need for computer simulation work that explores the trade-offs between water and forage availability. If an area contains abundant forage but no free water, and the forage is too dry to provide enough preformed water for ungulate survival, then the most obvious method for increasing the carrying capacity of the area is water development. The addition of a few catchments may result in ungulate population gains if water was the limiting factor. Then there will be less forage because of the consumption by ungulates (except in cases where the presence of ungulates provides a positive feedback stimulus for plant production; Savory, 1988). As the number of catchments rises, forage production declines. At some point, the construction of further catchments may have a negative effect on the ungulate population. By accounting for rainfall, water requirements, ungulate population dynamics, and forage composition, production, and consumption, computer simulation could help to ascertain the optimum number of catchments in an area. An exceptional computer model would be adaptable to a wide range of ecosystems.

Although the danger of predation at water holes is self evident, no research has focused on the interactions of desert ungulates and predators at catchments. With recent improvements in remote camera equipment (Kucera and Barrett 1993), it should now be possible to design descriptive studies that estimate mortality rates associated with watering. Without that knowledge, it is difficult to assess the cost:benefit ratio of water development.

A study to ascertain the opinions of wildlife managers on the value of water developments would be useful. Managers often have knowledge from firsthand observation. Furthermore, managers sometimes compile data that are not published and unavailable to the scientific community. A comprehensive manager survey could be an efficient method to increase the published literature base.

MANAGEMENT IMPLICATIONS

Managers of desert ungulates cannot depend on the literature for rules of thumb that go far beyond what is provided by common sense and a basic education in habitat components and limiting factors. However, a knowledge of the literature is helpful because it suggests phenomena to look for in the field,

provides insight on ungulate water conservation strategies, reveals the range of factors affecting the importance of water, demonstrates the complexities associated with prudent water development, and provides a list of contacts, some of whom may be helpful sources of further information. Prior to making decisions on water development, managers should consult the literature and pursue greater detail in the cited documents as needed.

Ungulate managers who have been in an area long enough may know more about the local weather patterns, plant communities, water sources, and ungulate movements than anyone else. When an agency considers whether or where to place a water development, the experienced manager is often the first source of information and the final decision maker. Of course, some managers are better than others. That suggests that it may be more important for an administrator to invest time in attracting good managers and providing incentives for keeping experience working in the same area than it is to obtain grants for research or water development.

Nevertheless, there are a few points that merit consideration because they are often overlooked. If water developments are to be perennial, then they usually must be much larger for mule deer, which tend to exist in larger populations. For example, Hazam and Krausman (1988) found that a population of 200 mule deer in the Picacho Mountains, Arizona would require 22,000 L of water/month.

However, we question the conventional wisdom that water developments are always beneficial. Wild ungulates are highly mobile and capable of finding water. When range conditions around water sources are poor (e.g., because of use by ungulates) the continued availability of water may invite irreversible destruction of the plant community. In theory, managers could establish a sort of rest rotation ungulate grazing system by rotating the availability of watering sources.

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RANGELAND WATER DEVELOPMENTS AND WILDLIFE II: FISH, REPTILES, AND AMPHIBIANS

The Influence of Stock Tanks on Native Fishes: Upper Verde River, Arizona

Pamela J. Sponholtz,[1,2] John N. Rinne[1], Laura M. Sychowski,[1,3] Daniel C. Redondo[1,4] and Brian P. Deason[1,2]

[1] USDA Forest Service, Rocky Mountain Station
Southwest Forest Science Complex
2500 S. Pineknoll
Flagstaff, Arizona 86001

[2]Department of Biological Sciences
Northern Arizona University
Flagstaff, Arizona 86001

[3]Department of Landscape Architecture
Arizona State University
Tempe, Arizona 86001

[4]Department of Forestry
Northern Arizona University
Flagstaff, Arizona 86001

ABSTRACT

There are over 450 stock tanks on the Prescott National Forest, Arizona and nearly 40% of these are within the Verde River watershed. Many of these tanks have been stocked with non-native sport fishes by state agencies and/or by private citizens. The Southwest's climatic regime is characterized by periodic heavy precipitation during winter frontal systems and summer monsoons. Heavy rainfall and runoff can cause some stock tanks to overflow and perhaps transport fish into the Verde River. We sampled stock tanks in the upper Verde River watershed to determine which tanks are possible sources for introduction of fishes into the Verde River, and developed a preliminary classification to aid stocking efforts. In addition, we interviewed landholders about undocumented introductions on private land. We found that very few stock

tanks pose a direct threat, but suggest that introductions of non-natives from some stock tanks is possible given heavy precipitation and tanks with a well-defined drainage to the Verde River.

INTRODUCTION

Stock tanks are a common surface feature in the desert Southwest. Typically, they have large littoral regions, are relatively shallow, have small volumes, surface areas and watersheds (Clark 1988), and are usually located on ephemeral streams or in natural drainage basins (Cole 1988). They provide a critical water source for domestic livestock, wildlife and terrestrial and aquatic invertebrates (Menasco 1986). Although many tanks are ephemeral, many are perennial (33%, of those in this study) and may provide suitable habitat for fishes (Menasco 1986; Aldon 1991). State agencies, in addition to private landholders, have stocked many of these tanks with non-native game fishes such as largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrocheilus*), channel catfish (*Ictalurus punctatus*) and several salmonid species (Table 1). From 1920 to 1995, there were nearly 31,000 stocking events in reservoirs, lakes, ponds, rivers, creeks and stock tanks resulting in more than 213 million fishes stocked in the state of Arizona (Pringle 1996). Of this total, more than 550,000 non-native fish were stocked in stock tanks within the Verde watershed (Pringle 1996). Stocking of non-native game fishes provides a popular resource for the public, although few published reports (Rosen et. al. 1994) have addressed the effects of non-native introductions on the indigenous fauna of the watershed.

Loss of habitat and introduction of non-native fishes are the most devastating factors in the decline of native fish populations (Minckley and Deacon 1991; Simberloff et al. 1997). Non-

native fishes may outcompete (Deacon et al. 1964; Schoenherr 1981; Douglas, 1994), prey upon (Meffe 1986; Marsh and Langhorst 1988; Blinn et al. 1993; Scoppettone 1993; Rinne and Alexander 1994; Rinne 1995), and sometimes eliminate native fish populations (Rinne 1991; Rinne 1995). Introductions of non-native species can also affect other vertebrates. Native leopard frogs (family Ranidae) have undergone massive population declines in the Southwest. Although many factors have contributed, predation by introduced species such as fishes and bullfrogs may be the primary cause (Rosen et al. 1994).

The desert Southwest is characterized by seasonal flooding produced by winter frontal systems and summer monsoon rains. These events have produced flows two to three orders of magnitude higher than base flows in less than 24 hours. Native fishes, which evolved in a flood disturbance regime, are thought to move to backwater areas or maintain position within the channel, while non-natives are often washed downstream (Meffe and Minckley 1987; Minckley and Meffe 1987). In the Verde River, native to non-native fish ratios are typically around 85:15: whereas the floods serve to "reset" the above ratio between native and non-native fishes, non-natives do recover and recolonize rapidly (Stefferud and Rinne 1995; Rinne and Stefferud 1997). Although the floods assist the recovery of native fishes, the same floods potentially bring more non-natives into the Verde River via an influx from stock tanks. Our objectives were 1) to survey stock tanks for fishes within the upper 60 km of the Verde River watershed, 2) to assess the potential of tanks to contribute exotic or other fishes to the river during heavy rain and runoff and 3) to develop a system whereby stock tanks can be classified with respect to their potential contribution of biota to the river. Our results indicate that although few tanks impose a direct

threat, the potential does exist in some stock tanks for floods to transport non-native fishes into the Verde River.

STUDY AREA

The Verde River watershed encompasses 6,282 km^2, much of which is within the Prescott National Forest, Yavapai County Arizona (Silvey et al. 1984; Figure 1). In the upper watershed, annual mean discharge increases from 1.3 m^3 sec^{-1} at the Paulden gauge (# 09503700) to 7.0 m^3 sec^{-1} Clarkdale gauge (# 09504000), but can exceed 400 m^3 sec^{-1} during 50 year flooding events (United States Geological Survey records for 1992 to present; Figures 2 and 3).

In the Southwest, the Verde River is unique among perennial desert rivers since water diversions, such as those used for agriculture and irrigation, are minimal and the upstream reaches still retain native fish populations. Currently, the Verde River provides habitat for six native fishes including Sonora (*Catostomus insignis*) and desert (*Catostomus clarkii*) suckers, rountail chub (*Gila robusta*), longfin dace (*Agosia chrysogaster*), speckled dace (*Rhinichthys osculus*) and spikedace (*Meda fulgida*) (Stefferud and Rinne 1995). Razorback sucker (*Xyrauchen texanus*) and Colorado squawfish (*Ptychocheilus lucius*), were historically recorded from the upper Verde River but were locally extirpated there. Both are currently on Federal Endangered and State Special Concern lists and are the subject of reintroduction efforts.

METHODS

We sampled 57 stock tanks within the upper Verde River watershed between May and

September 1997 (Appendix 1). Since sampling all the stock tanks within our study area was not feasible, we chose sampling sites based on accessibility, proximity and drainage to the Verde and approximate surface area based on USGS 7.5' topographical maps. Despite our small sample size and non-random method of sampling, we assume that our samples are representative of the entire population within the upper 60 km of the Verde watershed. We based this assumption on the large distance incorporated in the study and that our samples (stock tanks) were spaced fairly evenly throughout the study site.

At 48 of the 57 stock tanks, we recorded length and width of the catchment basin and estimated potential maximum water depth. Distance (km) to the Verde River was estimated using USGS 7.5' topographic maps. For each stock tank that contained water, we recorded length, width and maximum depth at current water level. The high evaporation rates, use by cattle, percolation, and locally and seasonally variable inflow make measurements of water depth extremely variable. To standardize these measurements, we determined potential depth from the ratio of sampling depth to the maximum catchment basin (top of the spillway) depth. Likewise, potential surface area was determined from the ratio of the sampled surface area to the surface area of the catchment basin. Measurements are given as median ± interquartile range, IQR, (75th percentile minus 25th percentile). Stock tanks were classified into four categories based on size, drainage area, water holding capacity and to a lesser degree, distance to the Verde River (Table 2). We measured water temperature (°C), conductivity (μmhos/cm^3), pH, and dissolved oxygen (mg/L) at six stock tanks using a Hydrolab (model 4041-110).

In the larger tanks that could support fishes or those that had a history of stocking, we sampled fishes with seine (3m x 1.2m x 3.17mm and 6m x 1.2m x 3.17mm) and trammel nets (30.5m x 1.8m x 38.1mm and 30.5m x 1.8m x 76.2mm). Trammel nets were deployed at sunset and checked every two hours until sunrise. All fishes were identified, measured (total length to1 mm) and returned live to the place of capture. Invertebrates and amphibians were identified and their numbers estimated.

RESULTS

Two thirds (63%, Table 2) of the stock tanks sampled were dry or nearly dry (< 12 cm water depth) when sampled May - September 1997. We classified these tanks as Type I. The likely absence or near absence of water for an extended period prevented fishes from establishing a presence, and precluded the threat of introduction to the Verde River. Type I tanks were usually found in natural depressions and were not obviously modified (i.e. collection berms were usually unmaintained or absent) for use as stock tanks . However, based on animal tracks at the edges of many of the tanks, livestock use these tanks during periods when water collects in the shallow basins. One-half of these tanks were proximate (<10 km) to the Verde River, with a median distance for Type I tanks of 12.91km (IQR=17.36; Figure 4). The median potential depth and median potential surfacearea for Type I tanks were nearly zero, the lowest of all the stock tank categories (Figures 5 and 6).

Type II stock tanks constituted 19% (Table 2) of the tanks sampled and contained water nearly year round. Water inflow is reduced before the onset of summer monsoon rains, and

water quality is reduced within the tank. These tanks were usually turbid due to heavy livestock use, and were usually modified to enhance water collection, with high, man-made berms and pipes leading to water sources. Over half of the Type II stock tanks were less than 10 km to the Verde River, with a median distance for all Type II tanks of 8.36 km (IQR=6.37). Fewer Type II than Type I tanks were dry during sampling (27% verses 94%). Type II stock tanks also have a higher potential depth ratio (0.09) and a higher potential surface area ratio (0.003).

Type III stock tanks were often found in natural depressions and comprised 8% of the sample. These tanks are perennial due to being spring fed and/or receiving reliable input from diversions or creeks. However, Type III tanks are typically around 10 km from the Verde River (10.11km ± 5.01). Non-native tiger salamanders (*Ambystoma tigrinum*) were the most common inhabitants of these tanks (hundreds per seine haul), followed by non-native crayfish (*Procambarus clarki*). Water chemistry parameters varied among the Type III tanks, but were characterized by warm temperatures (20 °C) and high dissolved oxygen (7.4–15.1 mg/L, Table 3). Potential depth and surface area ratios were greater than Type II stock tanks with median values of 0.27 ± 0.03 and 0.22 ± 0.03, respectively.

We classified tanks with perennial water sources, documented history of stocking, and well-defined access to the Verde River during heavy rains as Type IV tanks. Although only a small fraction (8%) of stock tanks within the Verde watershed were identified as direct threats of introduced fishes, Type IV tanks can support large numbers of introduced fishes. Most of these tanks (80%) were greater than 20km to the Verde River with a median distance of 22.34 km

(IQR=10.81). However, they were deeper (1.83m ± 1.50) and had a larger surface area ($822.92m^2$ ± 12342.35) than the other three categories. Additionally, the potential depth (0.59 ± 0.36) and potential surface area (0.66±.09) for Type IV stock tanks was the highest of the four categories.

Type IV tanks clearly have the greatest potential as sources of introduced fishes. Little Hell Canyon tank was last stocked in 1993 with 200 channel catfish; we observed thousands of 150-200mm adults feeding on the water surface in early morning. Aggregations of approximately 100-150 young of the year channel catfish were observed near the shore during dusk and early morning. Trammel net samples produced channel catfish, green sunfish (*Lepomis cyanellus*) and crappie (*Pomoxis* sp.). The latter two species were not listed as stocked in Arizona Game and Fish records (Pringle 1996). Del Rio Springs, another Type IV tank, is a perennial spring that flows directly into Sullivan Lake and contained significant numbers of mosquitofish. Using dipnets, we caught 25-50 mosquitofish per sweep, including large, gravid females. Other Type IV tanks such as Stringfield and Bass tanks contained sunfish and largemouth bass. Although no fish were caught by trammel net sampling in July 1997 in Upper Limestone tank, largemouth bass and fathead minnows (*Pimephales promelas*) were reported in fisheries surveys completed in 1995 by biologists from the Arizona Game and Fish Department.

Most landholders whom we contacted had 6-7 tanks on their property that were initially constructed for livestock use. According to several landowners, approximately 75% of these tanks are dry during summer although some do have intermittent flow to the Verde River via

Sullivan Lake . The most recent overflow of these tanks occurred during Spring 1993. Most tanks on private property contained bass, catfish and bluegill and were intentionally stocked by either the current or previous landowners.

DISCUSSION

Studies of the effects of floods on fishes concentrate heavily on occurrences within stream reaches and generally document reductions in fish species diversity, evenness and number of species (Rinne 1975; Meffe and Minckley 1987; Minckley and Meffe 1987; Collins et al. 1981; Erman et al. 1988; Fausch and Bramblett 1991). In the absence of studies similar to ours, we must predict impacts of floods that flush stock tanks from effects of tributary flooding on streams and the effects of floods on fishes in perennial streams.

Physical conditions that exist during floods that overtop stock tanks will likely equal or exceed conditions experienced by fishes during flooding events in streams. A major cause of mortality of fishes during flash floods is bedload movement (Fisher and Minckley 1978; Erman et al. 1988). Bedload includes the stream substrate itself, but also debris, such as logs, which become dislodged or washed into the stream from high water flows. Larval fishes and eggs are crushed or suffocated as water forces the substrate downstream. This effect is intensified when floods dislodge large volumes of particulate material from normally dry streambeds because there is little vegetation to hinder erosion (Fisher and Minckley 1978). This description pertains to the dry spillways and creekbeds which often run between stock tanks and the Verde River.

Fish can also be killed when they become stranded in isolated side channels. In tropical stream pools separated by dry streambed, 75% mortality of poeciliid fish occurred from fish becoming trapped in desiccating pools (Chapman and Kramer 1991). However, species such as red shiners and sunfish have wide tolerances for low oxygen levels (<1mg/L) and high temperatures (35.5-36.5°C) which could permit their existence in extreme conditions (Matthews 1987). Despite these tolerances, the distance to the Verde from Type III and IV stock tanks (between 10-20 km) is much greater than the above study, and we believe that fish mortality will be higher should transport occur from stock tanks.

Although intense flash floods displace or destroy larval and juvenile fishes, persistence is a function of their relative colonizing ability (Meffe 1984; Schlosser 1985; Harvey 1987). Prolonged spawning, and spawning during or after floods, are traits that allow species persistence despite harsh flow regimes (Resh et al. 1988; Poff and Ward 1989). For native Southwestern fishes, spawning post-flood is well-documented (John 1963; Harrell 1978; Meffe and Minckley 1987; Rinne and Stefferud 1996). However, in a study conducted on the Purgatoire River, Colorado, Fausch and Bramblett (1991) found that native fathead minnow, green sunfish, red shiner and black bullhead (*Amerius melas*) were the first species to recolonize upstream following an intense flash flood.

Recent post-flood fish collections from the upper Verde River indicate that stock tank introductions from flooding events may have occurred (Rinne and Stefferud 1996). In Spring 1993, a 50 year flood event produced maximal flows of 283 m^3/sec^{-1} at Paulden and 710 m^3/sec^{-1}

at Clarkdale. Subsequently, fathead minnows were taken during sampling in the Verde River in May 1994 (Rinne and Stefferud 1997). Prior to a 7 year recurrence flood in Spring 1995, green sunfish were rare along the upper 60 km of the Verde River. Following flows of 56 and 280 m^3/sec^{-1} at Paulden and Clarkdale, respectively, green sunfish increased 480%. Although fathead minnows have not been captured since 1994, their presence and that of green sunfish, immediately post-flood suggests that higher than normal flows may have been responsible for their introductions into the Verde River. However, other explanation deserve comment. First, the abundance of sunfish in the upper Verde river has been low since 1994. Therefore, taking 12 sunfish in samples in 1995 may not be particularly meaningful. Secondly, fathead minnows are common bait fishes and could have been easily introduced into the Verde River by fishermen.

The classification system presented here requires further research in several areas. First, based on the potential depth and potential surface area for Type II and III stock tanks, further refinement is required to distinguish between these two types of stock tanks. Secondly, stock tanks should be revisited in the winter to determine how winter storms and snow melt affect water levels and runoff. Finally, our classification is based on a relatively small sample size and should be further developed and tested to determine if it is consistent across the entire watershed.

Management of native fishes in the Verde River requires consideration of fisheries management on the watershed. Accordingly, management of stock tanks on the watershed should be evaluated with respect to potential effect on native fish in the mainstream Verde River. Eradication of non-natives fishes by conventional fishery management practices is virtually

impossible. Recently adopted regulations removing limits on introduced sport fishes and restricting bait fishes in the Verde River will be implemented in January 1998. These measures may aid in reducing introduced fishes, but if these same sport fishes are stocked into stock tanks on the watershed, this regulatory measure will be ineffective.

In addition to providing critical water sources for livestock and wildlife, stock tanks provide important recreational opportunities to observe or harvest wildlife. It seems likely that the demand for sport fishing will continue to increase in the Southwest, and stock tanks may meet some of that demand. Seasonal stocking of Type III stock tanks would provide angling opportunities with little threat to the Verde River's native fish fauna. Management agencies should fully explore the potential for transport of non-native species on native fishes in the Verde River before recommending a course of action on Type IV tanks. Cooperative management of the tanks by the Prescott National Forest and the Arizona Game and Fish Department will be necessary to achieve such objectives, and private landholders should be encouraged to do likewise. Education and information programs are a vital component of this process so that the public can be properly informed of the potential effects of stocking private tanks in the upper Verde River watershed.

ACKNOWLEDGMENTS

The authors wish to thank Jerry Stefferud, Mike Leonard and Linn Montgomery for their exceptional comments and assistance. Also, thanks to the Arizona Game and Fish Department and Bill Silvey who generously provided all the stocking records and were extremely helpful

throughout the duration of this study.

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Table 1. Fish species and the total number stocked in stock tanks within the Verde River watershed. Data are from Arizona Fish and Game stocking summaries 1920-1995 (Pringle 1996). Only the squawfish (*Ptychocheilus lucius*) is native to Arizona.

Fish		Number Stocked
Brook Trout	*Salvelinus fontinalis*	25,700
Brown Trout	*Salmo trutta*	13,876
Rainbow Trout	*Oncorhynchus mykiss*	324,470
Black Crappie	*Pomoxis nigromaculatus*	1,040
Bluegill	*Lepomis macrochirus*	35,695
Largemouth Bass	*Micropterus salmoides*	13,901
Redear Sunfish	*Lepomis microlophus*	29,980
Threadfin Shad	*Dorosoma petenense*	3,000
Channel Catfish	*Ictalurus natalis*	105,777
Flathead Catfish	*Pylodictis olivaris*	1
Fathead Minnow	*Pimephales promelas*	2,250
Squawfish	*Ptychocheilus lucius*	16
Tilapia spp.	*Tilapia spp*	2,240
Walleye	*Stizostedion vitreum*	1,666
TOTAL		**559,612**

Table 2. Classification of stock tanks in the Verde River Watershed.

TYPE	CLASSIFICATION	N
TYPE I	Dry year round except during runoff; characterized by a broad shallow basin; berm is usually unmaintained or absent. Does not support fish.	36
TYPE II	Has water but tends to dry up during dry years; usually intermittent input; water quality is low in dissolved oxygen and generally does not support higher aquatic vertebrates. Sustaining fish populations unlikely.	11
TYPE III	Perennial water either from strong inflow or underground spring and can support fish populations; little threat for input into the Verde due to high, maintained berm and distance to river is >10 km; typically utilized by both domestic and wild ungulates; little vegetation with heavy sedimentation; often abundant algal mats.	5
TYPE IV	Perennial water as above in TYPE III and supports high numbers of fishes, direct access of introduced fishes to Verde river if high flows, usually greater than 20 km to river.	5
TOTAL		57

Table 3. Stock tank water chemistry parameters.

STOCK TANK	TEMP (°C)	DO (mg/l)	pH	COND. (µmol)
Wagon Tire	23.1	Not taken	7.1	125
King	20.0	15.1	8.5	290
Stringfield	20.5	6.9	8.5	120
Hell's Canyon	20.9	8.4	8.9	121
Upper Limestone	22.8	6.7	9.5	97
Schwanbeck	19.8	7.4	8.4	129

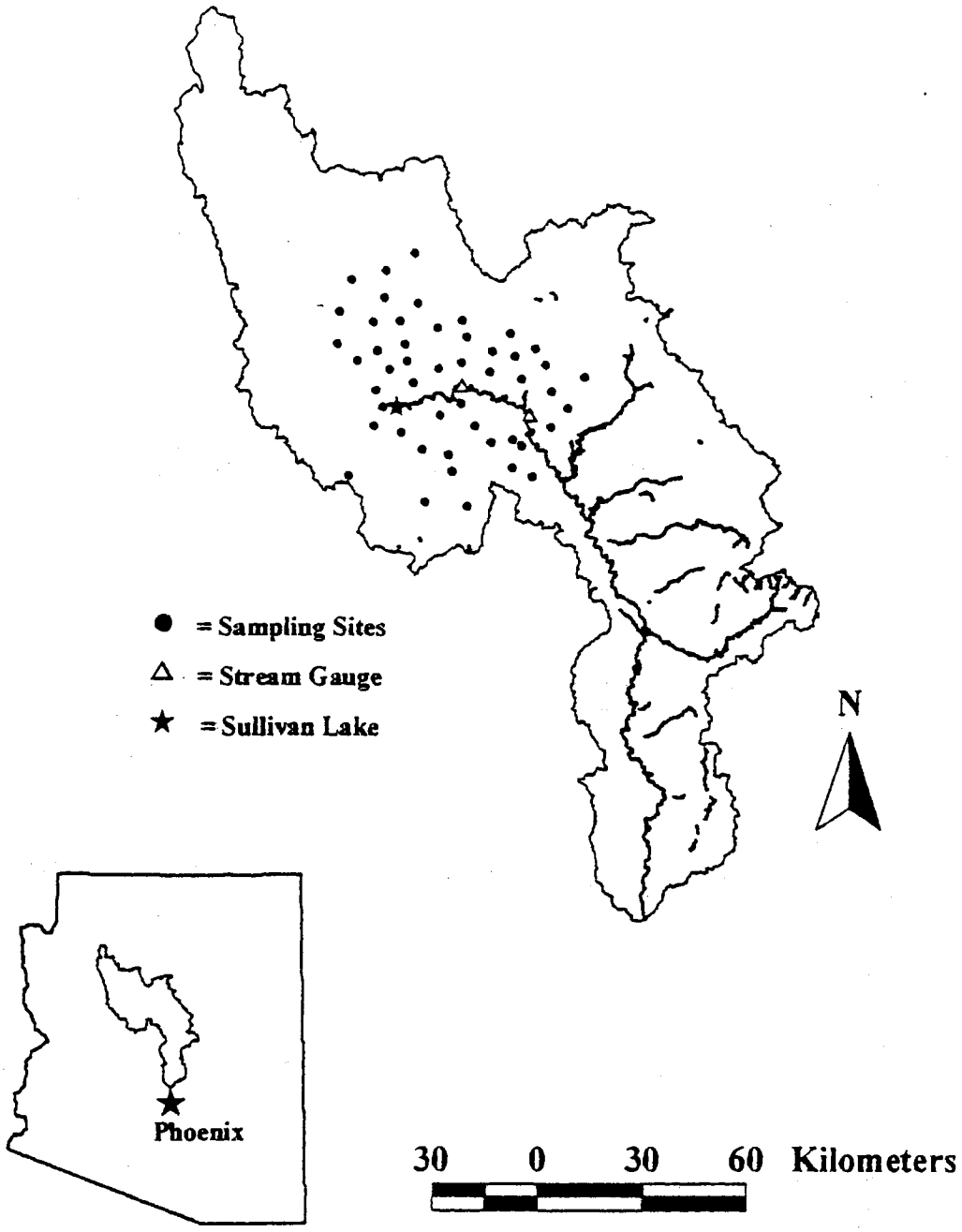

Figure 1. Map of the Verde River watershed. Paulden and Clarkdale stream gauges are indicated.

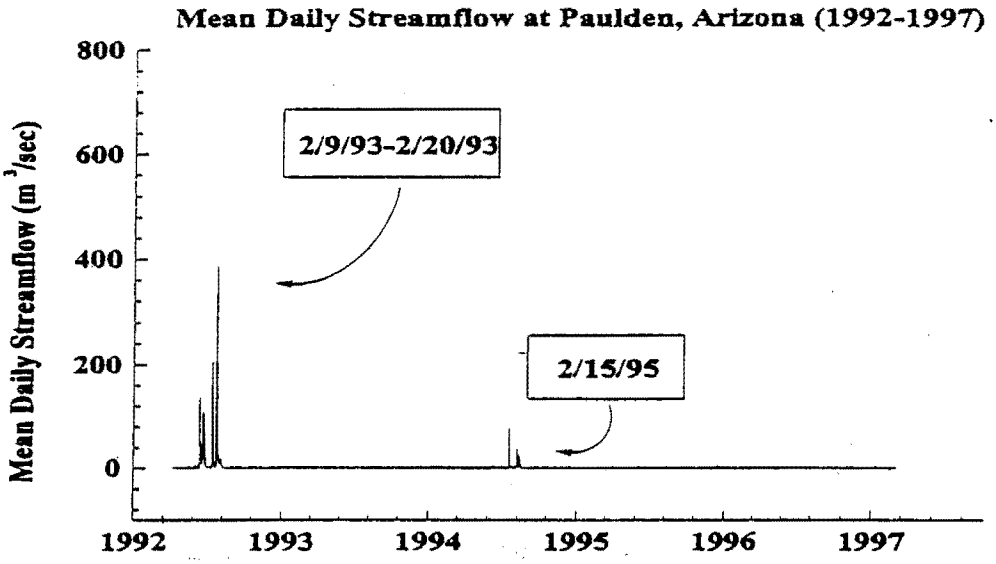

Figure 2. Mean daily streamflow of the Verde River at Paulden with dates of peak flows. Data are from USGS Water Resources Division and are provisional during the 1996-1997 water year.

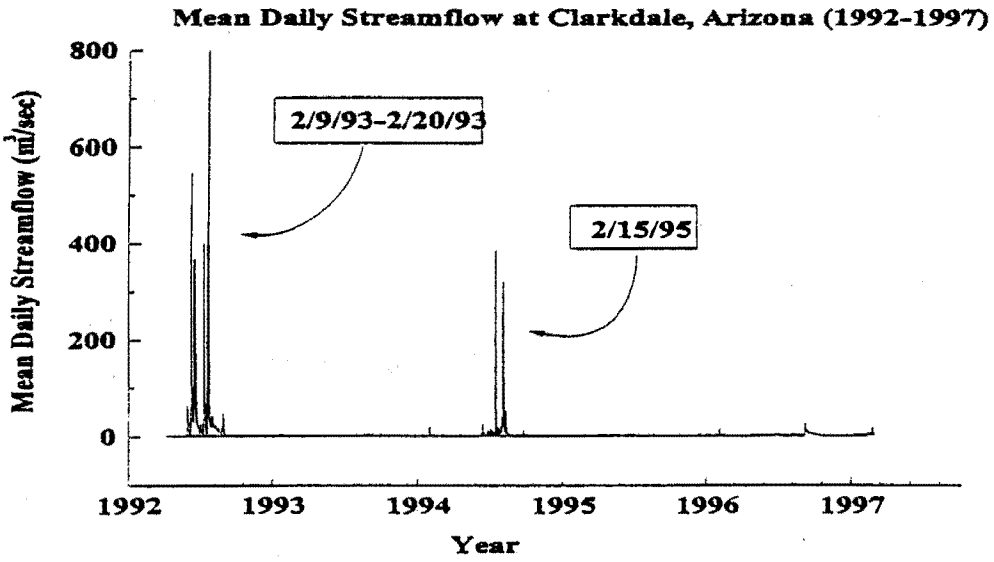

Figure 3. Mean daily streamflow of the Verde River at Clarkdale. Otherwise as for Figure 2.

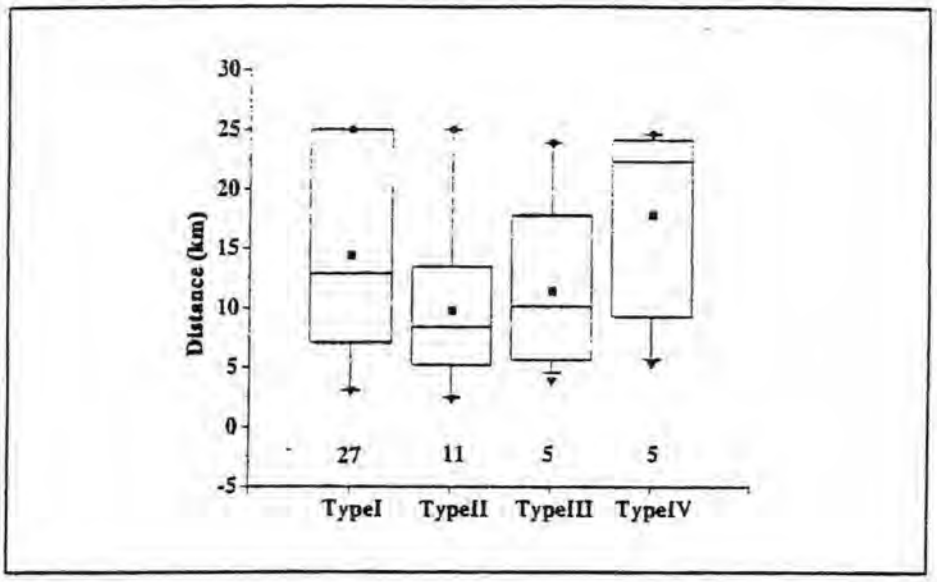

Figure 4. Boxplots of distance to the Verde River for Type I-IV stock tanks. Plots show minimum, (▼), maximum (●) and mean (■) values. The box lines show, from the top, the 75th, median and 25th quantiles. Sample sizes are given below the plots.

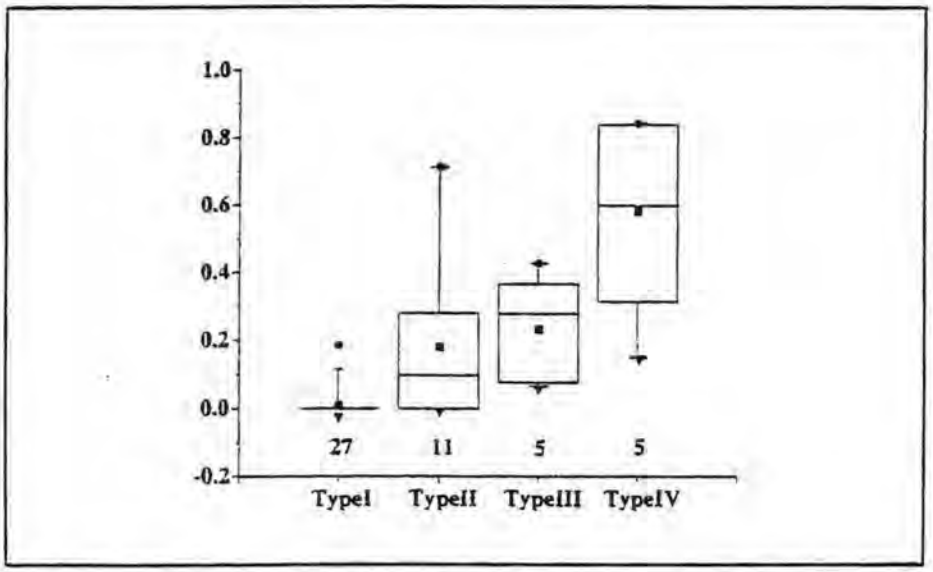

Figure 5. Potential depth for Type I-IV stock tanks. Potential depth was determined by taking the ratio of the sampled to maximum water depth. Maximum depth was estimated from the deepest section of the tank to the sill of the catchment basin. Otherwise as for Figure 4.

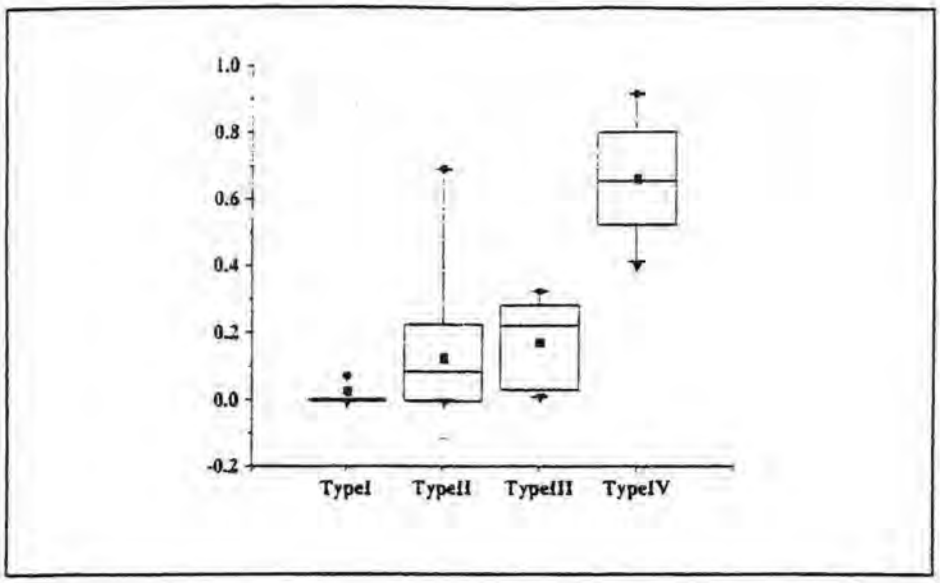

Figure 6. Boxplots of potential surface area for Type I-IV stock tanks. Potential surface area is determined by taking the ratio of the sampled to maximum surface areas. Maximum surface area was determined by the length and width at the spillway of the catchment basin. Otherwise as for Figure 4.

Appendix 1 . Stock tanks sampled from 5/23/97 through 9/24/97. When water was present, depth (CUR) was measured at maximum depth. Surface area (CUR) was determined from length and width measurements at the water surface. Potential water depth (MAX) was estimated as the maximum depth of the catchment basin. Potential surface area (MAX) was estimated from length and width of the catchment basin. Distance category is the estimated distance from the stock tank to the Verde River. See Table 2 for description of stock tank classification types.

STOCKTANK	DATE	DEPTH (m)		SURFACE AREA (m^2)		DISTANCE	TYPE
		CUR.	MAX	CUR.	MAX.	(km)	
Aikens	6/23/97	DRY	1.95	DRY	809.20	7.79	I
Bear	6/5/97	DRY		DRY		6.79	I
Betty's	5/23/97	DRY	1.52	DRY	12.28	4.93	I
Black Hills	6/6/97	DRY	1.98	DRY	25675.09	5.94	I
Boggy	6/5/97	DRY		DRY		3.39	I
Canyon	6/6/97	DRY	2.43	DRY	41145.99	7.17	I
China Dam	6/24/97	0.13	3.65	7.31	15056.39	10.26	I
Cordes	7/10/97	DRY	0.95	DRY	152.39	13.96	I
Cotton Dam	7/17/97	DRY	0.37	DRY	85.35	>25	I
Gale	6/30/97	DRY	0.91	DRY	493.75	14.19	I
Gas	6/23/97	DRY	1.22	DRY	123.16	>25	I
Gold Basin	6/23/97	DRY	1.52	DRY	792.75	>25	I
Greyhills	6/24/97	DRY	1.52	DRY	68.94.24	6.63	I
Halfway	6/24/97	DRY	1.68	DRY	91.44	13.34	I
Honey Bee	6/24/97	DRY	2.26	DRY	3352.64	11.34	I
Jimmy	6/30/97	DRY	6.09	DRY	1316.67	14.42	I
Little Page	5/23/97	DRY	1.98	DRY	24.38	11.95	I
Lower Wildcat	6/24/97	DRY		DRY		>25	I
Manzanita	7/17/97	DRY	1.52	DRY	1923.24	>25	I
Mark	6/6/97	DRY		DRY		3.16	I
McClure	5/29/97	DRY	1.83	DRY	27.43	4.20	I
McDaniel	7/2/97	DRY		DRY		2.62	I
Middle Trail	5/23/97	0.29	1.57	14.81	9600.73	3.01	I
Mormon Pocket	7/2/97	DRY		DRY		3.35	I
Muldoon	6/23/97	DRY	2.13	DRY	4762.27	>25	I
Page	5/23/97	DRY	2.44	DRY	253.73	10.68	I

Peavine	7/17/97	DRY	0.61	DRY	1115.51	>25	I
Railroad	7/17/97	DRY		DRY		>25	I
Ruin	7/10/97	DRY	2.90	DRY	7497.71	18.67	I
Sheep Camp	7/2/97	DRY	1.07	DRY	190.49	>25	I
Smokey	6/30/97	DRY	0.46	DRY	68.58	12.91	I
Tressle	6/5/97	DRY		DRY		2.46	I
Vineyard	6/30/97	DRY	3.66	DRY	493.75	12.76	I
West Side	6/24/97	DRY	1.37	DRY	512.04	3.12	I
White Hills	7/17/97	DRY	0.94	DRY	121.91	>25	I
Wildcat	6/24/97	DRY		DRY		>25	I
Deep Hole	5/23/97	0.2	2.04	4.19	14.62	8.36	II
Grindstone	6/5/97	1.37	4.88	4288.32	6171.90	15.42	II
Horseshoe	7/2/97	0.61	1.52	27.43	8137.76	10.11	II
MC	6/5/09	DRY	4.87	DRY	4096.31	10.95	II
Raphael	6/6/97	0.20	3.78	36.27	21712.89	13.43	II
Red Hat	7/17/97	DRY	0.85	DRY	922.30	>25	II
Robert E.	6/23/97	1.52	2.13	1554.40	6985.67	6.48	II
Roper	5/23/97	0.45	2.8	10.24	213.35	5.16	II
Upper Mormon Pocket	7/2/97	0.17	0.91	19.50	182.87	3.39	II
White	5/23/97	DRY	3.8	DRY	25.60	2.47	II
Witty Tom	6/6/97	0.36	4.57	2.74	60957.02	6.51	II
Baker's Pass	7/2/97	0.61	9.14	14.93	1950.62	10.11	III
Bull	6/30/97	0.34	3.96	91.44	1584.88	11.72	III
King	6/23/97	0.76	2.51	2133.50	8960.68	>25	III
Red Flat	7/2/97	0.91	2.13	3185.01	9792.75	4.51	III
Schwanbeck	5/29/97	1.06	3.81	12191.4	54861.32	6.71	III
Del Rio Springs	9/24/97	1.58	1.89	58.64	91.43	5.70	IV
Little Hell's Canyon	7/10/97	3.08	3.66	33511.10	36574.22	24.61	IV
Stringfield	7/10/97	3.65	6.10	822.92	1981.10	22.34	IV
Upper Limestone	7/10/97	1.83	3.81	12572.40	18241.39	23.61	IV
Wagon Tire	6/5/97	1.5	10	230.05	349.77	12.80	IV

USING MANAGED WATERS FOR CONSERVATION OF THREATENED FROGS

Philip C. Rosen[1] and Cecil R. Schwalbe[2]

[1]Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, Arizona 85721. [2]U.S. Geological Survey, Cooperative Park Studies Unit, University of Arizona, Tucson, Arizona 85721

ABSTRACT.

Native aquatic animals, especially frogs and fishes, have declined dramatically in the American West. Many are already threatened or endangered, and many continue to decline. One cause of the declines is predation and competition by introduced (non-native) species. Such exotics are difficult to control in natural waters, which tend to be large and complex. Man-made ranch ponds offer alternatives that are typically small, isolated from other waters, and manageable by drying or supplementation with wells. Wells may create the stable water level that some species need; conversely, some natives thrive under the fluctuating water conditions seen in most cattle tanks. Finally, introduced species may be controllable in tanks by removal, chemical treatment, or by drying the tank.

Ranch ponds can be refugia for native species that thrive and reproduce in still or slow-moving waters, including some ranid frogs (the "true frogs"), native fishes, and even invertebrates. It is possible to form public-private partnerships to manage native species in conjunction with livestock operations. Public partners (university and government biologists and managers) can provide expertise and resources. Private partners can provide knowledge of landscapes and existing populations, and can also function as on-site wardens. Both wildlife and livestock may benefit from enhanced quality and landscape distribution of waters. Thus, funding may be available for ranch-based biodiversity conservation.

We describe work with the Chiricahua leopard frog in the San Bernardino Valley of southeastern Arizona. We established a public-private partnership of university, state, and federal personnel, a ranching organization, a local high school, and an individual ranching family with a strong interest in conservation. Over 5 years we enhanced two existing frog populations, and founded new populations at 5 sites. Winter 1996-7 saw an unexplained decline at several sites, and our collective efforts appear to have prevented the disappearance of this species in the local management region.

This has led to a broader attempt to enhance Chiricahua leopard frog populations in the region. The objective is to secure enough populations that the species would be "recovered" (legally and ecologically) in the area. The declines we observed underscore the need to restore metapopulations, and, further, point to the importance of regular monitoring of populations. Such monitoring will assist in understanding and resolving causes of decline. While efforts like ours ought not substitute for restoration of natural waters, they may be the best hope for some species while we seek solutions to problems in the broader environment and in natural habitats.

I. INTRODUCTION.

One of the most pressing conservation problems in the American West, and particularly in the Southwest, is the decline of native fishes (see Minckley and Deacon, 1991) and amphibians (Vial and Saylor, 1993; M. Jennings, 1995; Sredl and Howland, 1995; Sredl et al., 1997a). Both habitat degradation and loss are occurring, but within existing habitat the presence of non-native predators and competitors appears to be a major factor affecting natives (Moyle et al., 1986; Minckley and Deacon, 1991; Rosen et al., *submitted*). The aquatic vertebrate fauna of the Southwest in particular appears to be in a broad and serious decline.

Declines of native "true", or ranid (genus *Rana*), frogs in the American West are now known to be caused by a variety of introduced species, including predatory fishes of many kinds (Hayes and Jennings, 1986; Bradford, 1989; Rosen et al., *submitted*), bullfrogs (Hammerson, 1982; Schwalbe and Rosen, 1988; Rosen and Schwalbe, 1995), and crayfishes (Fernandez and Rosen, 1996). These exotic species are now very widespread in Southwestern landscapes (e.g., Rosen et al., 1995), as well as elsewhere. It may be generally difficult to eliminate exotic species from complex natural systems (Rosen and Schwalbe, 1996a, 1997) because these systems have spatial and structural diversity that makes complete removal difficult, and because it can be difficult or impossible to de-water them as a means of exotic species removal.

The Chiricahua leopard frog (*Rana chiricahuensis*) is a native southwestern species that is in decline (Clarkson and Rorabaugh, 1989; Sredl et al., 1997a) and is likely to be listed as federally threatened in the near future (J. Rorabaugh, personal communications). Like some other native ranids, it is often abundant in cattle watering ponds in Arizona (Sredl and Saylor, this volume). It may persist in stock ponds that are isolated from sources of exotic species introductions or, in lower numbers, in ponds where exotics are eliminated by infrequent and temporary drying (Rosen et al., 1995; personal observations). Leopard frogs do not appear to tolerate prolonged habitat drying (personal observations), although there has been no systematic attempt to document or quantify this. The Chiricahua leopard frog has been eliminated from most natural waters by exotic species, habitat drying, and possibly by air pollution (Hale et al., 1995). In the current situation, metapopulations (Sjögren, 1991; Bradford et al., 1993) of frogs are disrupted, and recolonization of drought-impacted sites may now be infrequent or impossible.

One solution to the problem of conserving native wetland species that are affected by exotic species may be management in waters where the exotics are controllable (Rosen, 1997). The ideal situation would be one including the option of controlling the water, including drying as well as using well or spring water to stabilize water level, and one in which the habitat is not so complex that removal of unwanted exotics is difficult. The possibility that cattle ponds may meet these criteria, and may have other advantages for native frog conservation, is explored in this paper. We present the example of our attempt to implement this idea, and conclude with a general description of how such projects might best be carried out.

II. METHODS.

The Study System and Human Resources.

The lower San Bernardino Valley is a Chihuahuan desert grassland region in extreme southeastern Arizona that has historically supported Chiricahua and lowland (*R. yavapaiensis*) leopard frogs at several localities and in substantial numbers (Rosen and Schwalbe, 1988, 1996; Clarkson and Rorabaugh, 1989). San Bernardino National Wildlife Refuge (SBNWR) is on the valley floor at a rich riparian site with many springs and wells that support re-introduced native fishes, and where leopard frogs were formerly abundant (Lanning, 1981) but were apparently driven to extinction in the mid 1980's by the introduced bullfrog (Rosen and Schwalbe, 1995, 1996a). Other sites in the area have been increasingly affected by drought, in some cases also leading to recent elimination of populations (Rosen et al., *submitted*, and personal observations).

The refuge has served as a catalyst and was the early focal point of management efforts, primarily involving attempts to eradicate or control the bullfrog. These efforts have proven difficult (Rosen and Schwalbe, 1996b), in part due to the bullfrog's ecological resilience, and in part because of habitat complexity. Further, the primary mission of the refuge is native fish conservation, and this makes it difficult to use pond desiccation as a method to control bullfrogs. As a result, leopard frogs have not re-invaded the refuge successfully, and other species of wetland herpetofauna have continued to decline (Rosen and Schwalbe, 1997). The refuge has nonetheless been the focal point for the evolution of a coalition of university and agency researchers, land managers, and private ranching interests that has become active in leopard frog conservation and management in the study system.

Another important human factor contributing to the possibility of pursuing active management in the study system is the presence of a number of progressive ranchers who are organized into the Malpai Borderlands Group (McDonald, 1995). The objectives of this group are sustainable ranching within an ecosystem management framework that includes biological conservation and preservation of open space. The Magoffin Ranch, just east of SBNWR has a strong interest in conservation of endangered species of plants and animals on their active cattle ranch. Matt Magoffin is also a refuge officer at SBNWR, and he and his family have played a leading role in leopard frog conservation efforts on private lands in the area.

The research and management efforts leading to the conservation work described here originated with status surveys on public and private lands in the mid-1980's (Rosen and Schwalbe, 1988) supported by Arizona Game and Fish Department (AGFD) and U.S. Fish and Wildlife Service (USFWS). The AGFD then continued to play a key role in organizing, and, along with USFWS, subsequently funding experiments on bullfrog control at SBNWR. This early work attracted the interest and participation of personnel from other agencies as well as private individuals, a number of whom have played key roles as the broader conservation project developed. This broader, funded project expanded to include the leopard frog conservation efforts described in this paper.

Early Development of the Conservation Program.

The conservation program was not pre-designed or envisioned originally as a grand scheme. Rather, it developed from the bullfrog management work as opportunities and conservation crises arose. The bullfrog control program was initially established to attempt recovery of impacted populations of the Mexican garter snake (*Thamnophis eques*) at SBNWR (Rosen and Schwalbe, 1995), which is also affected by bullfrog predation on the smaller age classes of snakes. We recognized that eliminating bullfrogs as predators of the snake would also eliminate young bullfrogs, a primary food source for the snake population. This would leave the diet deficient in ranid frogs, its key component, unless native frogs could also be recovered. During this phase of the work, we observed the disappearance of leopard frogs from the refuge, and recognized the role bullfrogs were playing in the range-wide decline of the Chiricahua leopard frog and other native ranid species.

We confirmed that leopard frogs were, in fact, extirpated at SBNWR, but remained present at Magoffin Ranch. A drought that began in the mid-1980's and intensified in 1993 presented the opportunity to rescue tadpoles from a site on Magoffin Ranch that was drying, and to attempt to establish them at SBNWR under our regime of bullfrog removal. This effort mobilized the coalition of Magoffin Ranch, University of Arizona researchers (the authors), AGFD Nongame Branch, and USFWS to develop formal protocols and funding sources for active management of leopard frogs in the area.

The year 1994 saw a further intensification of drought in southeastern Arizona. At that time we began active management that has been ongoing since. It has included hauling water, adding of wells, digging of new and refurbishment of existing ponds, and construction of a concrete drought-refugium pool at a tank, all at Magoffin Ranch; establishment of a bullfrog exclosure for re-introduced leopard frogs, and erection of a small screened-in facility (a "ranarium") for frogs at SBNWR; and extension of leopard frog tadpole husbandry to a classroom and outside pond at nearby Douglas High School. In so doing, frogs were established at five new sites, and conservation efforts were also undertaken at the two remaining natural population sites in the area, both on Magoffin Ranch.

Specific Aspects of the Conservation Program.

From 1994, we developed the program in a relatively organized and planned fashion, although we also proceeded along serendipitous or necessary paths as these presented themselves.

Sources of tadpoles for reintroduction. Any frog conservation program must attempt to minimize its impact on existing populations. It is imperative that source populations not be seriously harmed by removal of large numbers of adults or tadpoles. We have attempted to solve this problem by (1) using tadpoles that were about to perish by desiccation at Magoffin Ranch in the 1994 drought, (2) harvesting partial egg masses from managed populations for rearing at the Douglas High School, and (3) utilizing tadpoles that were overcrowded in the wild managed population sites. In general, captive rearing and propagation are by far the most desirable approaches unless circumstances by chance afford an abundance of harvestable

tadpoles.

Tadpoles or newly metamorphosed frogs have been exclusively selected for translocation. Although egg masses can be safely transported with a modicum of care (Fernandez, personal communication), hatchling and very small tadpoles are likely to suffer high natural mortality. Rearing tadpoles is quite feasible, transporting them in aerated water by vehicle is uncomplicated as long as temperature extremes are avoided, and we believe growth to a total length of 25 - 50 mm (1-2 inches) greatly improves survival probability. Tadpoles are vulnerable at metamorphosis, and thus should be released well before that, or afterwards. We suspect that translocated older frogs may be likely to leave an introduction site, or may lose the advantages they have acquired through learning at their original locality.

Initial translocation of tadpoles. On June 10, 1993, 789 large *R. chiricahuensis* tadpoles were harvested by seine from the smaller of two drying pools in Rosewood Tank, Magoffin Ranch. They were immediately transported 11 km east to SBNWR and released in seven wetland sites, where bullfrog removal was underway, representing the full range of habitat conditions on the refuge. Trained personnel periodically searched the refuge for survivors of this experiment, beginning in September 1993.

Rearing of tadpoles. Tadpoles have been reared at Douglas High School as part of the science education program, and at SBNWR headquarters on a temporary basis. The tadpoles were collected as portions of three egg masses from Choate Tank (see below) in fall 1996, and as one entire egg mass from the SBNWR re-introduced population enclosure (below) in fall 1997. The have generally thrived on a diet of thawed frozen spinach leaves, with approximately 26% survival from hatching to release prior to metamorphosis. Rearing was in 15 gallon aquaria with aged (de-chlorinated) water with filtration. Better results may be obtained by feeding a combination of spinach, with finely sliced fish meat, and sliced cucumber or zucchini (M. Demlong, personal communication).

Use of outdoor enclosure. The active involvement of SBNWR has permitted the successful development of a leopard frog population in the bullfrog exclosure (Fig. 1). The exclosure consists of four small (4 X 6 m, 1-2 m deep), artesian well-fed pools. The water level of the pools is regulated by float valves, and they are surrounded by a 1 m tall hardware screen ("hardware cloth") fence (1/8 inch mesh) extending 15 cm into the ground and enclosing a terrestrial area of nearly one hectare. It was constructed in late winter 1994, and 188 tadpole stage and small juvenile Chiricahua leopard frogs were introduced in May-June 1994.

We were quickly confronted by several unexpected complications in the management of this enclosed leopard frog population. The shallow open habitat populated by a high density of relatively naive frogs immediately attracted green-backed herons (*Butarides striatus*) and great blue herons (*Ardea herodias*) in numbers. The pools were therefore covered with 10 cm mesh predator netting, which effectively eliminated avian predation on frogs in the enclosure. Then, following the first rains in July 1994, scores of small juvenile bullfrogs entered the exclosure by climbing the hardware screen; presumably, numerous leopard frogs also departed, and

these were probably consumed by larger bullfrogs that remained abundant elsewhere at SBNWR.

The immigrant bullfrogs were removed with some effort, and hardware screen eaves (Fig. 1) were installed on the enclosure fence. Nonetheless, a small number of juvenile bullfrogs continued to enter the enclosure, requiring regular monitoring and removal to prevent them from maturing and reproducing. Juvenile checkered garter snakes (*T. marcianus*, all removed) also penetrated the fence, as did kingsnakes (*Lampropeltis getula*). The snakes probably gained access through tunnels constructed by rodents, but the bullfrog entry points are not apparent. They may be able to squeeze through occasional irregularities between the eaves and the top of the fence, suggesting that eaves should be constructed by folding the top of the fence outward.

Use of ranarium. The ranarium (Fig. 2) was built in 1996 as a holding and breeding facility at SBNWR, based upon the design of Fernandez (1996). It differs from the original design as follows: (1) it is covered with hardware screen rather than fiberglass, (2) does not require artificial cooling, and (3) has recirculating water treated by ozonation. Ten adult Chiricahua leopard frogs from a drying puddle at a road crossing in Hay Hollow in August 1996 were released in the ranarium, and 6 tadpoles from Douglas High School were added in May 1997.

Management of cattle pond environments. *I. Hauling water.* Because of the critical situation during the 1994 drought when this project began, it was desirable to maintain some frogs at the originally strongest population locality, Rosewood Tank on Magoffin Ranch. This was a hedge against failure of tadpoles moved to the new enclosure at SBNWR. Immediately prior to drying of the tank in early April 1994, a small pool (3 X 3 m, 1.8 m deep) was excavated on an elevated bench of the tank bottom and filled with well water. Tadpoles (n = 400) were harvested from puddles in the tank bed and split evenly between SBNWR and the Rosewood refugium pool. The pool was fertilized lightly with cow manure and inoculated with pondweed (*Potamageton* sp.) from the original tank. Cattle were denied access to this pool throughout its existence.

It was necessary to haul approximately 1000 gal of water per week to sustain water levels in this pool. Poor rains over this portion of the Hay Hollow drainage during the remainder of this study necessitated continued water hauling until 1997, a task enjoyed by the Magoffin family at considerable expense.

II. Refurbishing stock ponds. Rosewood Tank, like all simple stock ponds, had over the years filled with in-washing sediment. All runoff-fed stock ponds can be expected eventually to fill with sediment and become increasingly less likely to hold surface water permanently. Rosewood Tank dried briefly in 1989, and nearly dried in 1993, prior to the early and prolonged drying in 1994. It is presumed that the 1994 drying would have killed all leopard frogs in the population, as no runoff occurred in the drainage until September 1994.

Matt Magoffin repaired and re-designed Rosewood Tank from July 1994 - March 1995, first

deepening it, and then adding a sediment trap and new overflow system. The sediment trap system he recommended (Fig. 3) is a key feature allowing the use of runoff ponds for conservation. This design permits sediment to accumulate in the trap, which also serves as a pond, while smaller quantities of finer particles are deposited in the main pond. As the sediment trap fills, it will hold less water but deliver more of the runoff to the main tank. The trap can be re-excavated with a bulldozer when it is thoroughly dry, on the presumption that aquatic amphibians and reptiles will be out of harm's way in the main pond. Alternately, the sediment trap may serve as a temporary pond or holding site for aquatic organisms during re-excavation of the main pond or some other management action requiring drying of the main pond (such as removal of an exotic species).

Rosewood Tank was excavated in two stages. First, two deep lobes were excavated around the perched refugium pool. Eventually, the refugium pool began to leak, and a concrete pool was installed just above the head of the tank (see below), and then the excavation was competed. A sediment trap was also added at Belency Tank, Magoffin Ranch, in 1994, at the other existing population site for *R. chiricahuensis* in the study system.

III. Creation of new pond population sites. Using existing wells, the Magoffins constructed small, non-runoff filled ponds at sites above Belency (Choate Tank, 1995) and below Rosewood (Headquarters Pond, 1997). These ponds were approximately 10 m in diameter and 1.5 m deep, perched on self-sealing clay substrata, and inoculated with pondweed. Choate was stocked with 66 under-sized tadpoles from the Rosewood refugium pool in late summer 1995. Headquarters Pond was stocked with 41 tadpoles from Douglas High School in May 1997; these were expected to be supplemented by immigration from Rosewood Tank at 3 km distance, as *R. chiricahuensis* normally appear at headquarters during very wet episodes (M. Magoffin, personal communications).

IV. Establishment of new wells at existing ponds. In order to guarantee a minimum of water for the native ranid frogs on-site, it was considered desirable to have wells to supplement runoff. Wells were installed with outside funding at Belency Tank (1995; funding from Malpai Borderlands Group) and near Rosewood Tank (1997; funding from AGFD Stewardship Program). The procedure was (1) conceptual review by university and agency herpetologists, (2) preparation of proposed plans for the wells by Magoffin Ranch, (3) evaluation of hydrology and engineering feasibility by funding agency, and (4) construction and contractor supervision by Magoffin Ranch. The Belency Well was placed within 100 m of the pond. The Rosewood Well was 3 km from the tank, where groundwater was accessible and storage and delivery to Rosewood and other sites was feasible.

V. Construction of concrete drought-refugium pool. The persistent drought at Rosewood Hollow and difficulties associated with long term water hauling encouraged the building of a 3 X 4 m, 1.3 m deep concrete pool (Fig. 4) as part of the AGFD Stewardship Program project. This pool was installed just above the upper end of the inundation area of Rosewood Tank, and fenced to exclude cattle. The new well supplied water to the pool as well as to a separate steel tank serving as a livestock drinker, both of which were regulated by float valves. Five adult *R. chiricahuensis* were removed from the small puddle remaining

in Rosewood Tank, and released in the pool in March 1997.

Predator removal. In addition to removal of bullfrogs (n=43) and checkered garter snakes (n=9) from the refuge leopard frog enclosure, we removed checkered garter snake from the Rosewood refugium pool (n=4), Belency Tank (n=25), Choate (n=2), and Headquarters (n=2). With the exception of the constrained situation at the Rosewood refugium pool (one large individual removed from this site consumed 180 ranid frogs in two years in captivity), we now regard these removals as questionable. Predator-prey dynamics are not understood in this system, and the effect of removing all or part of one class of predators (i.e., the snakes) is not clear.

Monitoring. Monitoring was accomplished by counting frogs during careful examinations of wetland sites. Additionally, data was recorded on egg masses, tadpoles, and unusual events including predator presence and abundance and appearance of dead frogs. The leopard frog enclosure at SBNWR was monitored regularly (9 - 28 times per year) by refuge and university personnel. The ranarium was monitored regularly by refuge personnel. Magoffin Ranch wetland sites were observed frequently by Matt Magoffin, with reporting to university personnel, and were monitored 1-3 times per year by university and AGFD herpetologists. Observation and monitoring were thorough searches using binoculars during the day and bright lights at night; attempts were made to locate and count every visible individual. All leopard frog egg masses observed were reported to university monitoring personnel.

II. RESULTS.

Population status in the study region.

SBNWR. The initial attempt to re-establish leopard frogs on the refuge by releasing at sites where bullfrogs were being removed yielded no evidence of success. Ongoing monitoring from 1993-1997 never revealed the presence of any leopard frogs on any of the unfenced sites on the refuge.

Chiricahua leopard frog tadpoles and small juveniles released into the SBNWR bullfrog exclosure in spring 1994 grew quickly to adult size and were observed breeding in September 1994. Breeding (calling males and subsequent egg masses and tadpoles) was observed during each fall 1994-1997. The enclosure population increased rapidly in 1995 and 1996 (Fig. 5). In fall 1996, a dead frog was found in the enclosure, and the population declined sharply between fall 1996 and early spring 1997. Two egg masses were observed at the site in September 1997, one of which was removed to Douglas high school for rearing.

The ranarium population was largely unsuccessful. Two of the original 10 adults died without evident cause in November 1996, and six more died in March 1997. In October 1997, the last two died, along with all but one of the juveniles derived from releases of reared tadpoles. These frogs had acquired a severe epidermal fungal mold disease (Chytridiomycota; G. Bradley, University of Arizona Veterinary Diagnostic Laboratory, personal communication)

which appeared to be the proximate cause of death. Whether this disease was triggered by some other, ultimate factor or cause remains unknown.

Magoffin Ranch. Southeastern Arizona has experienced generally poor summer rainfall, generally essential for filling runoff-fed ponds, since 1988. Summer 1996 was an exception, but the Magoffin Ranch area generally remained extremely dry during all years 1994-1997. Rosewood Tank and all of Rosewood Hollow had poor rains and meager runoff throughout the period. Belency Tank and surrounding Belency Hollow flooded in summer 1996, and received moderate runoff in 1997. Other tanks on the ranch, which hold water for generally shorter time periods and support immigrant individual leopard frogs, never filled during 1994-1997, and puddles in lower Rosewood Hollow and Hay Hollow, which also are occupied by leopard frogs, filled only once, in summer 1996.

Rosewood Tank. The large population at Rosewood (with hundreds, and probably thousands of tadpoles in 1993) was rapidly reduced from spring to summer in 1994, but remained remarkably stable during 1995-1997 (Table 1). By 1997, almost all frogs seen at Rosewood were very large adults, well over 100 mm snout-vent length.

Table 1. Trends in adult leopard frogs observed per monitoring count, and total egg masses observed, at Rosewood Tank, Magoffin Ranch.

Time Period	Adults (mean + SE)	Egg Masses (total observed)
Spring 1994	11.6 ± 2.38	0
Summer 1994	4.3 ± 0.64	1
Sp-Sum 1995	2.2 ± 0.71	2
Sp-Sum 1996	1.8 ± 0.75	0
Sp-Sum 1997	2.9 ± 0.78	5
March 20, 1998	3	4

Egg masses were observed in each year except 1996 (Table 1), and we assume that other egg masses were present but unobserved. Tadpoles were metamorphosing in the Rosewood refugium pool in substantial numbers in 1994. In 1995, 66 tadpoles from spring egg masses were removed and transferred to newly established Choate Tank, and in 1996 very young tadpoles were observed in May at Rosewood, and a few small juvenile froglets were observed. During August 1996, up to 25 young adult and subadult Chiricahua leopard frogs were found at a roadside puddle 3.5 mi (5.5 km) below Rosewood Tank; there is apparently no possible source for these frogs except Rosewood and Belency Tanks on Magoffin Ranch, and it thus appears that some of the 1994-1996 breeding at the Rosewood refugium pool was successful.

In March 1997, five large adults were transferred from the drying bottom of Rosewood Tank to the new concrete refugium pool at the upper margin of the tank, and two egg masses were

immediately deposited there. No tadpoles were observed. In late summer, 2 fertilized egg masses completely failed in the pool; pH was 10.8, although the well water filling the pool was pH 8 at the inlet. The pool was drained and re-filled, revealing 2 adult frogs and a third egg mass, which also failed. Alternative concrete and sealing processes, or a longer curing period prior to adding water, may have prevented the egg mortality. Eggs appear to be hatching successfully in spring 1998, as of this writing.

Belency Tank. Belency Tank was constructed in approximately 1970, and had very rarely gone dry in the succeeding two decades, including briefly in 1989 (M. Magoffin, personal communications). The water level declined to less than 0.5 m maximum depth in spring 1995, and the tank would apparently have dried without the newly installed well. The site appeared to support the most robust and secure population of Chiricahua leopard frogs in the region in the early 1990's. Yaqui chubs (*Gila purpurea*) were introduced to the tank in the early 1990's; no evidence of fish reproduction was found, and only a small number of larger adults were detected by seining during low water times in 1994 and 1995.

Table 2. Monitoring results for the Chiricahua leopard frog at Belency Tank, Magoffin Ranch.

Time Period	Individuals / census (mean +/- SE)	Egg Masses (total observed)
1994	23.5 ± 6.17	3
1995	13.7 ± 2.46	6
1996	14.2 ± 5.40	0
1997	0	0

It was initially common to observe numerous frogs at Belency Tank (Table 2), with counts ranging to 41 or more adults. Frogs were infrequently seen in spring-summer 1996, although large numbers of toads bred there in July. In August, as many as 50 adult leopard frogs were seen at Belency (M. Magoffin, personal communications), during and after the observation of what we presumed were numerous Rosewood Tank frogs 3.5 mi below Rosewood Tank (see above). In November 1996 a dead adult was found in the sediment trap; no frogs have been seen at the site since, despite repeated searches. In 1997, the sediment trap and main tank filled with water on July 31, but very few toads and no leopard frogs were observed at the site through the remainder of the year.

During 1994 and 1995, egg masses were seen in the tank, and in each case appeared to hatch normally. Despite the substantial number of frogs, we were never able to capture or observe many tadpoles, and we never observed a flush of metamorphosing juveniles, as expected in times of successful reproduction. It appears that this population has been extirpated. We can not explain the population failure at Belency Tank.

Other ponds on Magoffin Ranch. Choate Tank was constructed in spring 1995, and stocked with 66 tadpoles from Rosewood Tank in August-September 1995. In May 1996, 25 subadults were observed, but 15 were found dead when the pump failed and the water appeared to become anoxic. Seven to twelve frogs per monitoring census were observed thereafter, and 3 egg masses were found in fall 1996. Each of the egg masses was divided in half, with half left at Choate and the other half brought to Douglas High School for rearing. All three partial egg masses removed hatched successfully, yielding approximately 290 tadpoles. In December 1996, a moribund frog was seen at Choate. No more frogs were observed there until late summer and fall 1997, when two small adults were seen.

Magoffin Headquarters Pond was constructed in winter 1997, and stocked in May with 41 large tadpoles from Choate that were reared at Douglas High School. Two juveniles were observed in the pond in early August, and one small adult was regularly observed during early fall; a leopard frog egg mass was found hatching at this pond on March 12, 1998 (M. Magoffin, personal communications).

The Headquarters Pond was constructed in Rosewood Hollow at Magoffin Ranch headquarters, 2 mi (3 km) below Rosewood Tank. Leopard frogs were often seen in small pools at the site during wet years, including 3 in 1996, and large numbers of toads (*Bufo* spp.) and spadefoot toads (*Scaphiopus* spp.) normally bred there (M. Magoffin, personal communications). In 1997, only 4 spadefoot toads (*S. couchii*) were heard at the site (M. Magoffin, personal communication), but we found up to 7 juvenile checkered garter snakes at once, foraging in the new pond. The fate of the leopard frog populations at Choate and Headquarters remain uncertain.

Douglas High School. A small fenced pond was constructed for frogs on the high school property in winter 1997, and 27 of the reared tadpoles were released there in late May 1997. During August and September 1997, at least one frog plus several large tadpoles persisted at the pond (H. Bodenhamer, personal communication), and the site remained under observation.

III. DISCUSSION

The leopard frog management program appeared to be an un-mitigated success during summer and early fall of 1996, but by mid-1997 it was evident that some unexpected effect or set of causes had produced population declines at almost every site (Fig. 6). What had seemed to be the strongest remaining naturally occurring population, at Belency Tank, disappeared; other populations also declined sharply, although they persisted. We have been unable to locate the underlying causes of these declines (Rosen and Schwalbe, 1997), although they resemble unexplained declines seen at certain other sites in the region (Scott, 1992; R. Jennings, 1995; Sredl et al., 1997b; Rosen and Schwalbe, 1998 and personal observations).

While these unexplained declines are discouraging, they do not indicate that our conservation efforts have been a failure. The opposite is true. In 1993, the Chiricahua leopard frog existed

at three sites in the region: Rosewood Tank, Belency Tank, and Guadalupe Canyon. The 1994 drought eliminated the frogs in Guadalupe Canyon, and would have eliminated the Rosewood population without our efforts. The unexplained die-offs in 1996-7 eliminated the last natural population, at Belency Tank. The nearest Chiricahua leopard frogs would apparently be at Leslie Canyon and Limestone Mountain, 35 km distant, and probably beyond the range of natural recolonization under current ecological conditions. The latter populations are isolated and potentially at risk, as are most, if not all remaining populations of this species in the United States.

Without our active efforts, the Chiricahua leopard frog metapopulation in the study region would be gone. As of this writing, the species is known to have reproduced successfully at one site in the study region in fall 1997, tadpoles are present at least two places, and the species remains at five sites. Additionally, tadpoles from one clutch of eggs are being reared in captivity.

It remains to be seen whether our efforts ultimately succeed. Diversifying the population base within the metapopulation was initially a strategy to hedge against extinction, and one we thought, apparently incorrectly, was more than what was necessary. Our results thus far have supported the idea that introduced species, in this particular case the bullfrog, prevent re-establishment of native leopard frogs. They also tend to validate such general axioms of conservation biology (e.g., Meffe and Carroll, 1997) as the desirability or need to work with local people and to make conservation compatible with sustainable local economies. Our experience further clearly underlines the importance of careful monitoring. The more we know about the managed populations in these early efforts, the better. It will most likely be populations under such intense scrutiny that will finally provide the insight needed to decipher the unexplained declines now apparently plaguing Southwestern leopard frogs.

ACKNOWLEDGEMENTS

The support, advice, and direct participation of SBNWR Refuge Manager Kevin Cobble, the Magoffin family (Matt, Anna, Chris, and Mike), and Hans Bodenhamer have been central to the functioning and success of the project. The AGFD Nongame Branch contributed both field work and consultative advisement, and we especially thank Pat Collins, Jeff Howland, Mike Sredl, and Eric Wallace for their efforts.

Many have assisted importantly with the field work and advisement throughout this project, and we especially acknowledge the extensive contributions of Andrew, Cindy and Ted Cordery; Steve Hale; Paul Langdale; Robin Llewellyn; Verma Miera; Shawna Nelson; David Parizek; Shawn Sartorius; Myles Traphagen; and Tony Velasco.

Our work on this project has been supported by funding from AGFD Heritage Grants Program, USFWS, and USDA Forest Service. Additional funding for the leopard frog management activities by SBNWR was provided by USFWS. Funding for wells and pond management on Magoffin Ranch was supplied by the Malpai Borderlands Group and by AGFD through a Stewardship Program grant.

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Author contact numbers/addresses:

Phil Rosen: telephone 520.621.3187, fax 520.670.5001, email pcrosen@u.arizona.edu

Cecil Schwalbe: telephone 520.621.5508, fax 520.670.5001, email cecils@smr.arizona.edu

FIGURE CAPTIONS.

Fig. 1. A bullfrog exclosure-leopard frog enclosure at San Bernardino National Wildlife Refuge, Cochise County, Arizona. (a) Enclosure fence with eaves to prevent movement of frogs in or out. (b) One of four small, densely vegetated pools utilized by re-introduced Chiricahua leopard frogs within the enclosure.

Fig. 2. Ranarium for holding and breeding frogs under semi-captive conditions.

Fig. 3. Belency Tank, Cochise County, Arizona, exemplifying a sediment trap-main pond system. Run-off water from Belency Hollow enters the sediment trap from the left side of the photograph, fills the trap until it flows through a culvert in the mesquite-lined levee at center to fill the main pond to the right. Once the sediment trap and main pond are full, any further inflow runs around the system on Belency Hollow's natural floor, just beyond the tank system in the photograph.

Fig. 4. Concrete pool (3 X 3.5 m, 1.2 m deep) at Rosewood Tank, Cochise County, Arizona, serving as a refugium during drought times for a population of Chiricahua leopard frogs. This pool is gravity-fed through a float valve from a storage tank filled by a windmill-powered well. Cattle are excluded from the pool, but are served by a nearby steel tank on the same water system.

Fig. 5. Monitoring results for the Chiricahua leopard frog population introduced into the bullfrog exclosure at San Bernardino National Wildlife Refuge.

Fig. 6. Lineage and population history diagram for all known leopard frogs in the study region during 1994-1997. The populations to the right (Guadalupe Canyon, Belency Tank) became extinct. Arrows among the other populations indicate translocations made by resource managers to establish new population sites.

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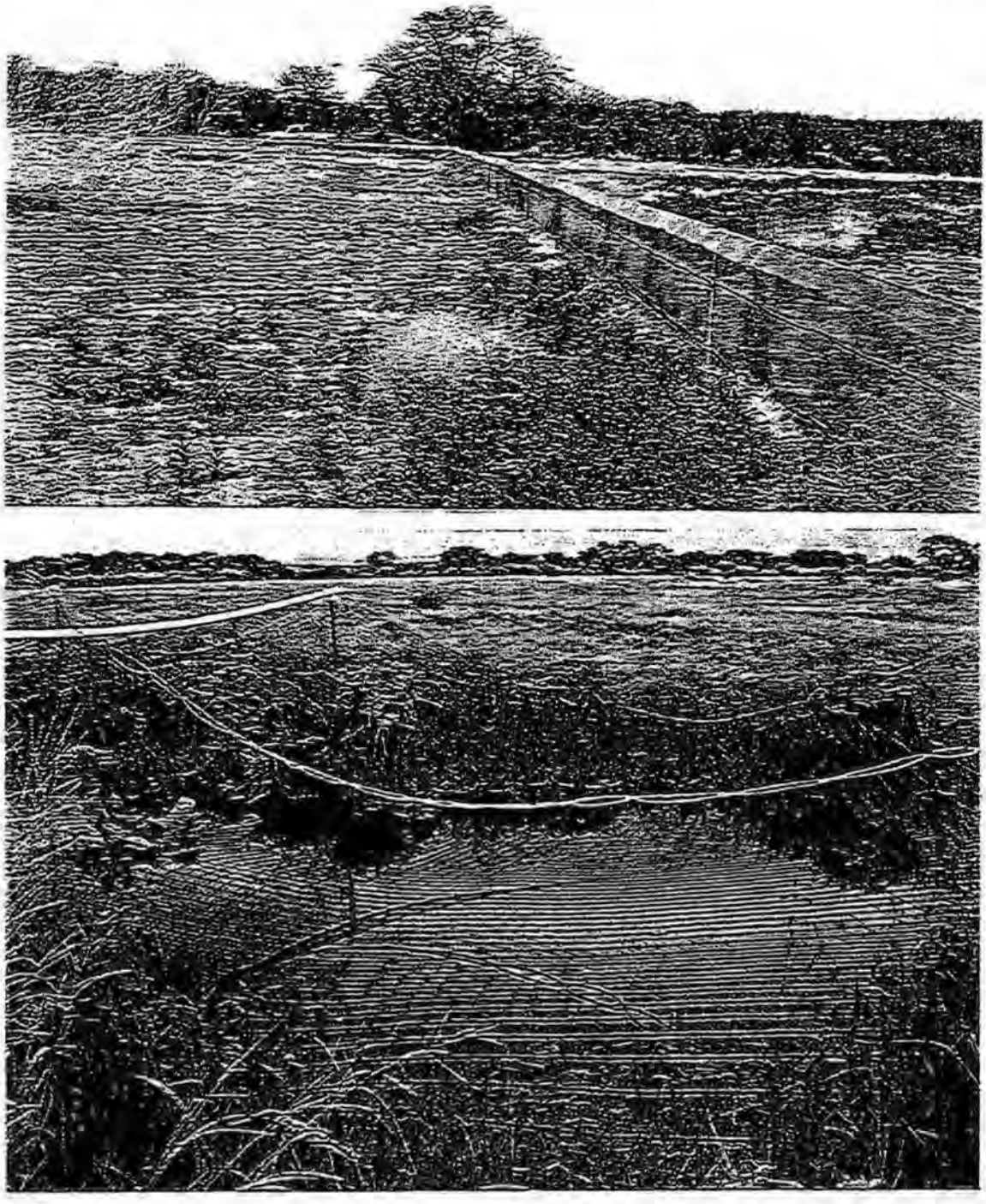

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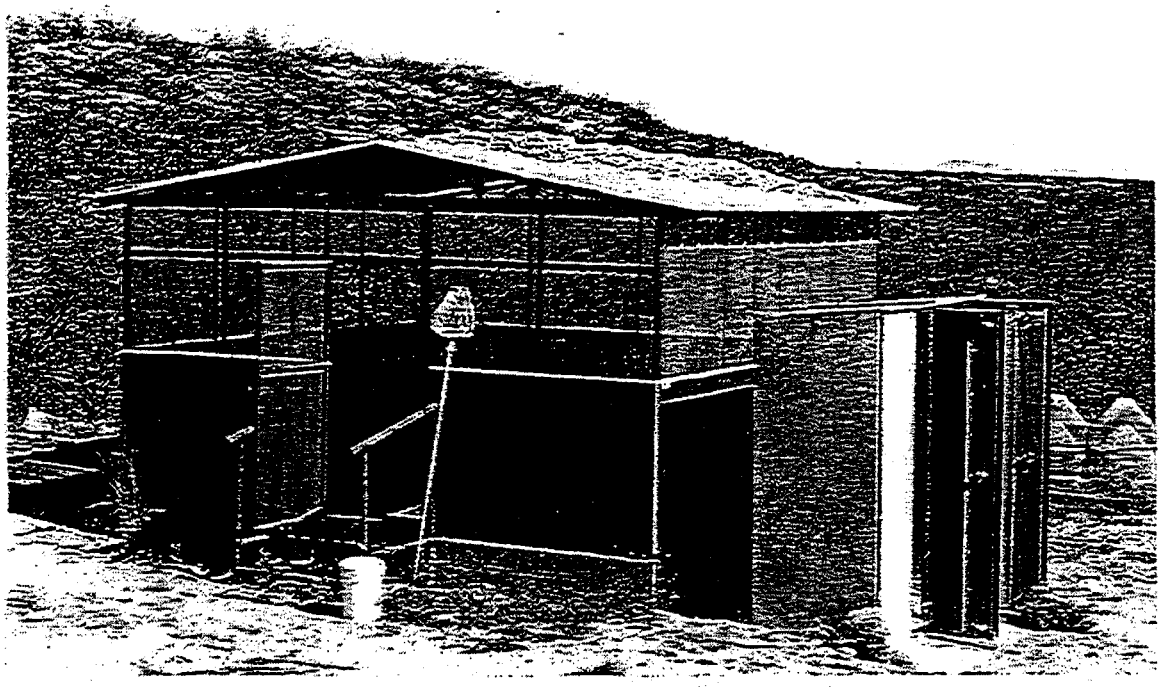

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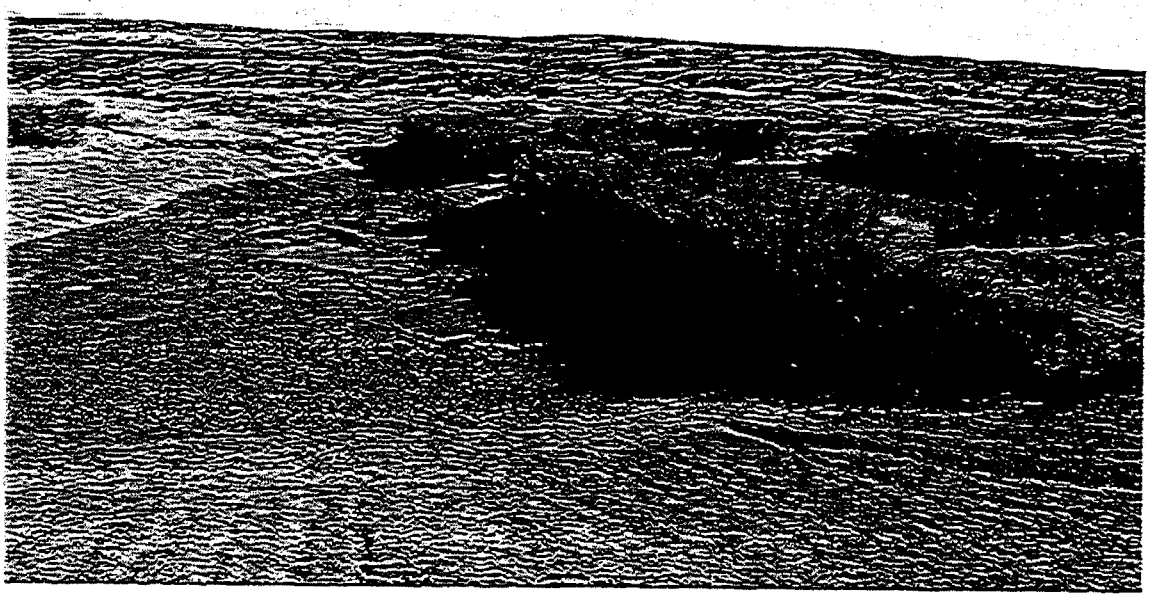

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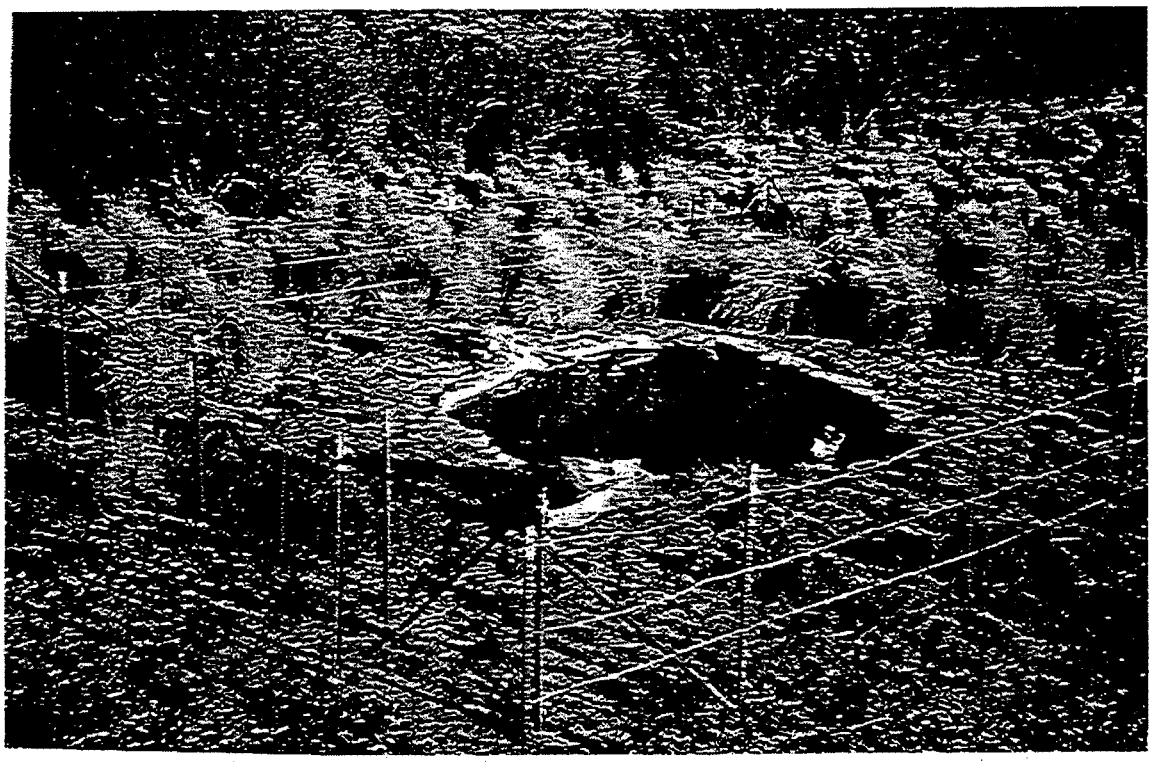

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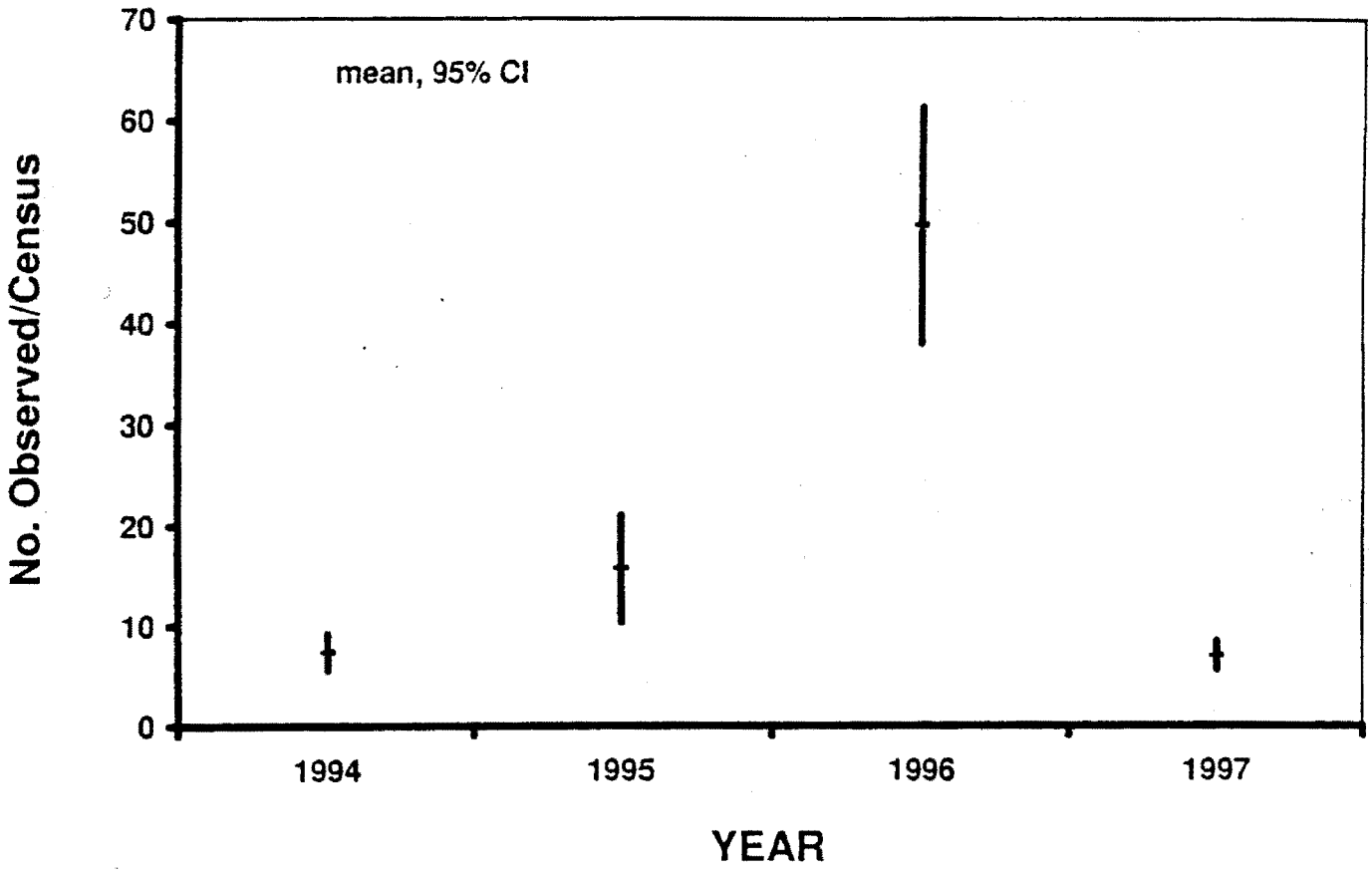

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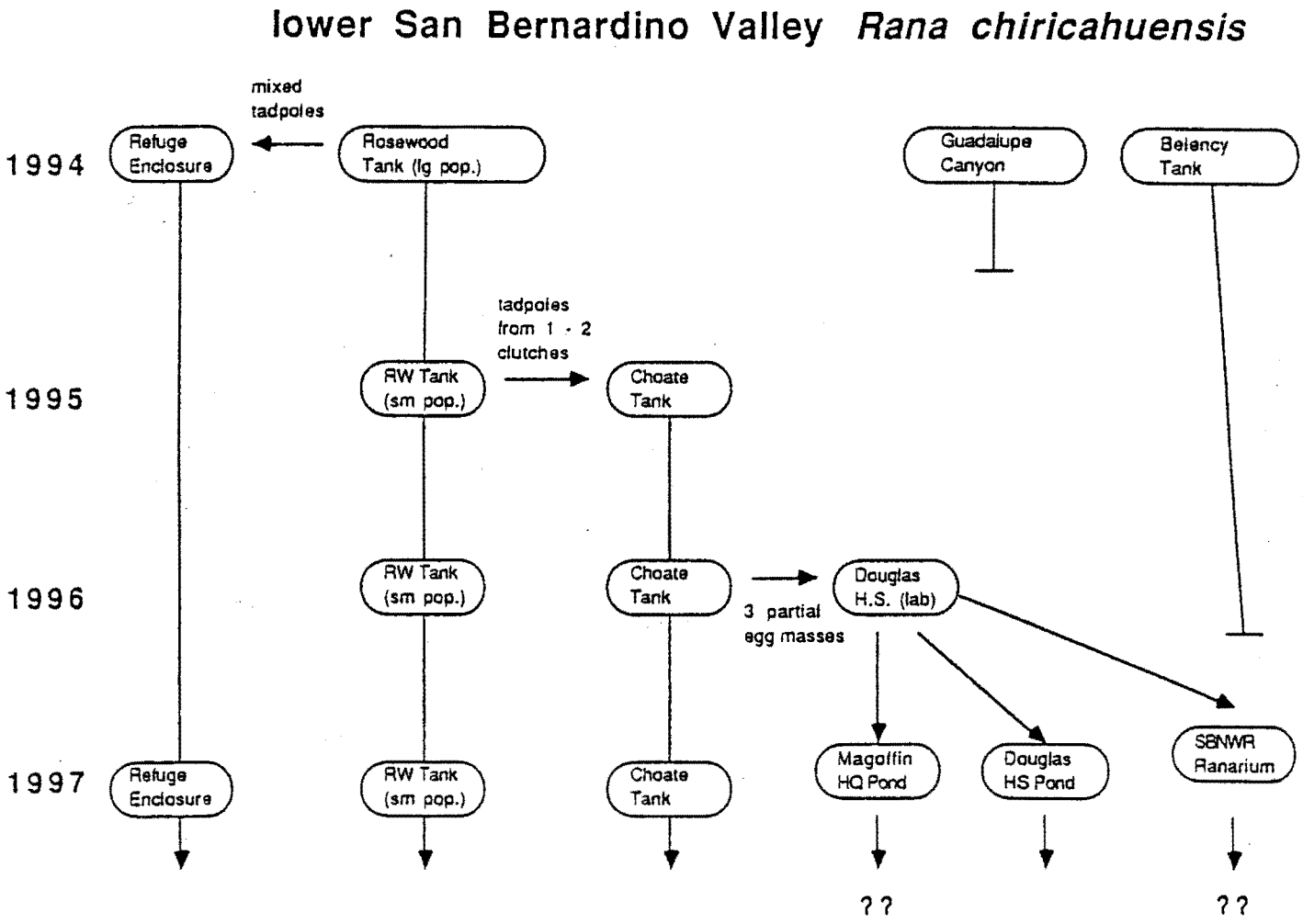

Some Effects of Stock Tanks On Aquatic Biodiversity in Arizona Streams

Jeff Simms
Fishery Biologist

United States Department Of the Interior
Bureau of Land Management
Arizona State Office

Introduction

Native aquatic biodiversity is threatened by various types of water development. Dams, diversion, and ground water pumping have greatly altered fish habitat (Miller 1961, Minckley and Deacon 1991). Riparian and watershed degradation has further altered Arizona's streams and rivers leaving native fishes, frog, and aquatic reptiles with only fragments of intact suitable habitats in which to occupy (LaRoe et al 1995).. In those remaining habitats the introduction and spread of exotic fish and frogs have displaced a large proportion native aquatic fauna. Native fish make a good example to illustrate the decline of this group of organisms.

The native fish fauna in Arizona is imperilled. Over half of this fauna is Federally listed (table 1). There are over twice the number of non-native fishes established in Arizona than native fishes at this time.

Table 1. Status of Native Freshwater Fishes of Arizona

Number of Taxa	Status
31	Fresh Water Species
19	Federally Listed
1	Extinct
5	Draft - Arizona Game and Fish Dept. Wildlife of Special Concern[1]

[1]Not including federally listed species already counted.

7	Not Yet Listed

Non-native fish and frogs pose the greatest immediate threat to native aquatic biodiversity through various mechanisms. These invaders feed on native fish, amphibians and reptiles ultimately resulting in their local extirpation or severely reduced numbers. In other cases, they may displace or crowd natives out of habitat. Finally, non-native fish and frogs carry diseases and parasites that may be new to native organisms. Some of thes diseased have the potential to decimate a population in a short period of time.

Although the Arizona Game and Fish Department (AGFD) recognizes the threat of game and baitfish to the state's native aquatic wildlife, their efforts to manage the distribution of these species is problematic. Anglers involved in amateur fisheries management (a.k.a., "Bait Bucket Charlie") have moved sport and bait fish around with little consideration for the law or the biological consequences of their actions (Table 2).

Table 2. Partial list of locations and species of illegal fish introductions in Arizona. (Provided by the Arizona Game and Fish Department)

Location	Species
Blue Ridge Reservoir	Golden Shiner
Willow Springs Lake	Largemouth Bass
Nelson Reservoir	Black crappie
Concho reservoir	Largemouth Bass
Woodland reservoir	Northern Pike
Dog Town Reservoir	Green Sunfish
White Horse Lake	Green Sunfish
Woods Canyon Lake	Golden Shiner
Ashurst Lake	Golden Shiner
Lake Pleasant	Blue Tilapia

Upper Lake Mary	Black Crappie Stripe Bass
Saguaro Lake	Tilapia
Lampshire Lake	Largemouth Bass
Cott tank	Largemouth Bass
Bog Hole	Largemouth Bass Black Crappie
Rucker Canyon	Fathead Minnow
Linx Lake	Black Crappie
Alamo Lake	Black Crappie Northern Pike Tilapia
Saddle Tank	Largemouth Bass

These sport fish, baitfish, and bullfrogs end up in ponds including rangeland water developments such as livestock watering tanks on public and private lands. These exotics are then transmitted to streams with natives through additional angler transfers or flooding.

Risk Assessment

Because of the importance of the few habitats with substantial communities of native fish and frogs left, two surveys were done on BLM lands to assess the risk of livestock watering ponds on native aquatic animals.

The first surveys of stock ponds was conducted on the watershed surrounding Aravaipa Creek which supports one of the most biologically rich native fish communities in the state and a population of lowland leopard frogs. Of the 7 native fishes, two are listed Federally as Threatened: loach minnow and spikedace. Green sunfish and yellow bullhead are present in small numbers and influxes of largemouth bass have been recorded. Since some of the green sunfish occur in tributaries above Aravaipa Creek, it stands to reason that they must have come from somewhere above on the watershed.

In 1987, the Arizona Game and Fish Department in cooperation with the Bureau of Land Management and Defenders of Wildlife conducted a survey of stock ponds in the Aravaipa watershed (Bagley 1987). Ninety-eight stock ponds were visited and 50 were determined to support permanent or semi-permanent water that could harbor non-native fish or frogs that could contaminate the creek below (Table 3).

Table 3. Results of 1987 Aravaipa Stock Tank Survey Graham and Pinal Counties, Arizona. Sample size 98 stock tanks.

Number of Tanks	Indicators of Permanence
15	with Frogs
18	with Salamanders
30	with Aquatic Plants
2	with Fish

Because of the high incidence of ponds with indicators of permanence and incidence of ponds stocked with salamanders, the rangeland water developments on the Aravaipa watershed present a relatively high threat to the creek. In fact, 2 of the ponds did contain green sunfish which prey on native fish and frogs and which can produce large populations in a short time. Should other fishes get added to ponds on the watershed, they too would likely contaminate the creek. The only factors that mitigated the risk were the rough roads and remoteness of these stock tanks. Some of the stock tanks that were not surveyed are on private lands adjacent to the creek. These ponds are known to be used for both fishing and watering livestock. Sport and baitfish stocked into these ponds are often fed by irrigation diversion. These canals provide ready access for these non-native fish to the creek.

The second watershed surveyed for rangeland water developments is Cienega Creek which has 3 native fishes including the largest population of Federally Endangered Gila topminnow in the United States and a large population Gila Chub (Federal Candidate). It is also inhabited by both lowland and Chiricahua leopard frogs(Federal Candidate), Mexican garter snake, and Sonoran mud turtle.

Over 130 stock tanks were identified on the watershed. Only those with the highest

potential threat to Cienega Creek were surveyed (Table 4).

Table 4. Results of 1991 Cienega Creek Stock Tank Survey, Pima County, Arizona. Sample size 57 stock tanks.

Number of Tanks	Indicators of Permanence
0	with Frogs
0	with Salamanders
3	with Aquatic plants
2	with Fish

The data collected on 57 stock tanks indicated a low risk for Cienega Creek (Simms 1991). Only 22 stock tanks had water and only 3 of those showed signs of permanence. The only non-natives collected have been 2 bullfrogs found over a 10 years period. However, few of the ponds on private land were surveyed. The two that were surveyed had an assortment of non-native fishes including goldfish, largemouth bass, smallmouth bass, and bluegill.

Management Implications

Rangeland water developments are managed differently on the Aravaipa and Cienega Creek watersheds. Aravaipa typically has larger more permanent stock ponds where the objective is to keep tanks full for long periods of time. In the Cienega Creek basin, most of the tanks are managed on a seasonal short-term basis. Cattle ranchers in this basin often move livestock by drying ponds in one pasture and filling them in another. Different water management practices present different levels of risk to native aquatic communities. Allowing ponds to dry in order to move livestock provides few opportunities for anglers to create small scale fisheries. In contrast a yerarround water supply for livestock may create a wide array of opportunities for angling which may put the local stream fauna at risk.

Even though most ponds on the Cienega Creek watershed are managed differently than those on the Cienega Creek watershed, both watersheds had some ponds with non-native fish. Ponds that hold water for long periods of time provide and opportunity for anglers to create a fishery. These more permanent ponds occur

more often on private land and often harbor sport and bait fish. On Aravaipa largemouth bass are periodically encountered. In one case that occurred in 1991 the most likely source was determined to be a private stock pond adjacent to the creek (Velasco 1994). Rangland water developments on both public and private lands must be cosidered for the effective management of aquatic biodiversity.

In many cases we don't know whether the non-native fish were stocked directly into the stream or washed out from a stock tank during a flood event. The management of the Gila chub in southern Arizona is a case that is very dependant on non-native fish control. Redfield Canyon is very remote with a long drive and few stock tanks. Nevertheless this stream supports populations of both Gila chub and green sunfish. The source of the sunfish is unknown but were likely stocked directly into the creek. O'Donnell Creek has easy access but few stock tanks on the watershed. It's native fish population is threatened by green sunfish and will need chemical renovation soon to save the few remaining chub. On the other hand, Bass Canyon has limited access but has a large 5 acre stock tank with sport fish located upstream. Occasionally largemouth bass have been collected with Gila chub in Bass Canyon. Whatever the source of non-native fish, chemical renovation of Gila chub habitat to remove the offending nonnative is usually the only practical solution. Unfortunately this activity is very expensive and often controversial.

In the past, many rangeland water developments were often looked at as opportunities for several uses such as livestock waters plus small wetlands for waterfowl, year-round water for wildlife, or small scale sport fisheries. And these waters still do provide opportunities to enhance wildlife and can provide important habitat to endangered species if managed intensively to prevent their conversion to a sport fishery. Because most ponds on public lands cannot be managed intensively enough, however, they often pose a risk in watersheds with native fish, amphibians and aquatic reptiles. Consequently, the following measures are recommended to reduce the potential of contaminating waters important to native aquatic animals.

Recommendations

- Keep surface area small (<1/4 acre) and shallow (<3 ft. Deep)
- Provide troughs if water is needed year-round
- Locate tanks outside of drainages

- Dry stock tank annually
- Minimize ease of access if tank may potentially be attractive to anglers
- Close watersheds with sensitive streams to fishing

By keeping most rangeland water developments unattractive or unavailable to fish and fishermen in areas with sensitive aquatic wildlife, the risk of accidental establishment of detrimental nonnative fish and frogs can be reduced.

Scientific Names
Loach Minnow *Tiaroga cobitis*
Spikedace *meda fulgida*
Gila Chub *Gila intermedia*
Gila Topminnow *Poeciliopsis occidentalis occidentalis*
Yellow Bullhead *Ameiurus natalis*
Largemouth Bass *Micropterus salmoides*
Smallmout bass *Micropterus dolomeiui*
Goldfish *Carassius auratus*
Green sunfish *Lepomis cyanellus*
Bluegill *Lepomis macrochiris*
Black Crappie *Pomoxis nigromaculatis*
Striped Bass *Morone saxatilis*
Northern Pike *Esox lucius*
Golden Shiner *Notemigonus crysoleucas*
Fathead Minnow *Pimphles promelas*
Blue tilapia *Oreochromis aureus*
Lowland Leopard Frog *Rana yavapaiensis*
Chiricahua Leopard Frog Rana Chiricahuensis
Bullfrog *Rana Catesbieana*
Mexican Garter Snake *Thamnophis equis*
Sonoran Mud Turtle *Kinosternon sonoriense*

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Conservation and Management Zones and the Role of Earthen Cattle Tanks in Conserving Arizona Leopard Frogs on Large Landscapes

Michael J. Sredl and Loralei S. Saylor[1]

Abstract -- Populations of many species of amphibians throughout the world have declined during the past twenty years. In the arid West, Arizona's leopard frogs, which include five or six native and one introduced species, have also been documented as having declined. Although none are federally listed as Threatened or Endangered, two are Candidate species and, if declines continue, more will be listed or become Candidates. Historically, these frogs occupied a variety of permanent and semi-permanent aquatic habitats, and recent surveys indicate that populations occupying a relatively recent type of aquatic habitat, earthen cattle tanks, may play an important part in the short-term conservation of this group. The role of cattle tanks in long-term conservation planning will be dependent on their manageability and the viability of populations in earthen cattle tanks compared to more natural systems. 1) We examined the current importance of earthen cattle tanks for all native leopard frogs by comparing the frequency of extant and extirpated populations in riverine and cattle tank sites within a historical data set. 2) To evaluate population viability, we developed a simple index of viability for localities of the southeastern Arizona and Mogollon Rim populations of the Chiricahua leopard frog (*Rana chiricahuensis*) using survey data collected between 1993-1996, then compared this index between riverine and cattle tank sites. 3) To examine the possible management implications of four non-native species on native leopard frog populations, we tabulated the frequency of encounter of non-natives during surveys of riverine and earthen cattle tanks. Our data indicated that for *R. pipiens* and *R. chiricahuensis* in southeastern Arizona, there is a significantly higher number of extant populations in cattle tanks; for *R. blairi*, *R. yavapaiensis* and Mogollon Rim form of *R. chiricahuensis*, rates of occupancy between these systems do not differ. Although our data indicate that population viability of *R. chiricahuensis* in southeastern Arizona cattle tanks and riverine systems did not differ, riverine systems of the Mogollon Rim form of this species were more viable than cattle tanks. Among four non-native species, we found that warm water fish, crayfish and cold water fish were significantly more common in riverine systems than tanks. For bullfrogs our data indicated no significant difference in habitat preference. With adequate precautions and monitoring, we conclude that cattle tanks will play an important role in the short- and long-term conservation of Arizona leopard frogs.

A successful statewide approach to the conservation and management of Arizona leopard frogs will identify entities whose priority for conservation is highest, and apply multiple conservation approaches in an area of sufficient size, while using the best available habitats. We outline such an approach for areas we designate as Conservation and Management Zones (CMZs). CMZs are defined as discreet geographical areas within which conservation and management goals and objectives are set. Once established, activities within a particular CMZ are implemented and their effects monitored. Potential CMZ activities which Arizona Game and Fish Department (AGFD) and cooperators have begun investigating are: 1) *ex situ* rearing of tadpoles and release of metamorphs, 2)

translocating wild frogs, 3) removing non-native species, 4) renovating habitats, and 5) building captive breeding facilities. CMZs could be used to systematically implement the array of activities required to stabilize portions of the ranges of Arizona's leopard frogs. Using Arizona leopard frogs as models, we will develop the CMZ concept further and discuss advantages of CMZs including: 1) implementation of conservation measures at a time when they may be most effective, 2) streamlined environmental review, and 3) concentration of limited energies on species and areas of high priority.

INTRODUCTION

Since the 1970s, amphibian population declines have been reported from numerous localities throughout the world (Barinaga, 1990; Blaustein and Wake, 1990; Vial and Saylor, 1993). Many factors have been implicated in these declines, including: 1) non-native species (Bradford et al., 1993; Hayes and Jennings, 1986; Rosen et al., 1995); 2) UV radiation (Blaustein et al., 1994); 3) acid precipitation and toxic substances (Berrill et al., 1993; Carey and Bryant, 1995; Dunson et al., 1992; Hale and Jarchow, 1988); 4) disease (Carey, 1993; Laurance et al., 1996; Scott, unpublished data); 5) destruction and fragmentation of habitats and populations (Bradford et al., 1993; Hedges, 1993; Sjögren, 1991); and 6) extreme climate changes, including drought and flooding (Corn, 1994).

Because of their natural history and physiology, many amphibians may be important indicator species of environmental change: 1) The biphasic life cycle of most anurans (aquatic larvae that are usually herbivorous and terrestrial adults that are exclusively carnivorous) exposes them to both air and water borne toxicants that may be concentrated in either plant or animal foods. 2) They occur in habitats ranging from deserts and rain forests to alpine and subpolar tundra, across the globe (only the marine environment lacks a significant amphibian fauna). 3) Amphibians are important components of energy and nutrient cycles of many ecosystems, often comprising a significant fraction of total biomass. 4) Their moist, permeable skin and egg masses leaves amphibians vulnerable to a variety of environmental insults such as air and water borne pollutants (Vitt et al., 1990).

As currently recognized, Arizona's ranid frog fauna includes the Tarahumara frog (*Rana tarahumarae*) and six or seven species of leopard frogs. This leopard frog fauna is surprisingly diverse and is among the largest in North America (Platz et al., 1990). It includes a disjunct population of the plains leopard frog (*R. blairi*), the southwestern end of the distribution of the northern leopard frog (*R. pipiens*), the northern end of the distribution of the Chiricahua leopard frog (*R. chiricahuensis*), the core populations of the lowland leopard frog (*R. yavapaiensis*), the only known populations of the Ramsey Canyon leopard frog (*R. subaquavocalis*), possibly a portion of the small range of the relict leopard frog (*R. onca*), and an expanding population of the non-native Rio Grande leopard frog (*R. berlandieri*).

In Arizona, most recent concern for population declines of native amphibians involves native ranid frogs, for which many populations have been reported to be extirpated or have declined (Clarkson and Rorabaugh, 1989; Hale and Jarchow, 1988; Sredl, 1993a). While it is

unclear exactly when these declines began, they were first noticed during studies of *R. tarahumarae* in the late 1970s (Hale and May, 1983; Hale and Jarchow, 1988; Hale, 1992). Hale and May (1983) suspected concurrent declines of other native leopard frogs, but historical data were unavailable for comparison. However, nearly every native leopard frog species in Arizona has been included as a species of concern at the state or federal level. *R. blairi* is on the list of Wildlife of Special Concern in Arizona (WSCA; Arizona Game and Fish Department, in preparation) and has no federal status. *R. chiricahuensis* is a WSCA listed species and is a federal Candidate. *R. pipiens* and *R. yavapaiensis* are WSCA listed species with no federal status. *R. onca* was previously considered to be extinct, but we now believe that a few populations still exist, and it is now a WSCA listed species. *R. subaquavocalis* is a WSCA listed species with no federal status, but a multi-party Conservation Agreement was recently signed to ensure implementation of a Conservation Strategy aimed at stabilization and recovery of the species. *R. tarahumarae* is a WSCA listed species with no federal status.

Although reasons for declines of Arizona's amphibian populations are not fully understood, factors which have been identified include: 1) negative impacts of non-native species such as bullfrogs, sportfish, and crayfish (Rosen and Schwalbe, 1988; Sredl and Howland, 1992; Fernandez and Rosen, 1996), 2) epidemic disease (Jancovich et al., 1998; Sredl, 1993b), 3) damming, diverting and draining of wetlands (Sredl and Howland, 1995), and heavy metal toxicity (Hale and Jarchow, 1988).

During the past century, ciénegas and other wetland habitats within the arid Southwest have greatly decreased (Hendrickson and Minckley, 1984). Damming, draining, and diverting of water have fragmented formerly contiguous aquatic habitats. This loss and reduction has undoubtedly resulted in small, isolated, unstable local populations (Sredl and Howland, 1995). Local populations of leopard frogs in Arizona are prone to extinction (Sredl and Seim, 1993; Sredl and Howland, 1995; Sredl et al., 1997a) and metapopulation dynamics have likely been disrupted. In parts of the West, fragmentation of frog populations has been accentuated by non-native species, leaving potential dispersal corridors between available aquatic habitats impassable (Bradford et al., 1993), a process likely to have occurred in Arizona.

Due to major modification of natural leopard frog habitats in the Southwest, earthen cattle tanks may provide a vital alternative for Arizona's leopard frog populations (Sredl and Howland, 1995; see also Rosen and Schwalbe, this volume). Many of these waters could provide permanent or semi-permanent aquatic habitat for colonization by leopard frogs occurring naturally in riparian habitat lower in the same drainages, adding to regional population stability. In this paper, we address three questions. 1) Are earthen cattle tanks important aquatic habitats for leopard frogs? 2) Are leopard frog populations in earthen cattle tanks viable? 3) How does the presence of non-native species compare between riverine and cattle tank habitats? Finally, we explore how earthen cattle tanks can be used in management plans to conserve Arizona's leopard frog populations.

METHODS

Between September 1990 and April 1997, Arizona Game and Fish Department (AGFD)

conducted 2089 statewide surveys at 1274 localities. This overall data set includes records from AGFD surveys and historical records (museum records, published literature, technical reports, and observations of knowledgeable individuals). Information in these records include locality, habitat conditions, source, and herpetofaunal observations (Sredl et al., 1997b). For this analysis, we used all records of native leopard frog localities, their aquatic habitat type, species observations by life stage, and non-native species observed. Because *R. chiricahuensis* will soon be split into two species (J.E. Platz, personal communication), all analyses using sites occupied by this taxon were divided into subsets of the nominate species, *R. chiricahuensis*, and the Mogollon Rim form to detect possible differences between these entities. For all habitat comparisons, we used data from riverine and cattle tank systems which account for 91.6% of the sites in the overall data set.

Importance of cattle tanks. Our analyses examine the importance of cattle tank populations utilizing records from all native leopard frog species except *R. onca* and *R. subaquavocalis*. We did not include *R. onca* in our analysis because no verified Arizona records exist. We did not use records for *R. subaquavocalis* because it was only very recently described (Platz, 1993) and is found only in one non-cattle tank system (AGFD, unpublished data). We determined the occupancy status of a site following Sredl et al. (1997b) by comparing presence/absence of pre- and post-1993 survey data. Sites occupied prior to, but not after 1993 were considered extirpated, whereas sites occupied after 1993 were considered extant. We used Fisher's exact test to determine the importance of habitats for each native leopard frog by comparing the number of extant and extirpated cattle tank and riverine systems.

Population viability. We developed our index of population viability using data collected between 1993-1996 during statewide surveys of *R. chiricahuensis* and the Mogollon Rim form. For each year, we assigned a reproductive status to sites according to the following criteria: sites without eggs or larvae were categorized as non-reproductive, while sites with eggs or larvae were categorized as reproductive. Some sites were visited more than once in a given year. To make the likelihood of detecting aquatic life stages relatively equal for all sites, our viability index for each site is based on the latest visit prior to mid-October.

We constructed a 2 × 2 contingency table (habitat types × index of viability) for each year, tested for heterogeneity among years, and combined data for all years when we found habitat types × index of viability to be homogenous across years (Zar, 1974). As an overall test of significance of the relationship between habitat and viability, we performed a separate a Fisher's exact test for *R. chiricahuensis* and the Mogollon Rim form.

Non-native species. Using data collected during statewide AGFD surveys (1990-1996), we compared the frequency of encounter of four non-native species (bullfrogs, crayfish, warm water fish and cold water fish) in riverine versus cattle tank systems by constructing 95% confidence intervals (Sokal and Rohlf, 1981).

RESULTS

Among populations of *R. chiricahuensis* and *R. pipiens*, we found a significantly higher

proportion of known extant populations in cattle tanks compared to those in riverine habitats (Table 1). *Rana blairi, R. yavapaiensis*, and Mogollon Rim form show similar occupancy rates in cattle tanks and riverine habitats.

No significant difference in reproduction was found between riverine and cattle tank systems for *R. chiricahuensis*. However, data from cattle tank populations of the Mogollon Rim form indicate they do not reproduce as successfully riverine populations (Table 2).

Confidence intervals for proportion of riverine or cattle tank habitats occupied by non-native species groups indicate non-random habitat use by warm water fish, crayfish, and cold water fish (Figure 1). These non-natives were encountered at a much higher rate in riverine systems. Bullfrogs were encountered as frequently in riverine systems as in tanks. In riverine systems, frequency of encounter of warm water fish was greater than bullfrogs and cold water fish, but not crayfish, and encounter of crayfish was greater than cold water fish, but not bullfrogs. In cattle tanks, frequency of warm water fish and bullfrog encounters did not differ, but both were encountered at a greater rate than crayfish and cold water fish, and encounter of crayfish was greater than cold water fish (Figure 1).

DISCUSSION

Recent population declines of Arizona leopard frogs (Clarkson and Rorabaugh, 1989; Sredl et al., 1997b) and the major landscape changes which preceded these declines have had profound affects on their metapopulation dynamics. This change in metapopulation structure will limit available approaches to conservation of this group. One landscape change in the Southwest, the creation of earthen cattle tanks, has the potential to be a beneficial tool to conserve Arizona leopard frog populations.

In the late 1800s and early 1900s, construction of earthen cattle tanks in upland drainages became a common range management practice (U.S. General Accounting Office, 1991), one which continues to this day. While data on historical occupancy of these habitats is lacking, dispersal capabilities of native leopard frogs (Frost and Bagnara, 1977), lead us to suspect many of these waters were colonized by native leopard frogs soon after their creation. During this period natural Southwest riparian systems had not degraded to the extent they have today, so that use of cattle tanks by leopard frogs may not have contributed significantly to metapopulation stability. It is even possible that additional habitat provided by cattle tanks may have actually have allowed native frog populations to expand for a time.

Some desert amphibians, such as spadefoot toads and true toads, are able to successfully utilize temporary aquatic systems (Ruibal, 1969). Native leopard frogs require relatively permanent waters due to their inability to survive loss of a high percentage of their body water and their comparatively long larval period (Duellman and Trueb, 1986). While these frogs can survive short periods without standing water by burrowing in mud (AGFD, unpublished data) or taking refuge in mammal burrows, members of the leopard frog complex are not well adapted at withstanding long periods of drought.

Observations of Sredl and Howland (1995) and others lead us to believe that leopard frog populations occupy patches of aquatic habitat, connected by drainages that can be traveled by dispersing individuals. This mosaic forms the microgeographic basis for the development of metapopulations (Harrison, 1991). Furthermore, the life history of Southwest leopard frogs predisposes them to high rates of local extinction and recolonization (Sredl and Howland, 1995). Rates of reproduction and recruitment are highly variable and dependent upon rainfall and other environmental factors (Sredl et al., 1997a). Leopard frogs are strongly aquatic and are therefore vulnerable to desiccation, especially as larvae. Stimuli such as sudden cold snaps may result in devastating disease outbreaks, especially at local sites where overcrowding occurs (Sredl, 1993b). Leopard frogs are mobile, so dispersal should occur between isolated perennial aquatic sites using intermittent or ephemeral aquatic corridors. We suspect that population declines among southwestern leopard frogs can, at least in part, be attributed to disruption of normal metapopulation dynamics. Various human disturbances lead to increased rates of extinction accompanied by decreased rates of recolonization, changing basic metapopulation structure (see Sjögren, 1991 on the importance of connectivity for metapopulations of aquatic frogs).

Habitat has been reduced to small pockets that are capable of supporting only small, unstable populations of leopard frogs. Big rivers, with dams and introduced predators and competitors, no longer provide suitable habitat for large populations. Ground water pumping has dried many springs, ciénegas, streams, and other wetlands, further reducing habitat availability. Dispersal corridors have suffered the same fate. They are impassable due to lack of water or, in the case of perennially flowing corridors, the presence of large populations of bullfrogs and non-native predatory fishes.

Sredl and Howland (1995) found few large river populations of *R. chiricahuensis* in southeastern Arizona. Further, they hypothesized that as natural aquatic systems became degraded the importance of cattle tank populations increased. Our data lend support to this hypothesis. While leopard frog populations in cattle tanks are important statistically for only two species of Arizona leopard frog, most likely they are important for nearly every species of native leopard frog, except the lowland leopard frog. For two species, *R. blairi*, and *R. subaquavocalis*, earthen cattle tanks are practically the only habitats where they are found. While for other species, these cattle tank populations have been extirpated at a lower frequency than riverine populations, and are likely starting points for short-term conservation planning. In addition to being important demographically, isolated cattle tank populations are likely to be important evolutionarily (i.e. to stabilize populations with unique genetic information), and for long-term conservation.

Earthen stock tanks are generally filled by surface runoff from rainfall or snowmelt. Permanence of water in a given cattle tank is dependent upon factors such as size and depth of basin, permeability of substrate, and size of watershed from which it receives runoff (Cole, 1983). Other factors affect evaporative water loss. Aspect of the basin and surrounding topography may affect exposure to wind and solar radiation. Species composition and density of bank and emergent vegetation affect incidence of solar radiation and wind and also influence evapotranspirational water loss (Cole, 1983).

Permanency of cattle tanks falls along a spectrum (see Sponholtz et al., this volume). At

each end of the spectrum, there are tradeoffs to resident leopard frogs. In temporary cattle tanks, water may not last long enough for dispersing frog to survive and reproduce. On the other end, permanent water may be conducive to maintaining viable leopard frog populations, but it also allows invasion by non-native species, especially warm water fish and bullfrogs (this paper; Rosen et al., 1995). Once introduced into these systems, these species are particularly problematic and difficult to remove (Rosen et al., 1996).

Conservation and Management Zones. There are adequate data to support the contention that *R. tarahumarae* and at least three of five native Arizona leopard frog species (*R. pipiens*, *R. chiricahuensis*, and *R. yavapaiensis*) have declined or been extirpated from Arizona (Hale and Jarchow, 1988; Clarkson and Rorabaugh, 1989; Sredl et al., 1997b). Although reasons for these population declines are not clear, the time is ripe to develop an approach to conservation and management of native amphibians. This approach will need to 1) identify important populations and metapopulations, 2) implement activities aimed at improving the habitat, populations, and metapopulations in those areas, and 3) monitor the effects of applied conservation activities and modify them as necessary to ensure they are effective. Key to the success of this strategy will be the use of an array of conservation and management activities, including those which utilize earthen cattle populations.

One of the first steps in formalizing our approach to conservation and management of Arizona leopard frogs is development of the concept of Conservation and Management Zones (CMZ). We define a CMZ as a discreet geographical area within which conservation and management goals and objectives are set, implemented and monitored. Using our statewide survey results, we will identify areas of critical conservation need. We will first establish criteria for priority, ranking the importance of populations from a statewide conservation perspective. These criteria may include: 1) overall status of the species, both statewide and rangewide (a highly sensitive species endemic to Arizona receives higher conservation priority than a geographically widespread species whose status in Arizona is less critical); 2) geographical context of a population or metapopulation (those in a region of severe decline or in a remote area that is unlikely to be naturally recolonized in the event of a local extinction event receive highest priority); 3) evolutionary context of a population or metapopulation (those that are evolutionarily important due to genetic distinctness or diversity receive highest priority); 4) manageability of the population or area (populations in areas where threats are most likely to be controllable and land owners or managers are more willing and able to cooperate receive highest priority); and 5) complexity and cost (those populations that can be stabilized or recovered through use of the fewest, simplest, and most cost-effective conservation actions receive highest priority).

Statewide surveys by AGFD and others have provided, and will continue to provide, most of the information we will need to address the first two criteria. We have begun to develop an identification method using Geographical Information System (GIS) software that will aid us in selecting potential CMZs. Contrasting local status (population or metapopulation) to modal locality status of a river basin, we identified unique populations and metapopulations of each species leopard frog in Arizona.

We have begun to collaborate to collect genetic information necessary to address the third

criterion. We have some information concerning the last two criteria, but they will require additional investigation specific to individual populations, areas, politics, and other factors that may be peculiar to each proposed CMZ. These will largely be addressed through cooperative, site-specific planning and negotiation with appropriate landowners and resource managers, and will culminate in public, academic, and interagency review of proposed actions.

After setting priorities, we will establish a particular CMZ designation through area-specific conservation planning, generation of funding, preparation of any necessary environmental compliance documents, and implementation of measures that are appropriate to each area. Although AGFD can coordinate this process and make significant contributions in funding and implementation, it is essential to have active participation and funding by cooperators, especially the affected public landowners or managers, if we are to have any hope that this approach will be successful on a large landscape level.

We have begun to develop and test management techniques to restore functioning metapopulations to appropriate areas. Techniques include: 1) *ex situ* captive breeding and/or rearing of eggs and tadpoles for release as metamorphs or adults to the wild; 2) translocating wild eggs, tadpoles, and frogs; 3) removing non-native species where feasible; 4) renovating or creating habitat. Our intent is to use a coordinated mix of these and other techniques, tailored to the needs of particular situations, to reconstitute functioning metapopulations in areas where frogs may be destined for extirpation in the absence of active conservation.

A promising new technique is working with ranchers to manage aquatic habitats for leopard frogs, which are generally compatible with livestock. We have assisted ranchers to renovate or manage two cattle tanks to the benefit of both livestock and leopard frogs. We need to continue to test and evaluate these manipulations, giving special attention to cost-effectiveness because of the tremendous range in cost of different types of habitat renovation or creation.

We recognize that our initial efforts to designate CMZs and implement conservation measures will be test cases. We will evaluate these first efforts and modify our approaches as needed to make them more effective and efficient. We can expect to encounter difficulties and outright failures at the beginning, but by making methodical evaluations and modifications, it should be possible, with adequate commitments from key resource managers and stewards, to successfully orchestrate stabilization and recovery of Arizona's native ranid frogs.

ACKNOWLEDGMENTS

For assistance with field work and logistical support in collecting statewide survey data, we thank: Rob Brauman, Bruce Christman, Pat Collins, Jacques Hill, Sharon Seim, Dana Waters, Eric Wallace and John Windes. For insightful observations and discussions on leopard frog cattle tank populations, we thank: Kevin Cobble, Pat Collins, Carl Lutch, Susie MacVean, Matthew Magoffin, James Rorabaugh, Philip Rosen, Cecil Schwalbe, Joan Scott, Sheridan Stone, Eric Wallace, John Windes and Richard Zweifel. For providing advice, assistance, and support in development of conservation and management planning and implementation, we thank: Dave

Carrothers, Kevin Cobble, Mike Demlong, Philip Fernandez, Dan Groebner, Brenda Healy, Jeff Howland, Randy Jennings, Terry Johnson, Matthew Magoffin, Verma Miera, Terry Myers, Charlie Painter, Don Pollack, James Rorabaugh, Philip Rosen, Cecil Schwalbe and members of the Ramsey Canyon Leopard Frog Conservation Team. Linda Allison provided valuable comments that greatly improved this manuscript.

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Figure 1. Clustered bars show the percent of sites statewide occupied by either warm water fish, bullfrogs, crayfish or cold water fish for each habitat type (riverine [▫] and cattle tank [○]). Bars represent 95% confidence limits.

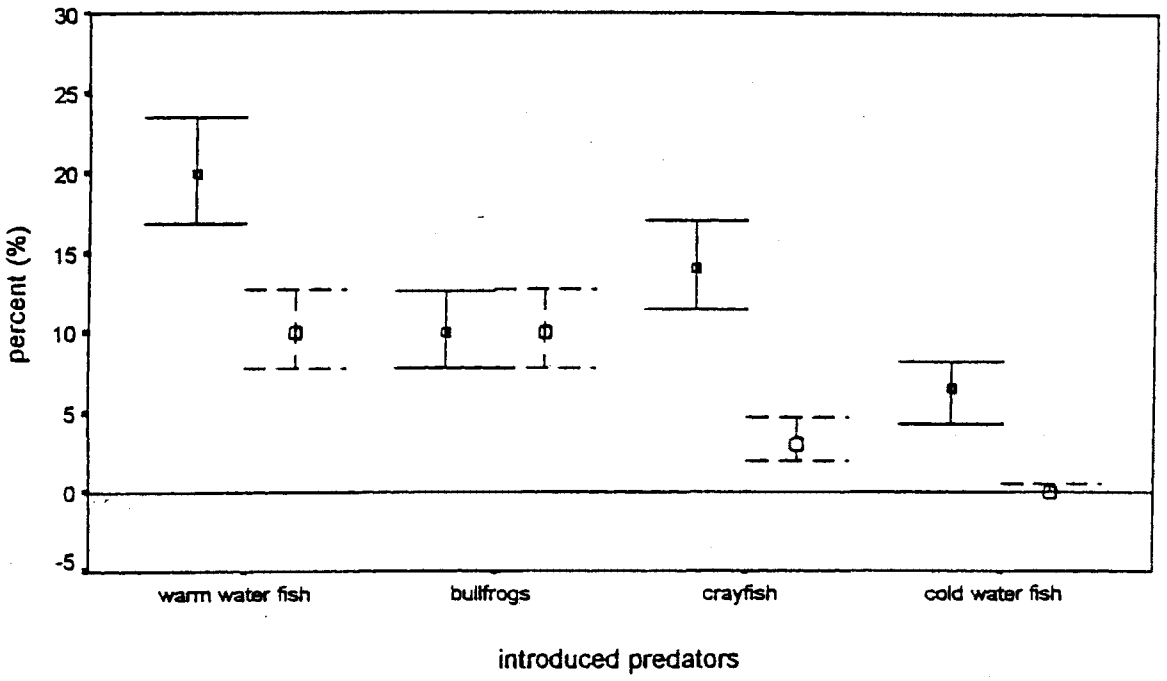

Table 1. Pre- and post-1993 status relative to riverine and cattle tank habitats for each species of native Arizona for which verified localities exist except *R. subaquavocalis*. Sites occupied prior to, but not after 1993 were considered extirpated, whereas sites occupied after 1993 were considered extant.

species	habitat	status		n	Fisher's exact (p)
		extant	extirpated		
Rana blairi	riverine	0	6	19	0.128
	cattle tank	5	8		
R. chiricahuensis	riverine	22	42	124	0.002
	cattle tank	38	22		
Mogollon Rim form	riverine	7	11	32	0.476
	cattle tank	8	6		
R. pipiens	riverine	6	14	46	0.007
	cattle tank	19	7		
R. yavapaiensis	riverine	76	60	168	0.113
	cattle tank	23	9		

Table 2. Number of sites assigned a reproductive or non-reproductive status, broken down by aquatic habitat type, for *Rana chiricahuensis* and the Mogollon Rim form. Sites without eggs or larvae were considered non-reproductive, while sites with eggs or larvae were considered reproductive.

Rana chiricahuensis

	non-reproductive	reproductive
riverine	19	8
cattle tank	22	15

Fisher's exact, p=0.435, n=64

Mogollon Rim form

	non-reproductive	reproductive
riverine	3	4
cattle tank	8	0

Fisher's exact, p=0.026, n=15

Adjudicating nature: science, law, and policy in a southern Arizona grassland

James P. Collins [1]

Abstract -- The Sonora tiger salamander was described from the San Rafael Valley in southern Arizona in 1954. This subspecies has the genetic properties of a hybrid, likely originating by the union of two other subspecies. Sonora tiger salamanders live in ponds (stock tanks) created and maintained for supporting livestock in this valley since as early as 1822. None of the aquatic habitats that are most similar to what those in this southern Arizona grassland were like before the arrival of European-derived settlers have salamanders.

In 1993 conservationists from New Mexico petitioned to have the Sonora tiger salamander listed as an endangered subspecies based on its restricted range and special genetic characteristics; the subspecies was listed as endangered in January, 1997. A consequence of this listing could be the limiting of grazing rights by local ranchers.

This case raises a number of questions at the interface of biology, law, and policy. Categories like "rare" or "endangered" species are often specified in legal policies. How do these categories affect how biologists theorize and describe phenomena? How are questions like, "What is natural?" and "What we are trying to preserve?" addressed in law and science? Who qualifies as an expert in society, and how do these qualifications as an expert vary between societies and over time? How is access to scientific knowledge affected by other rights, like legal property rights?

As a society we are increasingly asked to make judgements that involve complex issues involving science, law, and policy. Institutions, like the courts, often do not seem as flexible as we might like for adjudicating complex environmental cases because at the heart of these cases multiple variables often shape the issues and "answers" often rely on the contingency of scientific knowledge. The Sonora tiger salamander case challenges us to consider the question, "What kind of institution(s) would enable us to address more creatively the complex issues surrounding use of our natural resources?"

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[1] Department of Biology
Arizona State University

INTRODUCTION

An increasingly vexing question facing scientists and non-scientists with interests in the environment is, "How do we make judgments and recommendations regarding issues related to the environment based on incomplete information?"

Three examples offer cautionary tales. Chlorinated hydrocarbons are a case in which original enthusiasm for a product seen as having positive economic and agricultural benefits was reversed (Carson, 1964). Since the mid-1980s we have seen increasing acceptance of the technology supporting deliberate release of genetically engineered organisms, reversing an original reluctance to embrace it (e.g., Chevre et al., 1997). The public and the scientific community seem to be slowly accepting the reality of global environmental change, and this recent movement to action is a change from the apathy and skepticism characterizing the debate to this point (Kaufmann and Stern, 1997; Mahlman, 1997; Rayner and Malone, 1997; Zilman, 1997).

The question of declining amphibians is a fourth example that is still undecided. In 1989 at the First World Congress of Herpetology in Canterbury many scientists described declines or losses of amphibians in diverse habitats around the world. In 1990 a National Research Council (USA) conference in California reinforced suspicions that amphibian populations were declining, and in response the Declining Amphibian Populations Task Force was established in 1991 (Blaustein and Wake, 1990; Heyer et al., 1994). Since 1990 declining amphibian populations have been reported throughout the Americas, Europe, Africa, and Australia (Corn, 1994; Pounds et al., 1997).

Populations of frogs and salamanders fluctuate in numbers naturally (Pechmann et al., 1991), but in the last 15 years the decrease in the population sizes of many species appears to exceed expected values (Pounds et al., 1997). Long-term studies in the western USA document losses in the Sierra Nevada Mountains [*Rana muscosa*, *Bufo canorus*], Oregon Cascades plus Willamette Valley [*R. cascadae*, *R. pretiosa*, *R. aurora*], and the Rocky Mountains [*B. boreas*] (Blaustein and Wake, 1990). Nineteen endemic North American species declined or disappeared from 1980 to 1994, while 28 North American amphibian species with widespread habitats declined or disappeared, a six-fold increase over those reported in 1980 (Bury et al., 1995).

Humans play a primary role in the decline or loss of some amphibian species by destroying wetlands and altering habitats. Humans may also indirectly foster declines by introducing exotic predators, like fish and bullfrogs, to native amphibian habitats in the western USA (Corn, 1994). The effect of acid precipitation on amphibian populations is uncertain (Pierce and Montgomery, 1989; Corn, 1994), and exposure to chemicals may cause developmental disorders (Ouellet et al., 1997). Increased exposure to ultraviolet radiation, perhaps because of a reduced ozone layer, is implicated in egg mortality of some amphibians (Blaustein et al., 1994, 1997).

In pristine habitats the cause(s) of amphibian declines are unclear (Pounds et al., 1997). Disease is a possibility. While mass mortalities occur (Jancovich et al., 1998), it is not clear if

mortality from disease is a recently appreciated, but still natural, feature of amphibian populations. Newly evolved pathogens might be lethal, or mortality might reflect enhanced pathogenicity of established diseases due to a weakening of amphibian immune systems by unknown environmental variables. Losses ascribed to disease include 14 species of rainforest frogs in Australia (Laurence et al., 1996; but see Alford and Richards, 1997, Hero and Gillespie, 1997, Laurance et al., 1997) and common frogs (*R. temporia*) in England (Cunningham et al., 1996). These fluctuations may be part of a natural, poorly understood pattern of population fluctuations characteristic of amphibians. Collectively, however, these studies raise the question: Is the threat of extinction increasing for amphibians?

The answer to this last question is a qualified "yes," but we do not know the full scope or geographical boundaries of amphibian declines leaving researchers and policy makers in a quandary. Some professional scientists (Blaustein and Wake, 1990; Wyman, 1990; Wake, 1991; Wake and Morowitz, 1991) and the public (Yoffe, 1992) argue that amphibians are declining and urge an active response, but other scientists disagree (Pechmann and Wilbur, 1994). At some point, if the weight of the evidence fails to support the claim that amphibian populations are declining globally, professional colleagues and the public may become jaded and less likely to respond to a future (correct) argument regarding population declines (e.g., see Kaiser, 1997b). Resources for research and mitigation are also limited, and investing funds studying thriving species diverts resources from threatened taxa. Finally, we could wait and seek more evidence supporting the claim that amphibians are declining, but while we gather those data do we run the risk of ignoring a crisis when it can still be averted (Blaustein, 1994)? The problem of global environmental change is instructive relative to this last question.

Ten years ago some scientists felt that global environmental change was real, but the data were inconclusive. In a recent review of human-caused global change Vitousek (1994:1862) made two points that apply to the question of declining amphibians. "First, human-caused global environmental change is with us now." This declaration differs from the caution expressed a decade ago, and in the case of amphibians raises the question, Is global environmental change causing a decline in amphibian populations? Vitousek also said, "Second, we will have to learn to deal more effectively with certainty. Ecologists who address public policy or globally significant issues are often advised to learn to deal with *uncertainty*, because generally neither policy recommendations nor global extrapolations are amenable to statistical 'certainty' at the 0.05 or 0.01 level.... There are uncertainties, but there is also a substantial core of knowledge, and it is our responsibility to see that it reaches policy makers and the public." There is a fine line between scientific claims based on incomplete evidence and environmental activism. David Wake summarized the difficulty of the position: "The loss of biological diversity is the great tragedy of our age.... We must define and study problems in biodiversity before other people will be convinced of a need for action" (Wake, 1994:xvi). Relative to the question of amphibian declines, population biologists and herpetologists are the "experts," and since World War II society, especially in the US, has increasingly looked to experts for advice and guidance on scientific issues (Jasanoff, 1990; Fenn et al., 1995; Maienschein et al., 1997, Zachary, 1997). What should the "expert community" of population biologists and herpetologists recommend as a course of action regarding the suspicion that amphibians are declining?

The questions surrounding use of pesticides, deliberate release of genetically engineered organisms, global environmental change, and population dynamics in amphibians highlight the difficulty of specifying a course of action in the face of incomplete evidence. A vehicle for identifying a course of action, while appreciating the complexity of decisions at the intersection of law, science, politics, and public policy, is to consider a specific case. The case I will review is taken from a broader discussion of the interface of biology and law (Maienschein et al., 1997). This case begins in 1954 in the grasslands of southern Arizona and ends in January, 1997, with a new taxon on the endangered species list. Along this route many questions are raised, questions that challenge the ways in which we adjudicate, that is how we make judgements about, nature.

CASE STUDY: THE SONORA TIGER SALAMANDER

The Sonora tiger salamander, a previously unrecognized subspecies, was described from the San Rafael Valley in southern Arizona (Lowe, 1954). Subsequent research into the systematic status of the subspecies revealed that this race has the genetic properties of a hybrid, and likely originated by the union of two other subspecies whose closest populations are now in northern Arizona and eastern New Mexico (Jones et al., 1995). Sonora salamanders presently live only in ponds (stocktanks) created and maintained for supporting livestock since as early as 1822 (Collins, 1988; Hadley and Sheridan, 1995). None of the aquatic habitats that are most similar to what habitats in this southern Arizona grassland were like before the arrival of European-derived settlers have salamanders (Bahre, 1991, 1995). In 1993 conservationists from New Mexico petitioned to have the Sonora salamander listed as an endangered subspecies based on the restricted range and special genetic characteristics of the subspecies (Beattie, 1995), and the subspecies was subsequently listed effective January, 1997 (Gerst, 1997). Listing means that the U.S. Fish and Wildlife Service must develop a plan for ensuring the protection of the subspecies, and ultimately this might result in a limiting of grazing rights by local ranchers on some lands.

Federally and privately managed lands comprise the San Rafael Valley. Ranchers generally prefer that the subspecies not be listed, thus avoiding any restriction of grazing rights that might result from implementing the Endangered Species Act. Often, the first question in such cases focuses on the basis for concluding a species or subspecies is "endangered." How do categories specified in legal policies constrain or structure the ways in which biologists theorize and describe phenomena?

- Do "rare, threatened, or endangered" statuses have conceptual or theoretical significance within biology? What, for example, is the explanation for an increasing interest among ecologists in "rare" species?
- How are the boundaries characterizing a species determined and how does the legal system influence who gets to define a species?
- How do legally defensible rights, like property rights, alter research practices and types of scientific information accessible to the researchers?
- How are the "rights" of information acquisition determined in these contexts?

Since salamanders now live only in "artificial" habitats, it could be argued that this diminishes the claim that the Sonora tiger salamander is a "natural" evolutionary unit worthy of protection, raising questions about values. How does what is natural and what we are trying to preserve get defined in law and science?

- How do conceptions of nature based on belief systems outside of science and the law affect legal policy and scientific practices?
- How do different groups draw boundaries between humans and nature and in what ways do these boundary constructions influence or impede social activism?
- How and when do environmental values of policy makers like legislators, judges, administrators, and scientists differ from those of the general public, and how do legal and scientific processes interact in resolving value conflicts?

Local ranchers claim that they are effective stewards of natural resources, arguing that persistence of salamanders in habitats they manage supports this claim. Environmentalists challenge this claim. Various governmental agencies argue that they have authority to adjudicate the issues and thereby determine who has expert status. All of these groups asked the scientific researcher to play a mediating role. Who qualifies as an expert in society and how do these qualifications as an expert vary among societies and over time?

- How does the concept of expertise vary among and within disciplines, like environmental studies versus genetics, or as a function of institutional association, like employer or society membership.
- How does the participation of scientists within legal and policy venues affect their standing and authority in the scientific and policy community?
- How do scientists playing active roles in other social institutions negotiate dual or multiple identities?
- How does litigation, and other decision-making processes, adjudicate among competing interests and knowledge claims of different stakeholders, allocate privilege to different views, and systematically include or exclude certain viewpoints and why?
- In areas of conflict and uncertainty, how are opinions developed at various levels of organization, from local to state to international bodies?
- How are conflicts among these organizations resolved?
- How does the representation of multiple stakeholders in environmental disputes affect understandings of scientific uncertainty?
- In general, how do law and science deal with ambiguity, as in definitions of "species," "subspecies," and "nature?"

The US Fish and Wildlife Service asked all parties concerned to participate in a "conservation agreement" detailing tactics all will follow to ensure protection of Sonora salamanders, as an alternative to listing the subspecies as endangered. Enforcement of this agreement requires sampling on private land, and some private landowners have refused access to their property for collecting scientific data, raising questions about access to scientific information. How is access to scientific knowledge affected by other rights, like legal property rights?

- How does differential distribution of these rights affect participation in environmental decision-making?
- What special problems of scientific access arise when environmental issues cross borders of multiple sovereign entities?
- To what extent are new legal doctrines needed to recognize scientific access to environmental data?

A few of the issues raised by this case are specific to the Sonora salamander. In general, however, questions stimulated by this case are general and also apply to other cases like managing salmon in the Pacific northwest of the US, managing the fisheries of the Georges Banks in the North Atlantic, and controlling acid rain in southeastern Canada and the northeastern and upper midwest of the US.

DISCUSSION

Resolving a case like the Sonora tiger salamander is hard. The biological material by its nature is elusive in several respects. What is a species? What is natural? What population density or geographic distribution qualifies as rare? Who gets to decide all of this? And we have not yet added diverse human values regarding preservation versus use of the environment.

Institutions, like the courts, which are designed to produce "yes" or "no" answers, may often not be the best places for adjudicating such complexity. Jasanoff (1995:1) reinforced this point: "American political culture derives its distinctive flavor as much from faith in science and technological progress as from a commitment - some might even say an addiction - to resolving social conflicts through law. These powerful cultural predilections have brought the institutions of science and technology into turbulent confrontations with the legal system, raising doubts whether the nation's intense concern for health, safety, environmental protection, and traditional moral values can be reconciled with its yearning for sustained economic growth and an endless technological frontier. Disenchanted with legal approaches to problem-solving, influential critics in universities, industry, and government have called upon the law to adopt a more deferential or hands-off attitude toward science and technology." As a society we need to continue exploring diverse means, like conservation agreements, that might settle environmental cases outside of the courts (Kaiser, 1997a; Mann and Plummer 1997; Shilling, 1997).

Basically, we can think of the Sonoran tiger salamander case as being driven by "risk." Conservationists do not want to risk losing a species, while private land owners do not want to "risk" losing certain property rights. We often feel that the way forward in such a debate is analyzing and quantifying the risks, using these results to set priorities, and proposing solutions. Cases like the Sonora tiger salamander illustrate, however, that the nature of the risks themselves may be elusive, or open to debate making progress to a solution difficult.

Nonetheless, attempting such a process seems to remain the best way to progress on solving these issues; however, openness and participation by scientists and non-scientists in evaluating the risks is essential. We need to strive for a system in which scientists can gather the information policy makers need to reach decisions, but scientific information needs to be

assessed in an environment where the concerns of all parties are addressed. This should be an environment in which arbitration and negotiation, as opposed to litigation, are the central features of the decision-making process. Participation in such a process would not necessarily be to generate a consensus - cases like the wild horses in Nevada, for example, will probably not lend themselves to a consensus. We will, however, likely broaden the scientific agenda, generating more useful advice by including scientists and non-scientists. Peer review and circulating early drafts of recommendations can highlight hidden or poorly justified assumptions. Involving all interest groups ensures all have had their say, but it also ensures a wider appreciation of the complex factors underlying a particular case; so, even if your position does not prevail, at least you understand why it did not. In a democracy, this openness of the decision-making process may be the most important principle to support as we struggle to find the best ways to make judgements about nature.

ACKNOWLEDGMENTS

J. Maienschein and D. Strouse commented on details of the case study as part of a collaborative analysis of biology and law. E. Davidson commented on a draft of this paper. Arizona Game and Fish Department, National Science Foundation, and US Fish and Wildlife Service supported research that served as the background for this work.

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COST AND BENEFITS OF RANGELAND WATER DEVELOPMENTS

Reckoning Real Costs and Secondary Benefits of Artificial Game Waters in Southwestern Arizona

Bill Broyles[1]

Abstract -- For six decades artificial game waters in southwestern Arizona have been assumed to be a primary benefit to wildlife. A number of tacit social and psychological secondary benefits for wildlife agencies and advocates may accompany these water development projects, including recreation, fund raising, public relations, political clout, bonding and recruitment, psychological gratification, easy mitigation, and righteousness.

However, these artificial waters have real costs, including dollars, scientific standing, ecology, loss of knowledge, controversy, and credibility. Because the primary benefit of artificial waters to wildlife still has not been adequately demonstrated, secondary benefits by themselves do not appear to offset the costs.

Alternative projects that may help wildlife while fulfilling secondary benefits should be investigated. These may include fence removal and modification, purchase of habitat and conservation easements, limiting human disturbance of wildlife, purchasing grazing allotments, and changes in land designations and policies to preserve and unify wildlife habitat.

INTRODUCTION

For nearly six decades wildlife managers in the Sonoran Desert of southwestern Arizona have given priority to the development of artificial waterholes on the assumption that this water directly benefits wildlife, especially game species. The rationale has been that drinking water is required by desert species; it tides them through droughts; it redistributes them more widely throughout their potential range; it increases their density; it improves species diversity; and, it may avert extirpation (deVos et al., 1997).

Secondary benefits, which directly help people not wildlife, may follow these development projects. Though important, these secondary benefits are frequently unspoken, untallied and unwritten in a water project's formal plan, but in some cases they may be significant or even the real reasons behind a water project. This paper combines a review of published studies and gray literature with personal observation to examine some of the social and psychological reasons driving management decisions.

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[1]Tucson, Arizona.

What are some of these secondary benefits? They include recreation, revenue, good press, politics, bonding, psychology, mitigation, and righteousness.

SECONDARY BENEFITS

Recreation: Water development provides public recreation on two levels. The first is the project itself. The projects involve wholesome exercise for the volunteer and agency workers. Walking and manual labor are therapeutic, both physically and psychologically. Subsequent monitoring and maintenance of the development add to the recreation-effect. When friends or family are involved, a water project rolls comraderie, togetherness, a camping trip, public service, exercise, beautiful country, and wildlifing into one weekend. For most outdoorsfolk, things don't get much better than that (Hook and Lee, 1988).

The second level is long-term recreation. Most southwestern waterholes have been developed to increase the numbers of game animals for hunters. Organizations, such as Arizona Desert Bighorn Sheep Society (ADBSS), Desert Wildlife Unlimited (DWU), Arizona Antelope Foundation, and the Arizona Game and Fish Department (AGFD) itself, provide funds and labor in the bottom-line belief that more water will mean more game to hunt. Some hunters use the water for bait by stalking and shooting their quarry at desert waterholes (Boroski and Mossman, 1990; Enlow, 1997). Waterholes also attract bird-watchers, photographers, hikers, scientists, and nature lovers. It is hard to put a price-tag on the thrill of seeing wildlife come to water.

Revenue: Water projects are a persuasive way to raise funds, both from voluntary contributions and from budget makers. Indirectly, water development helps influence hunters to bid tens of thousands of dollars on auction and lottery hunting tags for bighorn sheep. Bolstered by several auctions where bidders paid over $300,000 each for bighorn hunting tags (Hook, 1991; Smith, 1994a and 1994b; Lee, 1996), ADBSS has raised and donated well over $2 million by 1997. These are major contributions to any agency, and much of the money is directed to water development and animal translocations (Leek, 1995).

Too, grants and donations may follow because of donors' faith in water development. These funds, which underwrite research and habitat improvements, are significant additions to local and regional monies. Further, developments give the appearance of increasing species numbers and diversity, and so may sell more hunting licenses which in turn increases agency revenue. Water developments also help sustain outdoor groups by providing fund-raiser incentives.

Public Relations: Water projects are good press. By featuring a favored species, especially desert bighorn sheep, agencies and outdoor groups generate significant bonuses of positive publicity from the popular press (Burton and Ayers, 1991; Hatford, 1992; Sitko, 1993). Water projects tell the public that we're working hard and that we care. The image is one of heroism and compassion: who could resist providing water to thirsty animals? They're a sign of positive, active management, and they make agencies look busy and successful.

Political Clout: Because water developments require squads of dedicated volunteers to both construct and fund the projects, they simultaneously create a pool of political allies who can be readily rallied to support agencies and issues. These constitute a convenient cadre of letter-writers and voters, strong allies for any agency or advocacy group. Outdoor organizations such as DWU and ADBSS are politically powerful friends.

Bonding and Recruitment: Water projects in southwestern Arizona meld outdoor groups with state and federal agencies. These are strong networks and alliances. Projects are catalysts for bonding personal and business alliances, too. In this respect, water projects are inclusive and exclusive, analogous to country clubs and golf courses. They also team trained biologists with willing amateurs. Where else can an avid but untrained public get so involved with professional management?

Too, water projects are good ways for groups to recruit new members and to develop a constituency. Water developments provide agencies and outdoor groups with reasons to expand, and they provide extra leverage in management decisions for favored policies and projects.

Psychology: Working on a water project is instantly gratifying. There is enormous pride in the reward of a job well-done, a job earned by hard labor and ingenuity and perseverance. Unlike many other phases of wildlife management and politics, developments give a clear and immediate sense of grand accomplishment. We know that we helped wildlife and have made the planet a better place (Hook and Lee, 1988; Leek, 1995). This combines duty, self-interest, and altruism.

Mitigation. Water development may serve to mitigate human encroachment and fragmentation of wildlife habitat, so that wildlife needn't cross fences, highways, railroads, or canals to reach water. This is much easier than dealing with the tougher, intractable issues of booming human populations, declining resources, and diminishing habitat. It is far more convenient and politic to install water troughs than to fight urban encroachment, overgrazing, or industrial expansion.

Righteousness: Developments may fulfill personal religious or metaphysical precepts about the relationship between man and Nature. Some proponents tout waterholes as opportunities to do God's work, to play god, or even to defeat Nature and show that the hand of man rules supreme. Development may also be a way to achieve immortality. Some development projects can be "bought" at auction, with the high bidder underwriting the project and earning the right to name the tank after himself (Anon., 1997b).

Probably you are already thinking of other secondary, tacit benefits which follow water development.

COSTS

But these secondary benefits are dividends only if the central benefit of helping wildlife can be proven and only if the costs can be justified. These costs include money, scientific standing, effects on ecology, loss of knowledge, controversy, and diminished credibility.

Money: As with every significant endeavor and project, nothing is ultimately free, and water development is no exception. Monetarily, the primary costs to develop and maintain waterholes in Arizona run $25,000-50,000 per site (Mouton and Lee, 1992) and total nearly one million dollars annually (deVos et al., 1997). In fiscal year 1995, AGFD spent $359,339 to develop 7 new waterholes and to renovate 8 others, $396,935 to maintain the existing waterholes, and $194,000 to haul water (deVos et al., 1997). The cost to volunteers assisting these projects is unreported. BLM contends it needs $5.65 million for water development and maintenance projects in the western United States just for desert bighorn sheep (BLM, 1995). Besides the initial development costs, installing a waterhole becomes a moral contract for long-term maintenance. In Arizona this commitment costs an average of nearly $700 annually to repair and supplement each waterhole for its lifetime (deVos et al., 1997), plus the costs to monitor it. More money could be spent if it were available.

However, costs must be met by real results. How many more game animals do waters generate? With resident hunting tags for deer selling at $18.00 for deer, $53.00 for antelope, and $153.00 for desert bighorn (AGFD, 1997), how much more income from license sales will those additional animals bring? Amortized over 20 years, each waterhole would need to yield about 16 more huntable bighorn sheep per year in order to pay for itself; since hunting tags are issued on 1.5-2% of a given population, each herd would need to instantly increase by 750-1,000 animals in order for that particular waterhole to pay for itself. This number far exceeds the current populations or carrying capacities for most desert mountain ranges and is an unlikely result. It is doubtful that agencies would spend as much money on water programs if the funds were strictly from their own budgets instead of massive subsidies from advocacy groups.

Costs presume that the product works as advertized. Would we spend $50,000 just to have a weekend camp-out for the 75 sportsmen building a catchment? Should we spend $1,000,000 annually to look busy, to promote the agency, or to feel good? Few accountants would think so.

However, some less obvious costs also must be reckoned sooner or later. Where else might we pay?

Scientific standing: To date, proof for the efficacy of water developments has been largely anecdotal, descriptive, and without scientific rigor. Some biologists contend that the effects of waterholes on wildlife can't be studied in a test-tube, that experiments can't easily be done because of complex environmental variables. DeVos et al. (1997:49) contend, "Our understanding of the benefits and impacts of artificial water developments is incomplete because there have been few experiments that test the effects of water developments on

wildlife populations."

If benefits can't be proven, then one must question whether wildlife management is a science, and if it is, where if stands in the hierarchy of sciences. Aldo Leopold (1948:253) noted that "Control of game food, water, and special factors...is necessarily an empirical art, in which predictions are never wholly safe, classifications of phenomena are more or less arbitrary, and we know what much oftener than we know why (emphasis added)." The researched resolution of water development issues will help raise the mark for scientific rigor and elevate the standards of wildlife management.

Ecology and effects on other species: At what point do we add so much water to the Sonoran Desert that it becomes Illinois? When do we change the desert into something else? When do we make a habitat too rich for native animals? Take desert bighorn sheep--watered, collared, and protected by man--when do they become domestic? At what point do we radically and forever alter the very things we're trying to preserve? Writing about management interventions on behalf of wildlife, Krausman (1993:250) noted, "We are at a threshold now. My deepest doubts are about those who call for further intensification of management.... How soon before the habitat available for wildlife is so limited that the degree of management intensity becomes identical to farm management? Every bit of domestication takes a little away from the wild side of wildlife."

The Desert Bighorn Council technical committee opposes artificial propagation of desert bighorn by interspecies embryo transfer using domestic ewes. It opposes on the grounds that these crossbreeds may transmit diseases to native herds, that the proposal diverts limited financial resources assigned to restore native species, that it "would be possible to end up with an animal that is habituated to humans and has no protective wildness," that offspring would be selected for traits other than those which "increase their fitness under natural conditions." and that the resulting animal would be "domestic" and therefore unqualified for Boone and Crockett Club scoring (Brigham, 1996:73). These same arguments could be used against water development.

Unless all other habitat requirements are increased along with added water, it is difficult to expand one species without limiting another (Leopold, 1948). Although agencies are reluctant to say they are doing single-species management (preferring instead terms like "distinct species focus" or "target species" [deVos et al., 1997]), the addition of water to a habitat is designed to change the numbers or health of discrete species. The fate of untargeted species is seldom studied and largely ignored. Tinkering with ecology is risky business if we write the book as we go.

Loss of knowledge: Because many of the early waters were developed without adequate site or area analysis, and some still are added after only precursory study, much knowledge about wildlife has been lost. We have installed waters first and asked questions later. The planning process still lacks detailed pre- and post-surveys of populations in the area. Information is needed on current densities, distribution, and trends of all affected species. We need baseline

data in order to assess the effectiveness of waterholes and to make sound management decisions.

The scientific loss extends beyond wildlife biology. Archaeology has paid an untold price for waterhole development. Virtually all desert waterholes are also archaeology sites (Broyles, 1996), but seldom has the modification of one of these sites done justice to the archaeology. Full and accurate photos, collections, descriptions, maps, and drawings do not exist for most sites before development or modification, even those installed after the Archaeological Resource Protection Act in 1979. At best, archaeologists find brief notes that something existed there, but have no real way to reconstruct the details of bedrock mortars, trails, rock art, or volume and sustainability of the natural tinaja. And, even with adequate documentation these sites lose their unique character and are forever damaged.

Limnology and invertebrate biology, too, have been affected. Collections and descriptions have rarely been taken at tinaja sites before construction. The limnology of natural desert pools is poorly understood, and there is much to know (Cole, 1979; Thames and Ziebell, 1988; Kubly, 1990 and 1992). Enhanced tinajas or catchments remain virtually unstudied. Questions about seasonal chemistry, cycles of flora and fauna, and water quality remain unanswered. For example, how does changing an ephemeral or intermittent waterhole to perennial affect its aquatic life (Graham, 1997)?

Credibility: Agencies find themselves in a bind. For decades management agencies have solicited money and time from wildlife advocates on the claim that water is necessary for wildlife. Promises have been made. The vision has been drawn. Some predicted that windmills and waterholes in the arid Southwest would produce conditions like the waterholes and game plains of Africa (Nichol, 1937). A draft of one recent management plan predicted that the additional waterholes in the sparsely vegetated mountains of southwestern Arizona would increase desert bighorn fourfold, from a density of 1.1 /mi^2 to 4.4/mi^2 (BLM, 1996), which would surpass any other range in Arizona and would rival bighorn herds in the lush mountain meadows of Alberta, Canada (Remington, 1989). The shibboleth has become "Sine agua mortis--without water, they die." But now, after close review of the scientific literature, the agencies realize that they lack concrete evidence of benefits. The evidence is circumstantial at best and contrary at the least. Biological opinion remains divided (Broyles, 1995; deVos et al., 1997).

DeVos et al. (1997:3) summarize the situation. "The published literature strongly suggests that availability of free water plays an important role in distribution, movements, habitat use, reproduction, and survival for some wildlife species." Suggesting that <u>some</u> individuals or species <u>may</u> benefit is hardly rousing confirmation or justification. The public has been told that waterhole projects are crucial and effective. When waters are found dry, un-used, or troublous, then public confidence is shaken. At stake is the trust of wildlife advocates and the general public alike. Writing for members of the Arizona Desert Bighorn Sheep Society, Hook and Lee (1988:185) remind agencies and advocates that "the primary purpose...is the bighorn sheep of Arizona. Not the members. Not the Society. Our <u>only</u>

purpose is the bighorn sheep" [emphasis in original]. Secondary benefits hang on that primary benefit.

Unfortunately, that primary benefit of helping wildlife has not yet been proven (Broyles, 1995 and 1997; deVos et al., 1997). Studies by Smith and Henry (1985), Burkett and Thompson (1994), Krausman and Etchberger (1995), and Cutler and Morrison (1995), among others, indicate that artificial waters are irrelevant to a number of desert species. None show a strong positive effect, and several suggest negative effects. The bighorn sheep literature lacks documented deaths from thirst or numerical assessments of population numbers in response to water. We do, however, have documented cases of wildlife die-offs from poisonous water and drowning (Mensch, 1969; Cunningham and deVos, 1992; Carmichael, 1994; Swift, 1996).

Biologists also ask if artificial waters threaten the wildlife they are designed to help. Water availability may imbalance prey-predator relations (McIvor et al., 1994), invite disease and poisoning (Jessup, 1985; Cunningham, 1989; Carmichael, 1994; Swift, 1996), and increase competition from livestock and other ungulates (Krausman, 1996). Some biologists doubt that artificial waters benefit even the target species. David E. Brown (this volume) contends that desert bighorn in the Kofa National Wildlife Refuge in southwestern Arizona have not benefitted from an aggressive and prolonged water development program.

No one doubts that bighorn can and do drink available water. But, do they need to? There are cases in the Sonoran Desert where perennial drinking water is neither a necessary nor a sufficient condition for a viable bighorn herd (Krausman and Etchberger, 1993 and 1995). Some herds do fine without water; some areas of apparently satisfactory bighorn habitat have ample water but few or no sheep (Broyles, 1995; deVos et al., 1997).

A number of conundrums follow the water-development mission. For example, the density of desert bighorn in the "dry" Granite Mountains of western Pima County (AGFD unpublished survey data) is similar to the density in the Silver Bell Mountains (of eastern Pima County), which have 50% more precipitation and which are blanketed by 13 perennial waterholes (Bristow et al., 1996; Bristow, this volume): 1.3 bighorn/mi^2 in the Granites in 1993 and 0.8/mi^2 in the Silver Bells in 1994. The density of bighorn in arid mountains of western Sonora equals or exceeds similar ranges in Arizona where waterholes have been developed (Lee, 1993a and 1993b). Not all bighorn use water in summer (Monson, 1958; Simmons, 1969). Some bighorn herds have survived prolonged drought (May, 1973). Some herds traditionally lived or still live in mountain ranges lacking perennial water (Lee, 1993a and 1993b; Lee and Lopez-Saavedra, 1994).

In their technical review, deVos et al. (1997:49-50) conclude, "The preponderance of scientific evidence... indicates... that some wildlife species have benefitted from increased availability of free water. In particular, mule deer, white-tailed deer, elk, and Merriam's turkey distribution and or population performance have likely been enhanced by water development." However, the absence of desert-adapted species from this list--such as desert

bighorn sheep, javelina, coyotes, doves, quail--is enlightening. Since even mule deer may live in desert areas lacking free water (Anderson, 1949; Krausman and Ables, 1981), we must wonder what artificial water development has accomplished in the southwestern Arizona desert. The efficacy of artificial waters for desert species remains unproven. Possibly, it is appropriate in some places at specific times for certain species, but it is not a universal panacea. McCarty and Bailey (1994:18) remind us, "Biologists should not presume that water is a limiting factor for desert bighorn everywhere." The need for wildlife waters requires case by case justification.

Further, the process of development itself needs to be fine-tuned in order to remain consistent with its goal to enhance habitat. Water projects for desert bighorn should be done in late fall, not in spring, as most are. In spring, water in the existing pothole is wasted in construction and polluted with cement residue. In spring, ewes have lambed and dislike intrusions in their area. In spring, water must be hauled if the tank is to have water before summer rains. But, in the fall a project can be expected to fill with winter rains, sheep are less likely to be disturbed, and any construction residue may be purged from the tank. Also, the development itself may sacrifice or damage the habitat of the very species we're trying to help. Work at two southwestern waterhole projects needlessly denuded and pulverized over an acre of habitat at each site to install and fill small tanks for bighorn. Such damage to habitat in arid lands is prolonged; for example, even the lowly bursage (Ambrosia spp.) may require 30-100 years to recover in a radically disturbed area (Artz, 1989). Bursages, which may live over a century, serve as a nurse plant for other desert plants and as food for several herbivores (Turner et al., 1995). Water projects should maximize the functions and values of habitat. Full costs to restore habitat disturbed by construction should be included in any project's budget.

Controversy: Until water development is proven by scientific study to be sound policy, dissension and controversy will continue to cause intra- and interagency friction and division, as well as conflict among wildlife advocate groups. Agencies internally argue over philosophy and funding of waterholes. Agencies argue with each other whether artificial waters conform to structural and aesthetic criteria within wilderness areas, how they should be maintained or monitored, and whether they should be built at all (Andrews, 1988). Wildlife groups, e.g. ADBSS and DWU, debate whose construction techniques are better. Until water is proven efficacious, these frictions are moot and pointless.

The most convincing current arguments for waterholes pivot on an animal's proximity to a given waterhole (Bristow et al., 1996; Bleich et al., 1997), but proximity does not prove that any substantive benefit is accrued by that individual or by the species. The proximity argument begs two questions: 1) is the wildlife there because of the waterhole, or was the artificial waterhole put where wildlife already were? and 2) even if wildlife are using a waterhole, are they benefitting from it? If the primary benefit of water on wildlife--and especially on a desert-dwelling species such as bighorn sheep--is presumably so obvious and pronounced, one would think it would have been easily proven by now. However, in their exhaustive review of bighorn literature, McCarty and Bailey (1994:18) were "discouraged to

find only 1 report (Leslie and Douglas, 1979) documenting an effect of water development upon the number of [bighorn] sheep."

In light of recent discussions and realizations that evidence is sparse, some proponents of waterholes have retreated to saying that waters do no real harm and that they haven't been proven detrimental (deVos et al., 1997). This results in a stalemate of the logical fallacy ad ignorantiam: something is true because it hasn't been proven false, or something is false because it hasn't been proven true. It would seem that the burden of proof lies with whomever must justify the costs. One wonders what evidence management agencies could muster to defend themselves against litigation opposing water developments.

If agencies are to avoid needless controversy and loss of confidence, it is critical that they scientifically establish the efficacy of artificial waters. So far they haven't, but they may. About fifty years ago Leopold (1948:297) noted, "The deficiencies in our dependable knowledge of the water requirements of game present a large opportunity for controlled experimentation.... Such experiments have so far been rare." Some forty years ago Herk Ogren (1957:54) stood before the Desert Bighorn Council and urged, "Let's accompany our management program with a research program in such a way we can objectively determine the value of the management. Let's try to get some measurements and figures which will tell us the value of developing water as we are doing it today." Nearly thirty years ago Norman Simmons (1969:102) noted of a recently refurbished desert waterhole for bighorn, "There is an excellent opportunity...to assess the value of constructing waterholes. Careful total counts of the sheep in the range before and after water development should be made to obtain a realistic evaluation." These counts were not done.

For decades the Research Branch of AGFD has been calling for definitive, experimental studies of the effects of water on wildlife. Some limited studies were done, including Steve Gallizioli's study of quail and doves which found that gallinaceous guzzlers made no difference to bird populations (Gallizoli, 1962 and 1965). The latest call for study is that of Jim deVos, head of AGFD's Research Branch (deVos et al., 1997; deVos, 1997; deVos et al., this volume; Ballard et al., this volume).

After I delivered a paper questioning water development at the 1994 Desert Bighorn Council (see Broyles, 1995), a BLM supervisor in southern California put the matter this way: "We've budgeted $5 million dollars for waterhole development and maintenance in the next few years; if they're not needed, that money sure could be better spent elsewhere." Another wildlife manager shrugged, "I haven't found any biological need for water, but politically I can't say anything. Sportsmen's groups believe in water like it's a religion." Still another state official said, "Agencies are slow to change and still slower to prove what they don't want proven. I hope you don't have to give this same paper again in another 50 years."

Fortunately, AGFD is now leading the way to discovering answers. This symposium and a recent AGFD Briefing Document (deVos et al., 1997) are major steps forward. It is time for experimental study of waterholes and their effects (see Krausman and Czech, this

volume). As Smith and Krausman (1988:10) wrote, "Enough descriptive information is now available that research should be designed to test experimental hypotheses." Wildlife groups and agencies must support this research if we are ever to unlock the riddles of water. Now is the time. Benefits to wildlife and to ourselves hang in the balance.

OPTIONS

But by focusing so intently on water, we may be overlooking other important strategies to assist wildlife. Water development is not the only game in town. Habitat fragmentation, degradation, and alteration, along with competition from other ungulates and disturbance from human activities, seriously threaten desert bighorns, as well as other wildlife (Smith and Krausman, 1988). According to a BLM survey, the three factors most limiting mountain sheep populations in the western United States are grazing by domestic livestock (by a large margin), disease and parasites, and "harassment caused by human recreation such as off-road vehicle traffic and hiking in lambing areas" (BLM, 1995:12). Water availability and allocation was rated only one of several perceived factors limiting desert bighorn habitat and populations; others limitations include habitat fragmentation, mining, wild horses and burros, habitat conversion, fire management, and natural predators (BLM, 1995:49). Wilderness restriction was also listed as a factor, but presumably on the assumption that wilderness inhibits managerial access to waterhole sites for construction, maintenance, and delivery.

Wildlife advocates and agencies might diversify their efforts to other projects. If we didn't do water, what else could we be doing?

- fence removal to permit wildlife movement and to provide movement corridors (Ockenfels et al., 1994);

- fence building, to exclude cattle from riparian zones and to guide wildlife away from dangerous roadways or canals (Cunningham and deVos, 1992; Kindschy, 1996);

- fence modification to make existing, necessary fences meet wildlife standards (O'Gara and Yoakum, 1992; AGFD, 1993);

- replanting riparian areas and springs; revegetating unneeded roads and denuded areas (Ohmart, 1996). Many water developments attempt to extend game species into marginal habitat; it would seem wiser to reverse degradation and fragmentation of good habitat where that game is already established and successful historically;

- gathering data at waterholes on rainfall, runoff, and usage (Gunn, 1990), so that we can thoroughly monitor the ones we have before we build more;

- cleaning up trash and pollution which may harm or inhibit wildlife;

• reviewing multiple-use policies; elevating wildlife values to primary consideration in management plans; setting wildlife values on state trust lands;

• limiting off-roading and human disturbances which interfere with the daily activities of wildlife (Berry, 1980; Webb, 1984; Clay, 1997);

• preventing disruption of migration corridors by roadways (Bleich et al., 1990 and 1997);

• encouraging alliances of all wildlife advocates, since hunters and non-hunters alike would benefit from more effective management. The Heritage Alliance already does this to some extent. And, a recent USFWS survey showed that hunters numbered 167,000 in Arizona during 1996 and they spent $208,972,000 on hunting; additionally, other wildlifers, bird watchers and photographers and the like, numbered 1,340,000 and invested $927,279,000 in their activities (USFWS, 1997). These numbers show strong public interest in wildlife;

• promoting eco-tourism as a way to expand the wildlife constituency and funds. Wildlife activities drew 745,000 non-resident wildlife watchers and about 16,400 hunters to Arizona in 1996 (USFWS, 1997);

• viewing wilderness as a way to protect habitat, not as a personal inconvenience (Haufler et al., 1995);

• promoting urban wildlife programs to educate and to instill wildlife values in the public;

• encouraging and purchasing conservation easements; pushing for unfenced private lands and for deed restrictions and zonings which protect habitat and open spaces (Ockenfels et al., 1994; Anon., 1997a).

• buying select grazing allotments and dedicating them to wildlife habitat. The income from all grazing leases on 8.4 million acres of Arizona State Trust Lands in 1993-1994 was $2.63 million--or $0.31 per acre annually (Bagwell, 1997). Since one cow consumes as much forage as seven deer or eight pronghorn (Holechek, 1988) and hunting license fees yielded over $10 million in 1995-1996 (AGFD, 1996), modest increases in license fees could cover this cost and should provide significantly higher yields of wildlife harvest, which in turn would increase recreation and revenue. The value of recreation, including hunting, far exceeds the value of grazing on arid lands (Loomis et al., 1991; see Souder, this volume). This mirrors public perception supporting restriction or removal of grazing on public lands in favor of increased wildlife and recreation (Fischer, 1997). The effects of grazing on wildlife are discussed in Fleischner (1994) and Krausman (1996), and by The Wildlife Society (1996).

Although these suggestions themselves need validation, many of them are already endorsed by wildlife advocates and agencies such as AGFD (AGFD, 1995; AGFD, 1996). If we value wildlife, we must act immediately and decisively to conserve and protect it and its habitat. In the decades to come, we'll find new ideas and new ways to benefit wildlife, but we need to base them, too, in science and fact. Researching the efficacy of water development is a fine place to start.

Acknowledgement: I wish to thank a number of biologists and wildlife managers for patiently sharing information and professionally discussing these issues. Several anonymous reviewers improved this paper.

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Ecological Economic Aspects of Rangeland Water Development

P. J. Daugherty and G. B. Snider[1]

Abstract – Ecological economics, an emerging transdisiplinary field, raises both positive and negative criticisms of current approaches to economic analysis of rangeland water development. On the positive side, correctly analyzed rangeland water developments can be viewed as investments in natural capital. On the negative side, current approaches to efficiency analysis overlook natural capital aspects, fail to include all costs and benefits, are conducted at the wrong scale. Efficiency analysis does not address equity aspects of water development. This paper discusses natural capital, efficiency, and equity aspects of ecological economics and their implications for the analysis of rangeland water development.

INTRODUCTION

Ecological economics is an emerging transdisiplinary field, that correctly recognizes that economics is an open subsystem, operating within and exchanging matter and energy with a materially closed, finite ecosystem. This paper will discuss three interrelated ecological economic concepts related to rangeland water development: natural capital, efficiency, and equity. The understanding and integration of these concepts into the analysis of rangeland water development is required for correct decision making. Rangeland water development involves the investment of resources to alter the spatial and temporal availability and distribution of water. If done properly, this investment can constitute an investment in natural capital, leading to an increase in the ability of rangeland resources to provide goods and services over time. Efficiency analysis involves the difficult process of assigning human values to the inputs and outputs of development projects, and serves as a necessary but not sufficient criteria in judging project merit. Equity analysis involves examining the distribution of the costs and benefits of development projects within and across generations.

The first section of the paper will define natural capital, and discuss water as natural capital. The upper Verde River system will be used to illustrate concepts. The natural capital aspects of rangeland water development have largely been overlooked or poorly analyzed, leading to decision analysis based on mechanically applied efficiency analysis. A critical question for rangeland water development is whether the water development will lead to an increase in the stock of natural capital. If water development does not increase or at least maintain natural capital, then the development constitutes a

[1] Assistant Professor and Doctoral student, School of Forestry, College of Ecosystem Science and Management, Northern Arizona University.

decrease in intergenerational equity, and a decrease in the sustainability of the system. The paper will then discuss the role of efficiency and its relation to natural capital. An inefficient project, by definition, constitutes a waste of resources and should not be undertaken. Current applications of efficiency analysis often focus on only the market or quasi-market values of projects, and fails to account for non-use values. If an efficiency analysis does not include all inputs and outputs, then at best, it must be viewed as partial analysis and should not be used as the sole criterion for decision making. Even if the efficiency analysis includes all inputs and outputs, decision analysis based on efficiency rely on the potential Pareto improvement criterion and fail to address the distribution of the costs and benefits. The final section of the paper will examine equity aspects of rangeland water development. Both within and between generation equity will be defined, and discussed in the context of rangeland water development.

NATURAL CAPITAL

Neo-classical economics has defines capital as the stock of material objects available to human beings at a point in time. Neo-classical economics also includes a concept of sustainability, which is incorporated into the definition of income:

> Income is the maximum amount that a community can consume over some period of time and still be as well off at the end of the period as at the beginning.

Being as well off means having the capacity to produce the same income in the next period. Capital is the source of this productive capability, and sustainability requires the maintenance of capital. Neo-classical economics has abstracted the economy as separate from the ecosystem. This abstraction has led to the view that capital consists solely of human-made objects. The role of cultural and natural capital is largely ignored (Daly 1994, Berkes and Folke 1994). Neo-classical economics ignores the capital aspects of the contribution of the ecosystem to the production process.

Ecological economics correctly recognizes that the economy is an open subsystem of a larger ecosystem, and exchanges matter and energy with this materially closed, finite ecosystem. Ecological economics recognizes that natural resources provide the basic raw materials and energy needed for all production processes, and defines natural capital as the stock and flow of natural resources existing at a point in time. Natural capital is the source of ecological goods and services, which provide the basis for society's continued existence and well being (Folke et al. 1994). Natural capital consists of two major types:

1) non-renewable resources such as oil, coal, and minerals, and
2) renewable resources such as forage, recreation, and ecological services.

Renewable resources can be further divided into two classes, truly renewable and conditionally renewable. The only truly renewable resource is solar power, and its derivatives wind and tidal power. All other renewable resources are conditionally renewable. These resources are renewable conditional on the maintenance of the productive capacity of natural capital. The recognition of natural capital changes the definition of sustainability in economics:

> An economy is sustainable if and only if it maintains the natural capital capacity of the system intact.

Just as firms must account for their capital depreciation and reinvest in their capital to remain viable, humans must account for natural capital depreciation and reinvest in conditionally renewable resources to be sustainable. No firm can treat its capital as profit or income and expect to remain in business, yet our economy has largely treated natural capital as income, leading to a depletion of natural capital over time (Daly and Cobb 1989).

Water Resources as Natural Capital

Water resources are unique in the fact that, depending on their source, they are both conditionally renewable and non-renewable. Water resources exist as stocks of resources stored in underground aquifers, and occur as flows of resources in streams and rivers. Water stocks in aquifers are conditionally renewable or nonrenewable depending on the recharge rate of aquifers. If the recharge rate is sufficiently slow relative to human time, then the stock of water is best viewed as non-renewable, leading to the correct usage of the common term, ground water mining. Surface water flows are renewable, conditional on the maintenance of the watershed and hydrological properties of the system transporting the water. The distinction between renewable and non-renewable types of water sources determines the type of economic analysis appropriate for judging development projects. The use of non-renewable resources decreases the stock of natural capital, and have direct impacts on intergenerational equity and sustainability. Sustainability requires that the use of non-renewable resources be compensated for by investments in alternative renewable resources. Conditionally renewable resources are sustainable if their use maintains the productive capability of the ecosystem providing the resource intact.

Water Developments as Investment in Natural Capital

Water development involves the alteration of the availability and timing of water resources to suit human needs. Water development can be evaluated in terms of natural capital impacts and can be viewed as investments in or withdrawals from the natural capital available to humans. A critical question for rangeland water development is whether the water development will lead to an increase in natural capital. Natural capital provides a variety of goods and services valued by humans for both use and non-use. In the case of water resources, these goods and services include: the direct use of water for crops, livestock, and recreation; ecological function values of flood control and waste assimilation; option values of saving water for later use; existence values associated with states of riparian systems, and bequest values associated with the desire to leave water resources intact for our children. Water development constitutes an investment in natural capital, if and only the development increases the capacity of the system to provide these services.

The following sections will examine several types of water developments in terms of investment to natural capital. The discussion is not meant to be exhaustive, but rather

illustrative of the type of considerations raised by the concept of natural capital. The question as to whether a water development is an investment in natural capital depends on whether the development has increased the capacity of the system to provide ecological goods and services. This question is not simply a question of whether we value the benefits higher than the costs, but rather a question involving the integration of the ecological impacts with our social valuation of these impacts. For this section of the paper, we will focus on the ecological capability of the system to provide goods and services.

Tanks

In arid rangelands where water is a limiting resource, the development of tanks for the capture and storage of surface flows may be investments in natural capital. Livestock tanks are developed to allow for greater utilization of existing forage, to spread the impacts of grazing over a wider area, and/or to minimize negative impacts of grazing on riparian systems. If the development of a rangeland water tank captures water that would have been lost to the system through evaporation and transpiration, then the tank constitutes an increase in the stock of natural capital. The temporary capture of the water expands the capability of the rangeland for forage utilization by livestock and wildlife. The contribution to wildlife may be substantial. Water development, primarily tanks, have led to a large increases in the elk herds in northern Arizona. The ecological costs in terms of the hydrologic cycle is a delay in evaporation and loss of some use by down tank vegetation. Additional benefits include the ability to minimize livestock use of riparian areas for water and forage. The decrease of impacts on riparian area may be the largest benefit as the largest negative impacts of livestock grazing in arid lands occur in arid riparian areas (Krueper 1996).

If the tank uses ground water, the analysis is complicated. The pumping of ground water involves the relocation of existing resources. In the Verde River case, minimal base flows of the river are maintained by ground water (Bonomo 1996, Owen-Joyce and Bell 1983). The increase in capacity of rangeland associated with tank development using ground water has remained the same as with captured water, but the ecological costs have changed. There is a transfer of resources from maintaining base flows of the Verde River, and a potential loss of natural capital associated with base flows. If the pumping of the aquifer, leaves base flows within the historic range, then little loss in associated values would be expected. This second example raises the issues of cumulative effects and management of the investment. The impact of pumping for a single tank, the marginal decrease in base flows caused by one tank, can not be evaluated in isolation from other water developments in the watershed. If variation in precipitation or other factors cause variation in recharge rates and base flows, then the management of the tank affects the impacts. The Verde River system is subject to a cyclic pattern of flood and drought (Owen-Joyce and Bell 1983). In these type of systems, the appropriate management regime would be to lower extraction rates at times of drought, when base flows are most dependent on the regional aquifer. This cyclic or opportunistic management would have to occur at the watershed level, and would run counter to many management approaches, which attempt to eliminate variability in managed systems. A

similar type of cyclic management has been shown to be optimal for grazing systems in rangeland subject to natural variation due to fire (Perrings and Walker 1997).

Water tanks in both cases can be viewed as investments in natural capital as the increase the ability of the rangeland to provide ecological goods and services. Tanks benefit wildlife limited by water availability and/or distribution, allow better distribution of livestock use of the range, and can be used to minimize grazing impacts on riparian areas. The first example assumes that the tank development captures water that otherwise would have been lost due to evapotranspiration, and clearly constitutes an investment in natural capital. The second example illustrates the case where the development is an investment contingent on management regime. Ground water supplied tanks can cause a decrease in the natural capital of the associated riparian system if it is not properly managed.

Water Diversions

Ditch diversions of surface water may be done to provide for agriculture and/or irrigated pasture. Ditch diversion represent a case similar to ground water supplied tanks, with the difference being that the resource transfer is direct from the surface flows, and is not mitigated by the storage capacity of underground aquifers. In this type of water development the investment leads to a one-to-one transfer of water from the riparian system to irrigation. Increases in rangeland capability are gained through the relocation of the water. The natural capital depreciation includes any decrease in riparian functions and processes due to the water transfers, and impacts on the assimilative capacity of the system by agricultural runoff, which may include pollutants from fertilizer, pesticide, and herbicide application.

In the upper Verde River system there are over 30 ditch diversions, with most built in the late nineteenth century or early twentieth century (Thompson 1996). These diversions do increase the productive capability of the land on which the water is used, and represent an investment in natural capital by a previous generation. This investment claim can be substantiated by the fact that the current generation can choose not to use them, thereby leaving the riparian flows unaffected, excepting direct interruptions in across land surface flows. Negative ecological impacts can be minimized by only using diversions during years of high flows. The upper Verde River system is also subject to low flows on a seasonal basis, with the lowest flows occurring in the summer and early fall. The low seasonal flows occur at the same time irrigation demand and evapotranspiration are the highest (Owen-Joyce and Bell 1983). This pattern increases the risk of ecological damage from water diversions in years of low flow. Base flow data are not available for the system prior to development of ditches, so it is not clear how much water is available for irrigation without risk to the ecological function value of the riparian system. While the uncertainty regarding safe water diversion levels complicates management, the diversions do represent an investment in capital passed to the current generation. The current generation has increased options in the use of the water, and can choose not to exercise these options, or to use them when the risk of negative impacts are the lowest.

Residential Water Wells

The final rangeland water development example is the development of residential water wells. These developments are carried out by individuals and municipalities. At the municipal level well fields may be developed to either wholly or partially supply water for consumption by city residents. At the individual level, the development provides water for consumption by individual households on small holdings. These water developments use water as natural capital and do not constitute investments in natural capital. The investments are made solely for obtaining water for consumption. The investments also lead to a decrease in productive capability of the rangeland by covering rangeland with houses and associated infrastructures such as roads. The developments can also negatively impact the assimilative capacity of the system through effluent discharge, leach fields, and road and landscape runoff. Currently these developments are not accompanied by offsetting investments in natural capital.

In the upper Verde River system, the Little Chino sub-basin provides an example of municipal development with the city of Prescott relying on this sub-basin as their principle water supply. Water levels have declined as much as 75 feet near the Town of Chino Valley (Thompson 1996). The rapid increase in urban development in the Chino Valley has been identified as one of the threats to the survival of the upper Verde River system, and its functions and processes (Thornburg 1993).

EFFICIENCY

Economic efficiency is concerned with allocating scarce resources among competing ends, with the goal of the allocation being the maximization of benefits to society. The concept has two related aspects, productive and allocative efficiency. Productive efficiency is concerned with waste; production should occur at the level where waste is minimized. This level occurs where the marginal benefit from the last unit produced equals the marginal cost of production. Allocative or Pareto efficiency is concerned with the allocation of resources. Resources should be allocated such that no other allocation exists, where at least one person can be made better off, without making someone worse off.

Defined in this manner, economic efficiency is clearly a rational criterion. When making development decisions, individuals and society would like to insure that the selected project is efficient. Wasting resources makes no sense. Choosing an allocation when another one exists that would make someone better off also makes no sense. When developing public projects, government agencies are correctly mandated to be efficient. Such projects use resources that otherwise could be used in private projects, and government waste makes no more sense than private waste. Economist use the perfect market concept as the standard for measuring efficiency. In theory, the operation of such a market obtains both productive and allocative efficiency. For public projects, agencies use cost-benefit analysis to insure that projects meet this efficiency standard.

In the arid southwest, where water is a precious resource, ninety-five percent of riparian areas have been degraded or destroyed (Krueper 1996). This fact suggests that

water development and management has been less than efficient. Using the development examples above, what would happen in the case of the upper Verde River system if one let the market dictate the direction of rangeland water development? At best, tanks provide little direct market value, excepting the harvest of livestock. Water diversions for cropland and irrigated pasture fare no better. The high value in the market is water development for residential use. It is not surprising that rapid urban development is occurring in the Chino Valley area. Yet of the three types of water development discussed, residential well development is the one type that does not constitute an investment in natural capital.

A comprehensive discussion of the reasons for market, governmental, and institutional failure in rangeland water development is beyond the scope of this paper. Instead, three reasons that lead to misallocation will be discussed: the failure to consider natural capital aspects of resource use, the failure to value all goods and services, and the problem of the common property and ecological nature of the resource.

Ignoring Natural Capital Depreciation

Neo-classical economic theory has abstracted the economic system from the ecosystem, and this theory reflects the practice of ignoring the capital aspects of ecological goods and services. The market, and the economic system in general, does not account for depreciation of natural capital in its transactions or analysis. At best, natural capital depreciation is recognized as an externality (e.g., water and pollution). Some progress has been made in addressing this failure at the macro economic level. Need for changes in the national accounting system are generally recognized (El Serafy 1991), and new national accounting measures such as the Index of Sustainable Economic Development (Daly and Cobb 1989) have been proposed. The economic value of ecosystem services and natural capital at a global level has been compiled and presented (Costanza et al. 1997). The calculated value of these services exceeds the global GNP as measured by human-produced goods and services. Less work has been done towards incorporating the concept of natural capital at the micro level or in cost-benefit analysis.

The term development, when used in the rangeland water context, should imply an improvement in the capability of the ecosystem to provide goods and services. If a project reduces natural capital capability, then it cannot be considered sustainable development. Yet most cost-benefit analyses of these projects have focused on the human-use values and not on natural capital values. A cost-benefit analysis which exclude the depreciation of natural capital will understate the true costs of the project. In the case of municipal water development, if the analysis focuses solely on the efficient extraction and allocation of water for residential use, natural capital depreciation to the aquifer and associated riparian system will not be charged against the project. As long as these natural capital values are excluded from analyses of water development, society will continue to develop current water use at the expense of the long-run service capability of associated ecosystems. Likewise, cost-benefit analyses which exclude increases in ecological services due to natural capital investments understate the benefits of projects. On the benefits side, this problem may not be as serious. A project is often

based on utilizing the increased capability of the system, and the time stream of these use values (e.g., increased in forage capability) is usually included in the analysis.

Failure To Value All Goods And Services

Successful economic efficiency analysis requires that all inputs and outputs of the project are identified and assigned values in comparable units (Davis and Johnson 1987, Gregory 1987). Economic values are human assigned reflections of preference (Brown 1984). Dollar values as reflected in market price or calculated willingness to pay are one expression of socially assigned values. Total economic value includes both use and non-use values (Young 1992). Use values include direct use outputs (e.g., crops, forage, and recreation), ecological function values (e.g., flood control and waste assimilation), and option values (i.e., the value associated with the option to use the resource at a later point in time). Non-use values include existence value (i.e., the satisfaction of knowing that the resource exists) and bequest value (i.e., the value of knowing that a resource is being passed on to future generations). Considerable work has been done on valuation methods for option, existence, and bequest values (Loomis and Walsh 1986, Walsh et al. 1984) and these values are beginning to be recognized as important components of total economic value. Total cost includes the cost of providing the resource, the cost of any lost ecological function, the cost of lost option, existence and bequest values, and the costs of any pollution imposed on other people. Failure to include all these costs and benefits results in a partial analysis, and any decision based solely on a partial analysis is unlikely to result in economic efficiency.

In public rangeland water development, cost-benefit analysis commonly includes only market and quasi-market (e.g., forage, wildlife hunting, and recreation) values and the direct monetary costs of the project. These values are used to calculate a summary index such as benefit/cost ratio or present net value. Non-market values, including ecological function values, are usually excluded from the cost-benefit calculation. At best, some of these values (e.g., water quality, soil erosion, and wildlife habitat) are assigned an ordinal scale value, and incorporated into a pseudo-quantitative environmental quality index (USDA 1982). Option, existence, and bequest values are generally excluded. While agency personnel may be aware of these excluded values, they often do not have the means to include them in the cost-benefit analysis. Valuation techniques for option, existence, and bequest values are expensive and time consuming, and research has not developed an approach for generalizing these values for use in project analysis. Even less work has been completed on providing estimates of ecological function value.

The current approach to cost-benefit analysis of rangeland water development fails to meet the condition for successful economic efficiency analysis. The summary index only illustrates the cost-benefit relationship between those inputs and outputs included in the calculation, and does not measure the worth or efficiency of a project. The information may be useful to decision makers, but does not provide enough information to solely decide a project's worth. Efficiency analysis attempts to avoid wasteful investment by insuring that the benefits exceed the costs. If the calculation of

the index excludes some benefits or costs, then the analysis does not insure that this criterion has been met.

Common Property and Ecological Nature Of The Resource

In private rangeland water development, the failure to include all values is closely related to the concept of externalities. Many of the benefits and costs of a project do not accrue directly to the private landowner. If a rangeland water development improves wildlife habitat, and the land owner receives no compensation for this improvement, the value will likely be excluded from the economic analysis. In general, the inputs and outputs of rangeland water development have a common property and ecological nature.

The common property nature violates the market assumption of exclusivity, and can cause problems when markets are used for allocation. Market exclusivity assumes that all benefits and costs from resource use accrue to the owner. When owners do not pay the full cost or receive the full benefit of an economic activity, the operation of the market will not be efficient. Paying less then full cost leads to over utilization of the resource, and not receiving full benefits will lead to under investment. In addition, the common property nature raises difficulties in assigning cost and benefits to individual actions. Rangeland water resources, particularly ground water, have common property attributes which make assignment of costs and benefits difficult. In the case of ground water pumping and water diversion, the cost of a unit of water from a single development cannot be evaluated separately from the total water use by all developments. This lack of independence is a problem when the costs involve negative impacts on a associated riparian system. The cumulative impacts on base flows needed to support riparian functions are not clearly assigned to individual activities. In ground water pumping, even the direct costs of pumping are non separable if the collective pumping lowers the water table and increases the costs of pumping. Many of the costs and benefits not only do not accrue to the user of the resource, but are also cumulative and depend on the actions of other users. Project-level cost-benefit analysis cannot address these common property and cumulative effects.

The ecological nature of rangeland water systems compound the common property problem. Rangeland ecosystems violate the continuous, reversible properties assumed by marginal analysis. Marginal and cost-benefit analysis assume that allocations may smoothly shift between multiple optimal states in response to supply and demand. Ecosystems are not necessarily twice differentiable. Southwestern fishes, while adaptable to fluctuation in water level, cannot adapt to a temporary loss of surface flows (Rinne 1996). In addition, the assimilative capacity of the riparian system to absorb agricultural and municipal runoff may have threshold levels and reach non-reversible states, depending on the type of pollution. The cyclic and seasonal patterns of high and low flows may radically change the marginal costs and benefits of management activities depending on the timing of these activities.

The common property and ecological nature of rangeland water development indicates that analysis must occur at several spatial scales. The loss of some ecological services, such as riparian functions which rely on base flows, can only be evaluated at the

appropriate watershed scale. The discontinuous and nonreversible properties of rangeland ecosystem raises addition difficulties in the evaluation and management of rangeland water development.

General Limitations of Efficiency Analysis

Even if natural capital aspects of a project and all costs and benefits are included in one analysis, and the common property and ecological issues are addressed, efficiency remains a necessary but not sufficient criterion for decision analysis. Economic efficiency is only defined for a given distribution of wealth, resource rights and institutional arrangements (Young 1992). If the project significantly changes any of these factors, it changes what we define as efficient. This problem has been long recognized (Kaldor 1939, Arrow 1950), and has largely been ignored through the use of the compensation principle or potential Pareto improvement. The compensation principle is invoked to avoid the difficult task of analyzing the distribution of costs and benefits. The compensation principle argues that if the benefits exceed the costs, the gainers could potentially pay off the losers, and the project should be undertaken. By relying on this argument, efficiency analysis loses the ability to state that a project is actually an improvement in social well-being. In practice, gainers are rarely required to compensate the losers. To fully evaluate the worth of a project, one must address equity.

EQUITY

Equity addresses the question of fair or just distribution of resource rights and wealth among people and over time. Many economist have recognized the link between equity and sustainability (Daly and Cobb 1989, Howarth 1991, Young 1992). Poverty and inequitable distribution has been associated with environmental destruction in developing countries, but we seem reluctant to apply this lesson to resource development in this country. Rangeland water development projects have both within and between generation distributional impacts. In order to be sustainable, rangeland water development must address distributional impacts. Any development that decreases natural capital constitutes a decrease in intergenerational equity. Any use of conditionally renewable rangeland water resources that does not reinvest in the natural capital supporting that resource also constitutes an intergenerational transfer.

It has become common to criticize public expenditure on rangeland development, as being an inefficient subsidy to livestock ranchers. Inefficient because costs exceed stated benefits or less costly methods can achieve the same benefits, and a subsidy because the monetary return to the treasury is less than the expenditure of public funds. The question of efficiency, and partial efficiency analysis has been addressed above. The question of subsidy directly relates to the issue of equity, and cannot be addressed by simple accounting of the direct monetary flows in and out of the treasury. The distribution impacts are also affected by the common property nature of rangeland water use, and the lack of exclusivity in capture of benefits and cost.

If a private rancher undertakes an investment in rangeland water development to restore a riparian area, the investment yields benefits that accrue to society at large. The

improvement in riparian areas is an investment in natural capital, and little of the value returns to the rancher. In addition, the water development may also improve wildlife habitat; again, the majority of benefits accrue to other than the rancher. Private rangeland provides a variety of habitats for species other than livestock, from which the rancher gains little monetary return. Private rangeland also provides valuable open space and green ways, and if the private land is interspersed with state lands, the rancher often provides free recreation access for hunting. In the case of checkerboard holdings, the rancher may have substantial cost associated with forage and water use by wildlife. In a number of ways, ranchers may be providing benefits to the public at large for no cost. We have yet to hear concerns regarding the subsidy of the public by private ranchers.

If the same development occurs on public rangeland which is used by a rancher with private land, then the investment is often criticized as a subsidy. Curiously, this type of criticism often come from members of the largest single subsidized user group on public lands, recreational users. Depending on the nature of the project, it may be shown that the public investment constitutes an income transfer from society to the rancher. Society has long chosen to engage in income transfers to improve the public well-being. These income transfers should be evaluated in the context of general equity, rather than the simple accounting of monetary expenditures and cost.

The question of alternate less costly alternatives to obtaining the same benefits is valid, and comparisons between alternative should consider all costs and benefits, and distributional effects. As an example, an alternative to improve riparian habitat may involve non-renewal of the grazing permit. This alternative has a negative distributional impact on the rancher who previously held the permit. The impact includes the value of forage forgone, and the decrease in private land values if the permit had been capitalized in the value of ranch. Even if this alternative has a higher benefit/cost ratio, one cannot assume the alternative provides greater social welfare. The compensation principle gives poor guidance for situations where a few are made very worse off and many are slightly better off (Young 1992). In addition, if the impacts makes the associated private ranch non-viable, then the analysis needs to account for induced land use changes. If the ranch becomes 2-acre residential parcels, with the right to pump up to 35 gallons per minute, the impact on riparian areas and wildlife may be more costly than the income transfer. The income transfer may be better viewed as a payment to maintain a type of land use, rather than as a subsidy to a particular individual.

SUMMARY

The concepts of natural capital, efficiency, and equity are interrelated and intertwined in a manner that allows separate discussion only for exposition purposes. The concept of natural capital raises issues in rangeland water development that have been largely overlooked. Rangeland water development is only sustainable if it maintains natural capital. The natural capital aspect of rangeland water development has largely been ignored in conducting cost-benefit analysis. Cost-benefit analysis is based on the concept that a project may increase the social well-being. In order for the long-term benefits to exceed the long-term costs, water development must constitute an

investment in natural capital. Several types of rangeland water developments were evaluated in terms of investment in natural capital. Water tanks and diversions can be viewed as investments in natural capital, while residential development constitutes a use of natural capital, and may decrease the natural capital capability of associated ecosystems. This latter type of development needs to be accompanied by reinvestment in natural capital in order to be sustainable.

In addition to ignoring natural capital aspects, current approaches to efficiency or cost-benefit analysis of rangeland water development fail to include all inputs and outputs. This failure limits the use of efficiency analysis in decision analysis. The common property and ecological nature of rangeland water resources also severely limits the ability to conduct project-level cost-benefit analysis. The common property nature aspect of rangeland water development suggest that correct analysis must occur at various spatial scales. Efficiency is a necessary but not sufficient criterion for judging project worth.

Rangeland water development affects both within and between generation equity. Private investments may generate services for the general public, with little or no return to the investor. Public investment in rangeland water development may provide income transfer to individuals. Rangeland water development also have between generation equity consequences. If a rangeland water project causes a decrease in natural capital, the project constitute a wealth transfer from future generations. If the development increases natural capital then the project constitutes a bequest from the current to future generations.

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The *Use, Role, and Relevance of*

Economic Analysis

in Evaluating

BLM & USFS

Rangeland Developments

Charles G. Romaniello & Gary B. Snider

The Use, Role, and Relevance of Economic Analysis in Evaluating BLM & USFS Rangeland Developments

Charles G. Romaniello & Gary B. Snider

Abstract– The use by BLM range staff of economic analysis in evaluating rangeland water projects was investigated. All area and district offices were surveyed for their use of BLM's Investment Analysis Model (IAM), a somewhat antiquated cost benefit analysis program. Very low levels of use was found for the entire spectrum of rangeland projects. A follow-up telephone survey of users showed a high level of skepticism as to the usefulness of rangeland investment analysis (cost benefit analysis) in its current form. US Forest Service range staff when questioned corroborated the same skepticism in their organization.

The inherent problems in using cost benefit analysis as sovereign decision criterion is discussed. It's preferable use as complementary information that serves to inform stakeholders of the efficiency of potential tradeoffs is explored. The " Case of the Spikedace on the Verde River" is used as an illustrative example.

The Use, Role, and Relevance of Economic Analysis in Evaluating BLM & USFS Rangeland Developments

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"It is foolish to invest in an alternative future without knowing the economic value. It is equally foolish to invest in an alternative future knowing only the economic value."
(Peterson and Brown, 1996)

INTRODUCTION

The efficient allocation of scarce resources through a decision making process is a central responsibility of land management agencies. The scientific persuasion that studies the efficient allocation of scarce resources is economics. This paper documents an attempt to understand the correct use of economic analysis in evaluating and prioritizing rangeland development projects with an emphasis on rangeland water development. It attempts to answer the following questions:

1. What analytical tools are currently available to BLM personnel?

2. Who uses them and what for?

3. What is the opinion of users as to its usefulness?

4. How appropriate are the methods to the task?

5. Are there recommendations that can be made?

Question 1- What analytical tools are currently available to BLM?

Methods and Findings

Discussions with BLM led to the conclusion that a specific economic analytical tool is used in the arena of rangeland development. A complete description of the BLM Investment Analysis Model (IAM) can be found in the BLM document "The User Guide for the Investment Analysis Model (IAM) Computer Program" dated November 1994. The model used may be characterized as a Cost/Benefit model in as much as its ultimate purpose is to arrive at a comparison of the costs and benefits derived from a given potential rangeland project.

Question 2- Who uses it and what for?

Methods

BLM personnel documented that the use of the Investment Analysis Model was not required after the issuing of Washington Office Instruction Memorandum #95-136 dated June 1, 1995. The use of the IAM model in BLM was thus voluntary and further enquiry was required.

A survey was E-mailed to all users of the Grazing Authorization Billing System(GABS) by the GABS/IAM Administrator in May 1997. At least one GABS user exists in each BLM District and Area Office and this system is managed by the Range Staff. The question asked was:

" How many of you (people in your Resource Area, District, Field Office, what ever you are called) are using the Investment Analysis Model for calculating the benefit /cost analysis for Rangeland Improvement Projects?

Please enter yes or no for the following . Of course if your answer is no on #1 don't bother to mark the rest of them."

I am using the model
I am using it for water developments
I am using it for fences and cattle guards
I am using it for prescribed fire
I believe its use is required
I don't use it because it doesn't reflect real benefits

Survey Findings

Responses to the survey are categorized by State in Table 1 titled " IAM Use Responses" and Table 2 titled "User Responses".

Table 1

Investment Analysis Model Use Responses

STATE	NUMBER SENT	NUMBER RESPONSES	YES USE IAM	NO DON'T USE IAM	OTHER
ARIZONA	9	7	0	7	
CALIFORNIA	17	12	0	12	
COLORADO	25	6	1	5	
IDAHO	14	10	5	5	
MONTANA	20	12	1	11	
NEW MEXICO	16	19*	7	11	1
NEVADA	22	6	1	5	
OREGON	13	10	0	10	
UTAH	12	5	1	2	2
WYOMING	15	13	0	12	1
TOTAL	163	100	16	80	4

* Includes three responses forwarded to additional range staff and responded to.

Table 2
User Responses

Response Code	Use	Water Develop.	Fences Cattle Guards	Fire	Required	Doesn't Reflect Real Benefits summary
CO1	AMPs Only	No	No	No	No	Yes
ID1	Yes No use since policy change	Yes	Yes	Yes	No	Yes
ID2	Yes	No	No	Yes	Yes	Too easily manipulated
ID3	Yes	Yes	Yes	Yes	Yes	If data is best guess so is BC ratio
ID4	Yes	Yes	Yes	Yes	Yes	No
ID5	Yes	Yes	Yes	No	Yes	No needs updating for the 90s
MT1	Limited	Yes	Yes	No	No	Does not reflect same answer as MTSO economist
NV1	Yes	Yes	Yes	Yes	In Nevada	Model only as good as the analyst
NM1	Yes	Yes	Yes	No	Yes	Yes we agree but use it because it is required
NM2	Yes	Yes	Yes	Yes	Yes	Yes but is sometimes required
NM3	Yes	Yes	Yes	No	Yes	Blank
NM4	Yes	Yes	Yes	Yes	Yes	NO
NM5	Yes	Yes	Yes	No	No	Agree Program Not updated for costs results unreliable
NM6	Yes	NO	NO	No	Yes	Info as accurate as person who enters it. Can be manipulated for justification purposes
NM7	Yes 8100 projects only	Yes	Yes	Yes	Yes	Blank
NM8	Use Lotus	Blank	Blank	Blank	Blank	Blank
UT1	Yes	Yes	Yes	Yes	Boss thinks so	Don't like it
UT2	Could use it	Blank	Blank	Blank	Blank	Blank
UT3	UT will use cost risk Analysis for fire	Blank	Blank	Blank	Blank	Blank
WY1	I'm Just back into range think it will be useful.	Blank	Blank	Blank	NO	N.A. to me

3. What is the opinion of users as to its usefulness?

Method

The 20 responses by users and those categorized as "other" are reported in Table 2 "User Responses". The responses to the question "I don't use it because it doesn't reflect real benefits or costs" is revealing. Twelve responses appear to be of an adverse nature to the use of the IAM model while only two are clearly positive.

An attempt to resurvey all respondents (20) indicated as users (16) or categorized as "other"(4) was made in June and July of 1997. Fourteen respondents were ultimately contacted this time however using an open ended telephone survey. Questions were asked to stimulate a discussion about the usefulness of Investment analysis in general, and the IAM model specifically, in evaluating and prioritizing range land improvement projects. Users were asked :

How frequently does the range staff use the IAM model?
What do you use it for?
How useful is the information that you get from it?
How often are the values in the model updated?
Do you use any alternative form of range investment analysis.
Do you use any alternatives to investment analysis? If so what?

Telephone Survey Findings

Table 3

Open Ended Responses

CO1	We no longer use the model. We used to put in what we needed to in order to get a 1/1 CB ratio. The real benefits were always so obscure. The decision is made depending on what the issues are. If we have lots of money we spend more money. If we are doing it in a team or partnership we are simply documenting the process. We don't need another paperwork excersize. Some areas are of higher priority than others and managers feel that they need to invest in them. The EA process is sufficient analysis.
ID1	We really don't know how to use the model. There is valuable information in it. The program isn't set up to give us what we need. It is easy to manipulate the return data. The program needs to be more user friendly.
ID2	We don't really use the model because money is not spent unless justified by a land health issue at a relitively high priority.
ID3	We use the model. Our last use of it was last year. Our recreation and wildlife data are updated every year.
ID4	We use the model. Data Are updated every year.
ID5	The last and only time we used the model was in early 1996 justifying a cattle guard. I don't know when or how recreation and wildlife data are updated.
NV1	I wrote a negitive respone to the WO policy statment ending the requirment to use IAM. I updated the NV matrix 2 years ago.
NM1	We used the model 3 years ago. That was about the last time the recreation and wildlife date were updated. We only use this model because we are required to. It is necessary to justify our projects.
NM2	IAM is not a practical system. There is no way to get values. If you think that a project is going to benefit the range you figure out how to justify it. For a rancher to want to contribute to a project there has to be some kind of benefit to them.
NM3	It's been 2-3 years since we've used the IAM model. When you get the numbers together you always get a negative BC ratio. Then you go back and fudge the benefits. We are trying to put dollar values on aesthetic values.
NM4	We use the model on an allotment basis. IAM is the best model that we have. People need to have some personal ethics in using it. Range Cons and Wildlife Biologists work together to analyze the overall allotment. The model has lots of flexibility.
NM5	We used to use it but they stopped updating the recreation and wildlife data. The last time we used it was 3 years ago.. We used it to be able to put some kind of justification in the file. You can put anything you want into it but it usually tells you if you are way out of wack. I have nil confidence in the model.
NM8	We use our own system for prioritizing projects. This is based upon our management objectives. We try to improve the allotments in the poorest condition first. Riparian improvement comes before upland projects, management facilities come before veg treatments, protecting habitat and watershed comes before supplemental or contributing projects. We used to use IAM but it was pretty useless. BC analysis is only one of many factors to be considered in prioritizing projects
UT1	Our price file has not been updated in a long time. We use the model but don't like it , don't believe in it , but we use it for the file.

Summary of E-Mail and Telephone Survey Findings

The majority of BLM range personnel do not use the IAM model for evaluating rangeland development projects despite the fact that this is the only resource investment analysis model available to them. Of 100 responses only 16 reported use of the IAM model in their office.

Of 14 offices contacted reporting use of the IAM model only 4 gave generally positive responses as to the usefulness of the model. Nine gave generally negative responses, and one gave a neutral response.

A telephone survey of users showed that investment analysis is not considered useful in evaluating or prioritizing range projects. More use of it is made for project justification.

Informal discussions with US Forest Service personnel in Region 3 provide support for these findings. FSH-2209.11 is the USFS equivalent of BLM's IAM model.

4. How appropriate are the analytical methods to the task?

Method

An analysis was conducted of the IAM model.

The IAM model contains categories of costs and benefits. Costs reflect estimates of the present value of potential monetary expenditures for installations and maintenance. For example, the cost of installation and maintenance of a water tank. Benefits represent estimates of the present value of projected consumed or use related products. For example, cords of firewood or hunter days.

Discounting factors were standardized allowing the calculation of net present values from income streams such as a flow of maintenance costs or hunter days over a given length of time.
A list of costs and benefits used in the IAM model appears below followed by a list of values used for the year 1990.

COSTS

Reported in Dollars

STRUCTURAL PROJECTS
Springs
Reservoirs
Wells
Pipelines
Fences
Cattle guards
Water Control
Instream-Structures
Steambank-Improvements
Dens/Nests

NONSTRUCTURAL PROJECTS
Mech. Control
Chem. Control
Burning
Seeding (drill)
Watershed Till.
Wetlands Rip. Imp

BENEFITS

LIVESTOCK FORAGE
Reported in livestock AUM's

RECREATION USE

Reported in Hunting Days
Deer
Elk
Antelope
Other Big Game
Water Fowl
Upland & Small Game

Reported in Angler Days
Warm Water
Cold Water

Reported in Rec. Days
Devlpd. Site
Dispersed Use
WL View/Photo
Trapping

OTHER OUTPUTS

Soil/Water Damage
Soil Retention
Silt Reduction
Flood Damage

ANNUAL PRICE FILE
(Example dated 1990)

Cooperator Work Days-$77.10
BLM Work Days-$144.90
AUM-$8.70

Hunting Days
Deer-$40.70
Elk-$40.70
Antelope-$40.70
Other Big Game-$40.70
Waterfowl-$53.42
Upland and Small Game-$53.42

Angler Days
Warm Water-$32.89
Cold Water-$30.06

Recreation Days
Developed Site-$5.72
Dispersed Use-$10.50
Nongame Wildlife-$55.35

Model Findings

Installation and maintenance costs appeared to be completely accounted for.

Benefits were measured incompletely and indirectly and constituted a derivative of the actual value of an "improvement". For example improvement of riparian habitat, listed as a cost (see above), could only be measured in terms of AUMs, hunter days, angler days, or recreation days. No systematic method for measuring direct long term values of enhanced habitat was explained or evident.

Non-monetized costs (negative benefits) were not accounted for. As for example the loss of native vegetation if non-native species of grass is planted.

Costs and benefits were measured from a project or allotment perspective. No attempt to account for the effects of rangeland development from a broader perspective was evident. A range development may be potentially beneficial at the allotment level but disastrous at the watershed level.

No clear method was described for accurately determining local natural resource values. Discussions with BLM economists suggest that no such data is available. Hunting, fishing and recreation values are generally national values of dubious origin. The use of consumer price indexing with no consideration of location is what is meant by updating natural resource values.

No justification or rationale is evident for the use of discounting in determining net present values of cost or benefit streams. For example. Is future habitat really less valuable then present habitat and if so why and how much?

5. Are there recommendations that can be made?

Recommendations

1. Cost/benefit analysis should not be used as decision criterion. It should be used as information to help guide a decision making process.

2. Both costs and benefits should be measured with an ecosystem orientation in terms of the largest rational scale. For example the watershed as opposed to the project or allotment. A project that enhances an allotment may devastate a watershed.

3. To be valid benefits must be quantified in terms of their total value not only in terms of their monetizeable consumptive uses.

4. If accurate estimates of local resource values are unavailable admit it. Unjustifiable values should never be used.

5. Discounting values the present over the future. Unless you believe that present habitat is more valuable than future habitat don't apply a discount rate.

6. Equitable distribution of costs and benefits is important. Determine who pays the costs and who gets the benefits.

7. Cost/benefit analysis answers the question: What is the total value of the benefits when compared to the total value of the costs? Don't use cost/benefit analysis if you can't accurately estimate both sides of the equation.

8. If total project costs & benefits can't be measured and or monetized where possible estimate the costs and benefits of specific tradeoffs.

9. If only the costs can be accurately estimated, break even analysis is indicated. Break even analysis answers the question: How much will we have to pay for these benefits?

10: Use the education, intuition, experience, and wisdom of a non-conflicted multi-disciplinary team to answer the following questions:

Are the unmeasurable costs worth the unmeasurable benefits?

Is this project really good for the ecosystem, and will it result in an increase in natural capital?

The Case of the Spikedace (Meda fugida)

The Spikedace is a threatened species of short-lived minnow that lives in the upper Verde River. They usually grow to around 40mm in length and seldom live longer than four years. The Spikedace has evolved and adapted under conditions of periodic drought and extreme flood events. Disagreement exists as to the cause(s) of declining Spikedace populations and what should be done about it. Speculation about the causes of Spikedace habitat degradation include impoundment construction, de-watering of streams for irrigation, and groundwater mining. In addition, the introduction of non-native fishes has affected the species through predation and competition for food and habitat. Last (but apparently not least since efforts are invariably focused almost to the virtual exclusion of all other potential causes) livestock grazing has been implicated in the decline of Spikedace habitats and populations through stream bank deterioration (Near et al., 1996).

One option that has been suggested is the exclusion of livestock from along the river. Doing so would require the construction of many miles of fence along both sides of the river at a cost of approximately $6,000/mile of fence ($12,000/mile of river) depriving the livestock of their principle source of water. This option would subsequently require the development of alternative water sources. Putting in wells, pumps, tanks, and pipeline could quickly become expensive. Maintenance costs associated with each of these structures is significant and long-term. There is also the opportunity cost of lost carrying capacity in the excluded area. These costs are readily quantified. But what of the benefits?

The literature provides no evidence that clearly demonstrates a positive response in Spikedace populations as a result of these actions. Let's ignore this rather disturbing obstacle for the moment and assume we could predict and quantify a positive result on Spikedace populations. What is its value? How much does society value a potential increase of, say, five percent in Spikedace populations? Are the costs described above justified? Would the costs be justified if the cattle growers share put them out of business? What if significant money were spent, ranchers ultimately put out of business resulting in displaced families and no increase in the Spikedace population occurred?

Non-native sport fish constitute another potential cause of Spikedace habitat degradation and population decline. The State of Arizona invests significant funds in hatchery and stocking programs for non-native sport fish on the Verde River. At the same time, we are faced with the increasing loss of native fish and legal mandates of the Endangered Species Act (SEA). Is it rational to fund the stocking of non- native predatory fish, then fund barriers to their movement for the postulated protection of TES native fish species in the same stream (Beschta et al., 1994; Baker and Medina, 1997)? What if it were determined that sustaining the Spikedace requires the elimination of non native predatory fish and, in turn, the accompanying recreational fishing? Is society willing to forego recreational fishing on the Verde?

Neary and Rinne (1997) suggest that the greatest potential threat to base flows and, therefore, the entire upper Verde River system, is groundwater mining associated with rapid urban growth in Prescott and the Chino Valley. One need only look as far as the Gila and Salt "Rivers" in Maricopa County or the Santa Cruz "River" in Pima County to see the destructive effects of urban growth and groundwater withdrawal on our Southwestern desert streams. Thus, even if all the non-native fish, destructive recreational activities, cows, and cowboys are eliminated we may destroy the Verde River, and the Spikedace.

This example illustrates that the question to be answered in evaluating rangeland water developments goes beyond the simplistic: What are the costs and benefits of a given treatment. Rather the question to be answered is: What are the costs and benefits considering the whole biophysical and socioeconomic ecosystem, how are they related, and what is their distribution? A narrow single- species/treatment approach to riparian restoration which does not take a holistic, systems perspective is likely to fail to achieve the desired outcome. The probability of restoring habitats and species are greatly increased by shifting the focus to the integrity of the entire system. The entire system includes human beings.

It should be evident that many of the costs and benefits (values) involved in social choices and decisions do not lend themselves to easy measurement and quantification. Many (if not most) of the basic and essential values are likely to fall outside the realm of monetary accounting. Riparian restoration and sustainability may be such a value. Economics is the science and study of value, and need not be restricted to money alone (Peterson and Brown, 1996).

Rather than bemoan the human influence on the biophysical ecosystem, we are best served by dealing with it by adopting a systems view that goes beyond the narrow boundaries of academic disciplines. Humans are embedded in nature and human values are an integral part of any consideration of restoration and sustainability. The way in which resources and our environment are managed has and will continue to depend on our values.

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How Does Livestock Grazing Fit Into the Larger Societal Uses of Wildlands? Methods for Determining Benefits and Their Application To The Kaibab Plateau.

Jon A. Souder[1]

Abstract – Long before decisions about individual rangeland water developments are made, it is useful to consider the role of domestic livestock within the larger societal benefits received from wildlands. Yet determining societal benefits has often been considered too complex for individual allotments or ecosystem management areas. However, there is typically information available to provide gross estimates of public benefits received from grazing, hunting, and dispersed recreation, three common direct societal uses. Using an example from the Kaibab Plateau of Northern Arizona, this paper will explain how readily available information such as surveys and agricultural statistics can be used to determine benefits, what additional types information need to be collected to conduct analyses, and finally, how to apportion benefits among the direct recipients, the local community, and the larger region, state and nation.

INTRODUCTION

Long before decisions about individual rangeland water developments are made, it is useful to consider the role of domestic livestock within the larger societal benefits received from wildlands. The purpose of this study is to initiate the incorporation of considerations of the benefits that society receives from wildlands into decisions that are made about their management. Too often, resource managers have been resistant to using economic valuation information, often because they feel that determining societal benefits is too complex for individual allotments or ecosystem management areas, that the quality of the information limits its effectiveness, or that decisions should not be made on the basis of economics, or a combination of these reasons. It is my intent in this study to show that readily available information can provide an indication of the relative values associated with various uses of wildlands, and that this information—while not perfect—is at least comparable in quality to the quality of other types of data relied upon to make decisions. The process used for the valuation in this study is based on a systems approach that looks at the quantity and quality of resources that provide public benefits, attempts to place a value on the yield of these resources, and by implication, provides evidence of effective ways to gain additional benefits. Through the process of constructing this valuation, the limitations of available data became apparent, which has an additional benefit of indicating what information could be collected to improve the economic justification for resource management decisions.

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[1] Assistant professor of natural resources policy and economics, College of Ecosystem Science and Management, Northern Arizona University. The opinions found in the paper are solely the author's and do not necessarily represent those of the U.S. Forest Service who provided partial financial support and cooperation for this study.

This valuation analysis uses the Central Winter Ecosystem Management Area (CWEMA) of the North Kaibab Ranger District, Kaibab National Forest, as an example. The Kaibab Plateau, where the CWEMA is located, is unique in serving as the northern gateway to the North Rim of the Grand Canyon National Park, of having one of the best—if not the premier—mule deer population in Arizona and the southwest, and having traditionally provided support to surrounding local communities through recreation (including hunting), forage for livestock, and fuelwood for personal use. As times have changed, society's demands for services from the Central Winter EMA have also changed. This report illustrates how the relative balances of uses of the CWEMA have changed from the traditional focus on commodities to greater recent benefits from non-consumptive uses. Various uses of the area that provide value to humans are identified and estimates of the demand for these uses, and their uniqueness in the CWEMA are made. The resulting demand, uniqueness and values are intended to illustrate potential tradeoffs that occur in making choices among alternative courses of action.

Two broad categories of human uses occur in the Central Winter EMA and will be analyzed. The first are called "non-consumptive" uses, which mean that the object of enjoyment is not consumed by the user, but remain available to others. Dispersed recreational use is considered non-consumptive in this discussion. Typical examples of these non-consumptive uses are auto touring, sightseeing from viewpoints, nature study and viewing wildlife. Non-consumptive uses, while generally jointly available to others, can be adversely affected by crowding and resource degradation may be caused by overuse.

The second category of human use are those activities that "consume" resources. In these activities, one person's use generally precludes another person from obtaining the same benefit. For example, if a deer is harvested by one hunter, that deer is not available to another hunter; or if livestock eat forage, that plant material is not available for other species' use. Examples of consumptive uses in the CWEMA that will be evaluated are hunting, livestock grazing, and fuelwood gathering.

METHODS

A variety of mechanisms are available to determine the values that people place on the various human uses in the Central Winter EMA. If uses are sold in the open market, the price that people are willing to pay for a use provides the surest indication of the demand for, and the value placed, on that use. However, most uses on public lands are not sold competitively in the open market. As a result, other methods of determining demand and value are needed. One way to indirectly estimate values is to determine how much people spend to partake in an activity. Expenditures are commonly divided into fixed costs—such as the costs to purchase necessary equipment and travel to the location—and variable costs, such as food, etc., that reflect the amount of time spent in an activity. A third way to determine value is to ask people what they are willing-to-pay to have specific uses available, or conversely willing-to-accept to allow removal. This mechanism—called contingent valuation—is commonly used to determine non-market values.

The principal valuation mechanism used for the analyses in this section is transactions evidence of user expenditures as determined by surveys. Two primary surveys provide the source material for the non-consumptive uses and hunting values. The 1991 National Survey of Fishing, Hunting, and Wildlife Related Recreation (U.S.D.I., U.S.D.C., 1993) contains Arizona-specific participation and expenditure information. The results from this survey are used to characterize state-wide recreational uses and per-day state-wide expenditure information for non-consumptive recreation and hunting. The second survey was conducted by Dr. Martha Lee and others in 1992 for two Districts in the Kaibab National Forest (Lee et al., 1993, 1994). In this survey, visitors to the North Kaibab Ranger District were interviewed about the size of their group, where they were from, and the number of days they stayed in the area. Interviewees were provided with a mail-back written survey that requested information on the various types of activities that they participated in, where—and for how long—in the North Kaibab they visited, and how much they spent in the local area. In addition, Lee et al. specifically targeted deer hunters in a supplementary survey to determine how they used the North Kaibab Ranger District.

The demand for the various uses is an important component of the valuation process. One way to characterize demand is to look at the level of past uses in an area to project future uses. So if use of an area or resource has increased at an annual rate of 3% over the past ten years, it is not too extreme to expect that in the near-term equivalent increases will occur. However, the accuracy of projecting future uses from past trends is lower as the time horizon increases, or as the carrying capacity is reached. Future demand for non-consumptive recreational uses will use a trend projection technique (Rowlands, 1993) in combination with the visitor use information in Lee et al. (1993, 1994). For commodities that are marketed, demand is also indicated by the relative profitability of the enterprise. This technique will be used to characterize the demand for the products of livestock grazing.

A second way is to think that demand is an indicator of the uniqueness of a specific use in the CWEMA, compared to the availability of that use elsewhere. Uniqueness can be determined by examining the origin of visitors (i.e., how many are from out-of-state or from foreign countries), using the assumption that the further that someone travels indicates the uniqueness of a specific use or site. Uniqueness can also be determined—where the supply or availability is limited—by identifying the number of people who desire to use a resource compared to the amount available. Economists call this "excess demand", and it is again an indicator of the uniqueness of the resource if there are more people desiring it than can be accommodated. In a number of cases, there is an excess demand for resources throughout the region, state or nation. If the available quantity is fixed (so that prices do not rise to reduce demand), then the level of excess demand in one location relative to others is an indication of uniqueness. This characterization of uniqueness will be used for hunting opportunities in the CWEMA compared to other areas of the state, with the ratio of demand versus supply for the various hunts throughout the state ranked. Those hunts where excess demand is greatest are necessarily more unique than those where demand is less.

The data used for the valuation is from pre-existing studies; no original material was collected for this study. The data quality reflects the original purposes for which it was collected,

but its accuracy is generally within the range of acceptability for the purposes of the CWEMA. The geographic area covered by a number of studies is larger than the CWEMA; in these cases the studies' results have been interpreted and adjusted to reflect the conditions in the CWEMA. This has been done through consultation with the originators of the studies and the CWEMA Interdisciplinary Team. All monetary values are adjusted for inflation, and reported in 1996 dollars.

The valuation section is organized by major resource use, and within each resource part existing uses, the demand and uniqueness of the resource, and estimated values are discussed. First, non-consumptive recreation will be discussed. The second part discusses hunting use in the CWEMA, focusing on mule deer and Merriam's turkey. The third part evaluates the benefits of livestock grazing in the Central Winter EMA. This discussion is followed by an estimate of the economic values resulting from fuelwood gathering and timber harvests in the CWEMA. A final, concluding section summarizes the valuation information to provide the framework for discussing potential trade-offs and joint benefits among the various resources valued by humans in the Central Winter EMA.

RESULTS

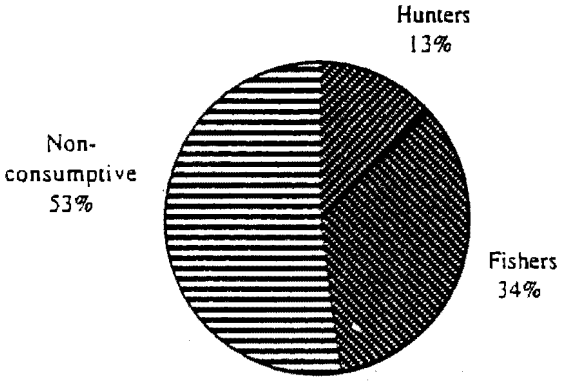
I. Non-consumptive Recreation

Because of its location adjacent to the North Rim of the Grand Canyon National Park, its close proximity to other National Parks and Monuments in southern Utah—the "Golden Circle"—and its comparatively pristine nature, the North Kaibab Ranger District receives high visitor use, both from state residents, from across the nation, and from throughout the world. The characteristics of this visitation can first be ascertained by looking at recreational uses, and values, in the state of Arizona. The analysis will then proceed by examining patterns in the recreational use of the North Kaibab Ranger District, and finally estimate values for an area that contains the Central Winter EMA.

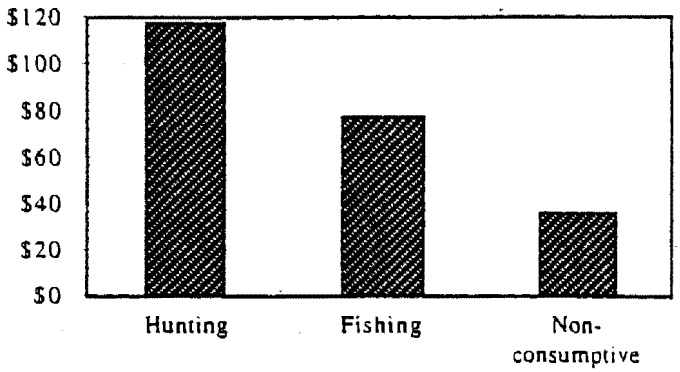
A. Overview of Recreation in Arizona

Recreation is immensely important for both residents and visitors to Arizona. Popular activities include not only hunting and fishing, but also a variety of non-consumptive recreation uses. Recreational usage on a state-wide basis can be described in terms of the number of people participating, what they do, how long and how much money they spend on their trips, and whether or not they are residents or visitors. State-wide information on wildlife-related recreation is available in the 1991 *National Survey of Fishing, Hunting, and Wildlife-Associated Recreation* (U.S.D.I., U.S.D.C., 1993).

Wildlife-related Recreation in Arizona



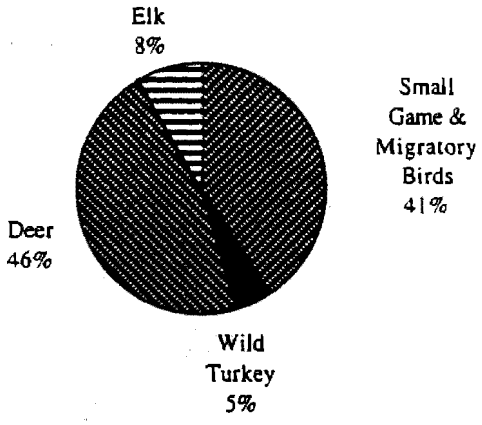
Arizona Recreational Expenditures
(1996 Dollars Per Day of Activity)



Fifty-three percent of Arizona residents and visitors reported in the *1991 Survey* that they primarily engaged in non-consumptive wildlife-related recreation: feeding, photographing, and/or observing wildlife in their trips outside of their home community (defined as greater than 1 mile from their residence). Consumptive wildlife-related recreation was primarily fishing (34% of respondents), with hunting being a distant third (13% of respondents).

However, the amount that people expend to engage in recreation is related to the type of activity. Hunters tend to spend proportionately greater amounts per day of activity than either anglers or non-consumptive recreationists. Expenditures are generally the amount paid to travel and stay at an activity site, and oftentimes also include equipment costs and fees. Nonresidents not only have the added expense of more travel costs in order to reach their destination, but also the higher charges for permits if they hunt or fish.

Hunting in Arizona
(Proportion by Number of Hunters)

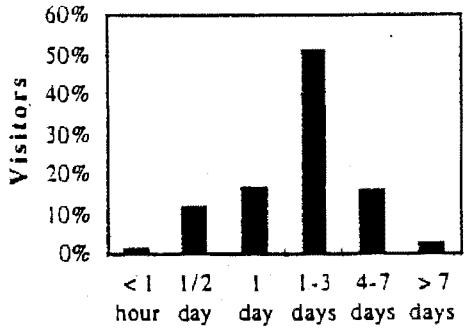


Hunting opportunities in Arizona exist for a number of different species. By far the most hunting occurs for deer (46% of hunters hunt deer). Small game and migratory birds provide another forty percent of hunting in the state. Elk (8%) and wild turkey (5%) provide the remainder of hunting recreational use.

1. North Kaibab Ranger District Recreational Use

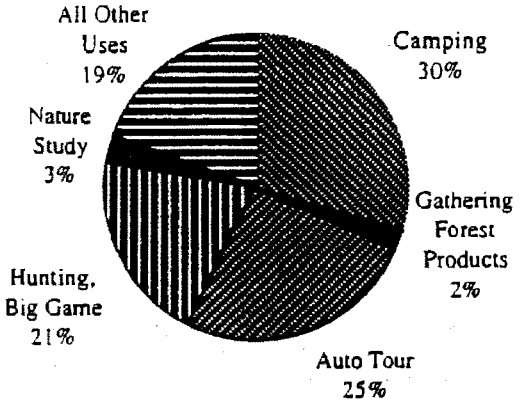
Use. Lee et al.'s (1994) study estimated that there were 533,525 visitors to the North Kaibab/North Rim GCNP in 1992. Of these visitors, 70% visit both the National Park and the National Forest, while 12% visit only the Forest. The majority of visitors spend from 1 - 3 days in the area.

Length of Visit to N.K.R.D.



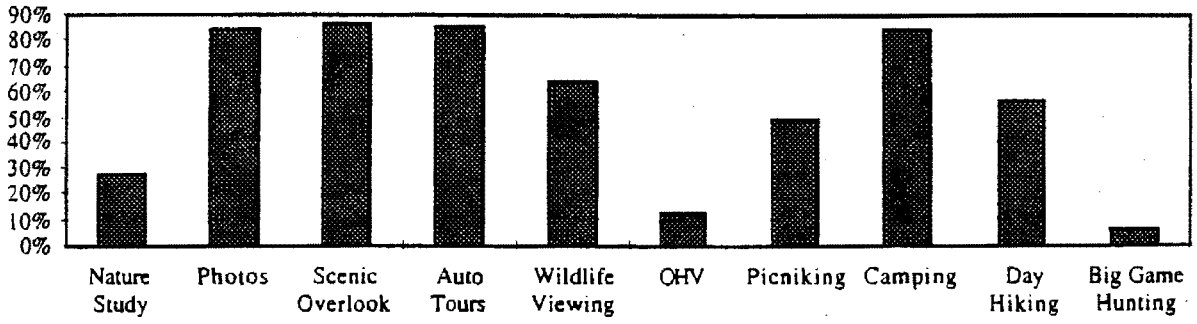
Two sources of information are available on recreational uses in the North Kaibab Ranger District. The first is the statistics collected by the Forest Service, called the RIM database. It is apparent from examining the database that consistency in data collection makes comparing year-to-year recreational use difficult, if not impossible. Nonetheless, the figure at right takes the median of reported recreational uses for the period 1988 - 1996 (excluding 1992), to provide an indication of the various types of recreational activities occurring in the North Kaibab Ranger District. Auto touring, camping and big game hunting are the three most common recreational activities, comprising over 75% of use in the District.

Major Recreational Uses on the North Kaibab Ranger District
(Median % of RVD's, 1988–1996)



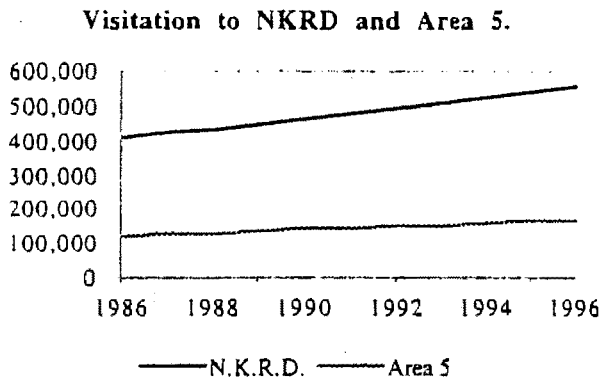
The second source of information on recreational uses of the North Kaibab Ranger District comes from the Lee et al. (1993) survey and accompanying reports. Lee et al.'s use categories differ from those contained in the RIM database. Additionally, rather than apportioning visitation to various uses, as the RIM reports do, Lee et al. (1993) asked survey respondents to check from a list which activities they participated in. The survey results indicate that most visitors

Visitor Activities in N.K.R.D. (Lee et. al., 1993a)



to the North Kaibab Ranger District camp—either in dispersed (19%), tents (39%) or in RV's (26%), and most drive through the Forest to scenic overlooks where they take pictures and watch wildlife. Compared to the RIM's data, the 1992 Survey showed higher rates of participation in nature study (28% compared to 3%) and lower rates of big game hunting (6.5% compared to 21%).

Demand. Rowlands (1993) projects increased visitation to the North Rim of the Grand Canyon National Park of just over 3% per year based on visitation over the period 1986 - 1996.



The uniqueness of the North Kaibab Ranger District and the North Rim of the Grand Canyon National Park is indicated by the percentage of visitors from foreign countries, 10%, and the percentage of visitors from states other than Arizona and Utah, 70% (Lee et al., 1993). Only 11% of the visitors were from within 150 miles of Jacob Lake (Lee et al., 1993).

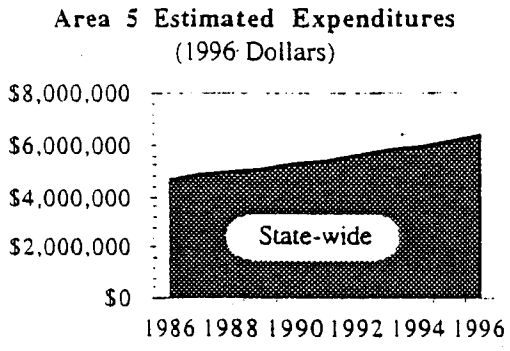
Value. Lee et al.'s (1994) study determined that visitors spent an average of $276.84 in the local area during visits to the North Kaibab/North Rim GCNP. In 1996 dollars, this would be about $313 per trip.

2. Central Winter EMA Recreational Use

Visitor use statistics are not collected separately for the Central Winter EMA. The closest proxy for this information is data reported in Lee et al. (1992) surveys for the North Kaibab Ranger District. Lee et al.'s Area 5 corresponds to the portion of the North Kaibab Ranger District lying to the west and outside the travel zone of State Highway 67, from Jacob Lake to Grand Canyon National Park, and south, and outside the travel zone, of U.S. Highway 89A from Jacob Lake to Fredonia.

Uses. Of those visiting the Forest or Park, 69% never went west of State Rt. 67 or U.S. 89A into Area 5. The 31% who did go into Area 5 spent an average of 26 hours there. Converting this to recreation days, this would approximate 179,800 visitor days, with the vast majority of this being non-consumptive (wildlife viewing, auto tours, etc.).

Value. Lee et al.'s (1994) study concluded that visitors spent an average of $276.84 in the local area during visits to the North Kaibab/North Rim GCNP. The value of this from the 1991 National Fish, Wildlife and Non-consumptive Wildlife Use is $36.77 per day (1996 dollars), which translates to about $6.4 million in 1996. The figure at right shows estimated expenditures for the period from 1986 to 1996.



II. Hunting

Hunting opportunities exist for mule deer, Merriam's turkey, blue grouse, Rocky Mountain bighorn sheep, and a number of other game birds and small mammals. In this valuation, the focus will be on mule deer and turkey, because that is where the bulk of the demand and value exists. The basic data source for the use and demand sections is the Arizona Game and Fish Department's "Hunt Statistics" database for the years 1986 - 1996. Use statistics were derived from the number of hunters and hunt-days in Game Unit 12A for turkey and archery mule deer hunts, and Unit 12A West for firearm mule deer hunts.

With the exception of archery hunts, big game hunt tags are allocated through a lottery system. Applicants submit their first, second, etc. choices for particular hunts (i.e., geographic area and time within the season), which are then randomly drawn in a lottery. Hunting demand, and the uniqueness of the Central Winter EMA, was determined in two ways. First, the number of first and second requests for a particular hunt where added and then divided by the number of available permits for that particular hunt. This provides an indication of the demand for that hunt relative to the supply of available permits. An excess demand for that hunt exists if the ratio of choices to permits is greater than one; while there is a surplus of permits if the ratio is less than one. The higher the ratio the greater the excess demand.

Hunter value information is derived from two sources: (1) the *1991 National Survey of Fishing, Hunting, and Non-consumptive Wildlife* (NSFHW, U.S.D.I.-U.S.D.C., 1993), and (2) Lee et al.'s 1992 survey of deer hunters on the North Kaibab Ranger District (Lee et al., 1993, 1994). The 1991 National Survey of Fishing, Hunting, and Wildlife Associated Recreation reports expenditures on a per-person, per-day basis state-wide. In contrast, the *1992 Lee Survey* asked respondents how much they spent in the local area on a per-trip basis. In both the following sections, regional expenditures are calculated by multiplying the number of hunters by Lee et al.'s per-trip figure ($297.64/trip in 1996 dollars). State-wide expenditures are calculated by taking the 1991 NSFHW per day value ($117.61/day in 1996 dollars), multiplying by the number of hunter days, and then subtracting the amount determined to be the regional expenditures.

A. Mule Deer Hunting in the CWEMA

Significance of the Kaibab mule deer population has been recognized since the 1900s, culminating with the establishment of the Grand Canyon Game Preserve in 1906. This mule deer population has been one of the most intensely studied, certainly in Arizona if not in the Colorado Plateau as a whole (Russo, 1964, Haywood et al., 1987; McCullock and Smith, 1991). Because of these studies, it is possible to provide comparatively detailed information on the herd's population dynamics, mule deer use of the Central Winter EMA, and hunting use and values.

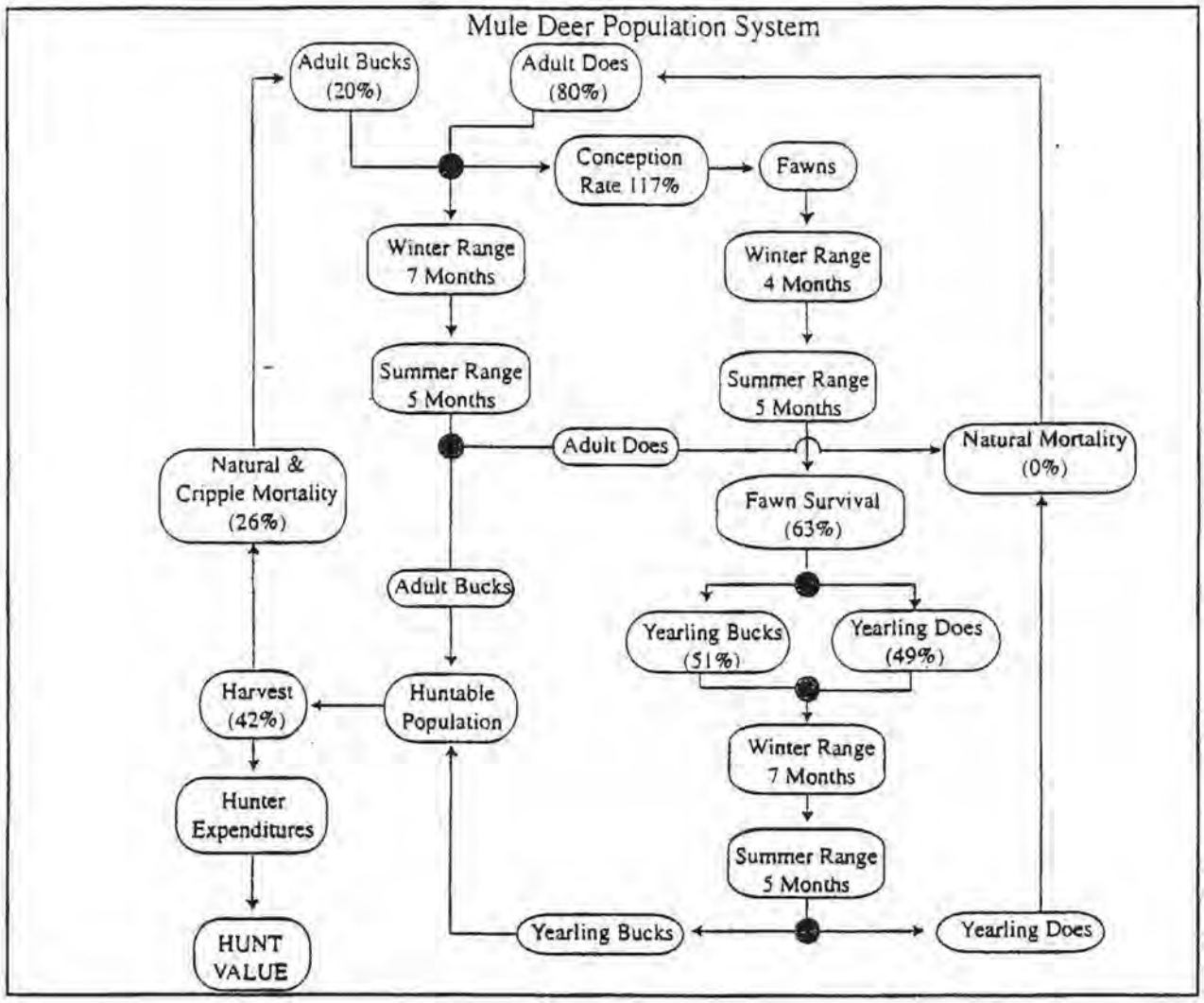
1. Mule Deer Populations on the Central Winter EMA.

The figure below shows a systems diagram representing how the inter-relationships among the components of the mule deer herd. The following two tables provide the data used to describe the population characteristics of the mule deer herd in the Central Winter EMA. The herd is comprised of bucks (males) and does (females), both adults (over two years of age) and yearlings (between one and two years old), and fawns (the young less than one year old. Due to hunting pressure, the ratio of bucks to does is relatively small, on average there are four adult does for every adult buck. This imbalance in sex ratios is not evident in the yearling animals, where bucks and does are relatively balanced. Adult does (usually reproductive at about two and a half years) generally have an average of more than one fawn, hence the conception rate is greater than one. Natural mortality is high for fawns, with only about 63% surviving to be one year old. Survival rates for yearlings are difficult to easily determine from available statistics, because the surviving yearlings go into the adult population comprised of multi-age classes. Because most yearling bucks have antlers, they are susceptible to hunting pressure the same as the adult bucks. Hunting mortality for these bucks averages about 42%, ranging from 39% to 49% depending upon the year. In addition to hunting mortality, bucks also suffer from cripple mortality (Russo, 1964) when they are wounded (or left as unsuitable), as well as natural mortality from severe winters and predation. For bucks, non-hunting mortality averages about 26% of their population, but can range from a low of 15% to a high of 46%. Doe mortality is basically from natural sources: birthing, predation, and winter stress. It averages less than 1% (the negative figure in the table probably represents survey error), to a high of about 7%. Because in recent years (since 1991), only antlered hunts have been permitted, the population available for harvest is represented by bucks and yearling bucks, although periodically the Game & Fish Commission authorizes antlerless hunts to reduce population levels and bring the buck:doe sex ratios up.

Population dynamics of the Unit 12A WEST mule deer herd.

Component	Median	Low Range	High Range
Adult Buck:Doe Ratio	0.25	0.22	0.40
Yearling Buck:Doe Ratio	1.03	0.94	1.05
Fawns:Doe	1.17	1.03	1.70
Buck Harvest Percentage	42%	39%	49%
Doe Natural Mortality	-1%	-2%	7%
Buck Mortality (Natural + Cripple)	26%	15%	46%

Source: Population data from the table below, using techniques in Russo (1964).



Population estimates for the Unit 12A West mule deer herd were provided by the Arizona Game and Fish Department. These are displayed below for the period 1986 – 1996. The entire mule deer population shown in the above table ultimately produces the huntable animals through the process described in the flowchart. It is these huntable animals that draw hunters to the North Kaibab and the Central Winter EMA. Both the mule deer population, and hunting activities, occur in an area greater than the CWEMA, but because the mule deer herd uses the CWEMA for its wintering grounds, and the late-season hunts typically occur within the CWEMA, it is reasonable to apportion the hunting benefits received according to the proportion of time that the herd spends on the winter range.

Estimates of mule deer populations and harvests, Unit 12A West, 1986–1996.

Year	Pre-hunt Population					Harvest	Post-hunt Population			
	Yearling Bucks	Bucks	Does	Yearling Does	Total		Bucks	Does	Fawns	Total
1986	2,206	1,383	6,054	2,206	11,848	3,135	1,352	7,510	5,557	14,418
1987	1,662	1,986	5,626	1,662	10,936	2,792	1,612	6,449	4,321	12,382
1988	1,529	1,863	5,427	1,631	10,450	2,164	2,038	6,175	3,952	12,165
1989	1,136	1,963	4,946	1,136	9,181	3,226	1,682	6,008	3,064	10,754
1990	912	1,819	4,559	897	8,188	3,581	749	4,407	2,688	7,845
1991	837	1,126	3,364	813	6,140	764	1,014	4,225	2,704	7,944
1992	999	972	3,337	973	6,281	804	961	4,368	2,883	8,211
1993	1,075	943	3,402	1,019	6,439	928	643	4,504	2,896	8,043
1994	1,018	871	3,483	966	6,338	856	677	4,514	2,663	7,854
1995	832	781	3,505	856	5,974	698	768	4,042	3,395	8,204
1996	1,066	867	3,685	1,066	6,683	797	757	4,453	3,073	8,283

Source: Population estimates provided by Mr. Todd Buck, Arizona Game & Fish Department, Fredonia, AZ., 8/1/97.
Harvest data provided by Arizona Game & Fish Department, Game Management Branch, Phoenix, AZ.

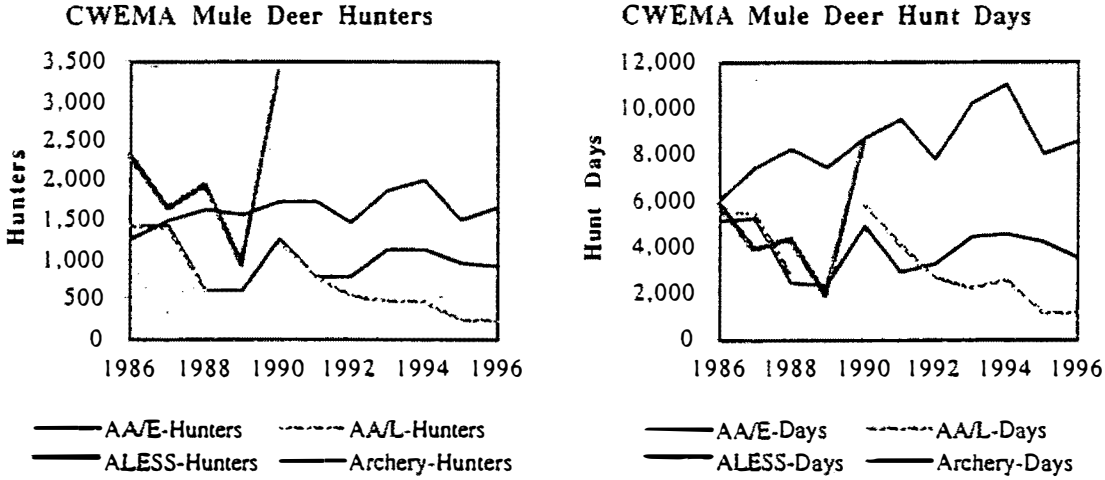
The mule deer population requires forage for its food. A commonly accepted way to measure forage use by mule deer is to convert their consumption to Animal Unit Months (AUMs). Because AUMs are also used to account for livestock forage use, it is possible to compare—and allocate—forage use between mule deer and livestock. Five mule deer are considered to be the equivalent of one Animal Unit (AU). It is possible to determine the mule deer's forage consumption by using the population figures in the above table. The following assumptions are required to estimate mule deer forage use in the CWEMA:

(1) Five adult or yearling mule deer comprise one Animal Unit (i.e., fawns are treated like calves in the calculation of forage use);
(2) The Unit 12A WEST herd spends 6 months from May to October on its summer range (including migration time), and 6 months from November through April on its winter range (including migration time) (Haywood et al., 1987);
(3) The average date of hunts is November 1;
(4) Thus, the "Pre-hunt" population is on the CWEMA for 4 months (January through April), and the "Post-hunt" population is on the CWEMA for 2 months (November and December).

Using the assumptions described above, over the last five years the Unit 12A WEST mule deer herd is estimated to have consumed an average of 13,777 AUMs of forage, of which 7,130 AUMs were located on the Central Winter EMA. The bulk of the remaining forage for this herd is provided by the Central Summer Allotment. These 7,130 AUMs of forage are considered to provide the sustenance that the Unit 12A WEST herd requires to produce the mule deer that are sought by hunters in the CWEMA.

2. Deer Hunter Use and Values in the CWEMA

Hunter Use. Four different mule deer hunts occur in Game Unit 12A WEST. Depending upon the weather, hunters during the late season hunts are likely to be physically present in the CWEMA, while those hunting earlier will be at higher elevations, but are seeking mule deer that require winter range in the CWEMA. Firearm hunts are divided into early (AA/E) and late season (AA/L) for antlered deer. Periodically, there are also antlerless (does and fawn) hunts (ALESS) to



reduce herd numbers. The anterless hunts typically occurred in late October when the herd was on its summer range. However, two of the antlerless hunts during the last time they were offered (1990) occurred during the first half of November when the herd was probably migrating from it summer to wintering grounds.

With the exception of archery hunts, mule deer tag numbers are set by the Arizona Game Commission based on recommendations from the Arizona Game and Fish Department (AG&FD). The AG&FD bases their hunt tag recommendations on the population size and hunter success. The Department also recommends antlerless hunts when population levels exceed what they consider to be the habitat's carrying capacity.

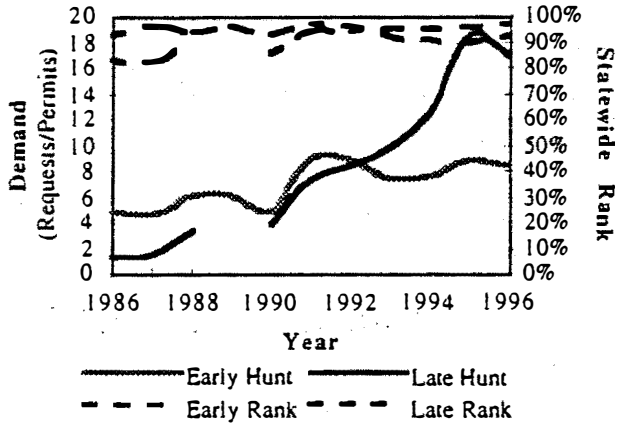
The number of mule deer tags available for firearm hunts for antlered deer has been between 1,250 and 1,650 for the early and late hunts over the past six years. Tags in recent years have been reduced from levels of about 3,000 per year for antlered deer that were seen in the late 1980's. Deer populations were also reduced in the late 1980's and in 1990 through high levels of antlerless deer tags: 11,100 were sold over the period 1986 - 1990, ranging from 1,000 in 1989 to 3,700 in 1990. Since 1990 no antlerless deer tags have been sold. In contrast to the recent reduction in firearm mule deer tags, the number of archery hunters has increased on the Kaibab Plateau.

The AG&FD only reports archery hunters and hunt days on a Unit 12A basis, but McCulloch and Smith's (1991) research that shows that 60% of the Kaibab Deer Herd winters in the CWEMA. Thus the AG&FD's archery hunt data has been adjusted to account for this 60%:

this means that an additional 1,500 to 2,000 archery hunters are afield annually in Unit 12A WEST. And the trend in archery hunting use of the CWEMA's mule deer herd is increasing as the number of tags for firearm mule deer have decreased.

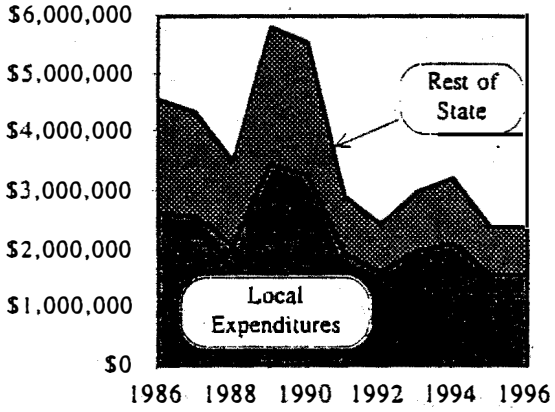
Demand. The reduction in mule deer firearm tags has coincided with increased demand for these tags statewide. Demand for the early hunt tags has been around eight times the available supply over the past five-years, while demand for the late hunt—which takes place in the pinyon-juniper and typically produces higher numbers of trophy deer—has exceeded the number of available permits by over sixteen times in the last three years. On a state-wide basis, these two hunts rank in the top 10% of demand, with the late one generally being in the top three most demanded hunts in the state. And the Unit 12A WEST firearm hunts allow at least as many tags as the total number of higher-ranked hunts, testifying both to the uniqueness and the productivity of the Kaibab mule deer herd.

Deer Hunting Demand in CWEMA



Value. The value of hunting in the CWEMA can be determined from the number of hunters, and the number of days that they spend hunting the Unit 12A WEST mule deer herd. We know from statistics compiled by the Arizona Game & Fish Department that over the last five years an average of 3,150 tags for all hunts on Unit 12A WEST (including pro-rated archery tags). These hunters generated an annual average of 3,079 trips for an average of 15,145 days for each year.

Value of Deer Hunting in CWEMA
(1996 Dollars)

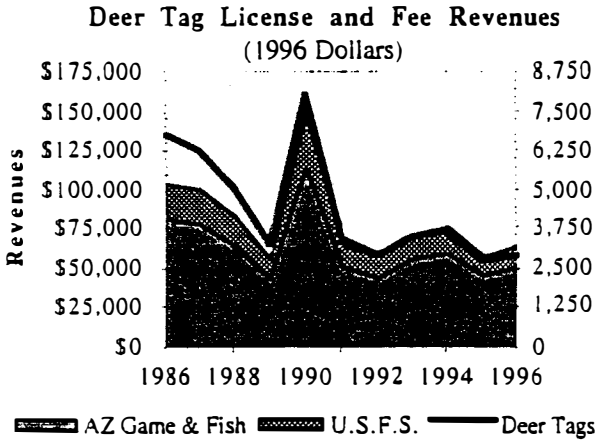


The figure at right shows the values received from this hunting, both for expenditures in the local area ($297.64/trip; Lee et al., 1993, 1994), and statewide ($117.61/day; NSFHW, 1993). The five year average value for the Unit 12A WEST mule deer hunts is estimated to be $1,783,000 (1996 dollars), divided 51% for expenditures in the local, North Kaibab area, and 49% for the rest of the state (or nation).

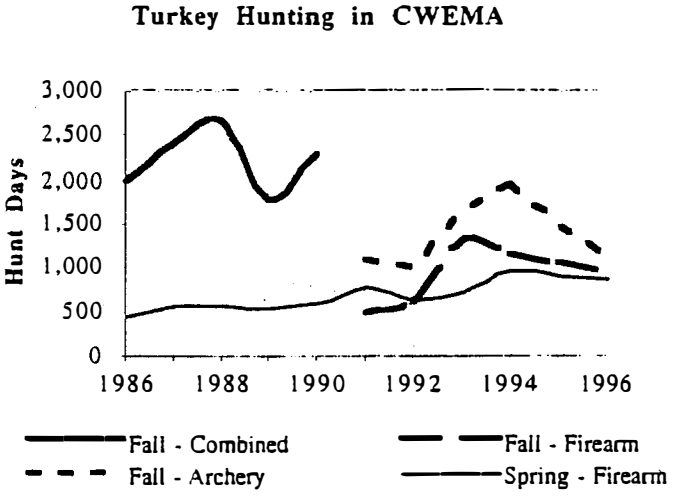
The value of the forage consumed by the Unit 12A WEST mule deer herd can be imputed by combining the valuation information from above with the forage consumption information

provided earlier. Assume that the average mule deer hunting value is about $1,800,000 per year, and the deer herd is estimated to consume about 14,000 AUMs of forage annually to produce this benefit. The value of this forage is estimated to be $129.41 per AUM. The hunting benefit produced by the forage consumed by mule deer on the CWEMA is estimated to average $922,604 per year.

The mule deer hunts also provide direct revenues to both the Arizona Game and Fish Department through their license fees, and to the North Kaibab Ranger District through the $5.00/tag surcharge for hunting in the Grand Canyon Game Preserve. On a last five-year average basis, the Game and Fish Department received about $52,000 per year (inflation adjusted to 1996) in license fees for hunting in Unit 12A WEST. The Department and the North Kaibab Ranger District received in addition almost $15,000 per year for habitat improvements funded by the $5.00/tag surcharge.



B. Merriam Turkey Hunting in the CWEMA

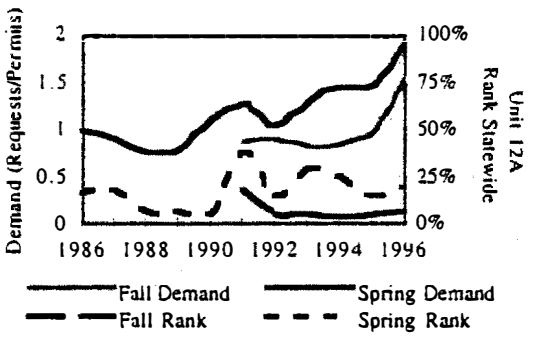


Turkey hunting data and values were determined similarly to mule deer. First, turkey hunt data for the period 1986 - 1996 for Unit 12A was extracted from the Arizona Game & Fish Department's turkey hunt database. The AG&F estimate that 75% - 80% of the turkey habitat, populations, and hunting occurs in the Central Winter EMA. For our purposes, the 75% estimate was used. Hunting values, and local and state-wide economic values used the same day- and trip- expenditure information that was used for mule deer.

Use. Between 750 to 1,400 turkey hunters annually use the Central Winter EMA for 3,000 to 5,000 hunter days. Firearm hunts occur in the spring and fall, and archery hunts in the fall. The majority of use is in the fall (75%), while the number of hunt days is divided almost equally between firearm (55%) and archery (45%).

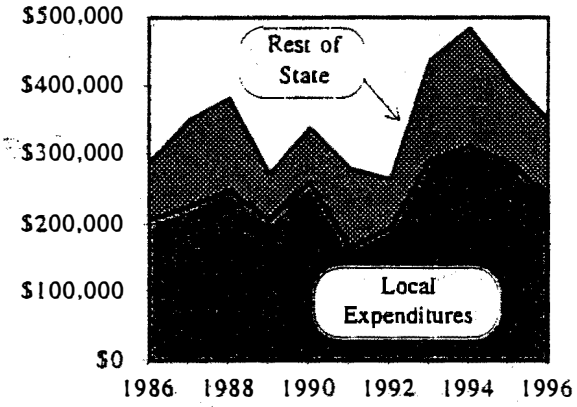
Demand. Estimates of demand for turkey hunting, and the relative attractiveness of the Central Winter in contrast to the remainder of the state were determined using the same procedures as for mule deer. In contrast to mule deer in the Central Winter, the demand for turkey hunting tags was much less than that for mule deer. The comparative rank that the turkey hunts rated statewide was almost the opposite of the mule deer: turkey hunting in the Central Winter is in much less demand, and is considered much less unique, than is mule deer hunting. The Unit 12A turkey hunts were often ranked near the bottom of demand state-wide. This is shown by the dashed lines in the figure below. Spring turkey hunts are in more demand than fall firearm hunts (archery turkey tags are sold over-the-counter outside the lottery system). The demand for spring firearm turkey tags has recently ranged from 1.5 to 2 times the number available, and the Unit 12A hunts rank at about the bottom 25% statewide. In contrast, there is little excess demand for fall firearm turkey tags: until 1995 the number of requests for tags in the lottery was less than the number available. This can be seen from the solid, light-colored line in the figure above.

Turkey Hunting Demand in CWEMA
(Firearm Tags Only)



Value. Three general categories of value are received from turkey hunting in the Central Winter EMA. First, there are the tag and license sales revenues that the Arizona Game & Fish Department receives. Second, the hunters using the Central Winter purchase goods and services in the local area. And third, these hunters make purchases in the remainder of the state for equipment and supplies. These latter two categories are shown in the figure below for the period 1986 - 1996.

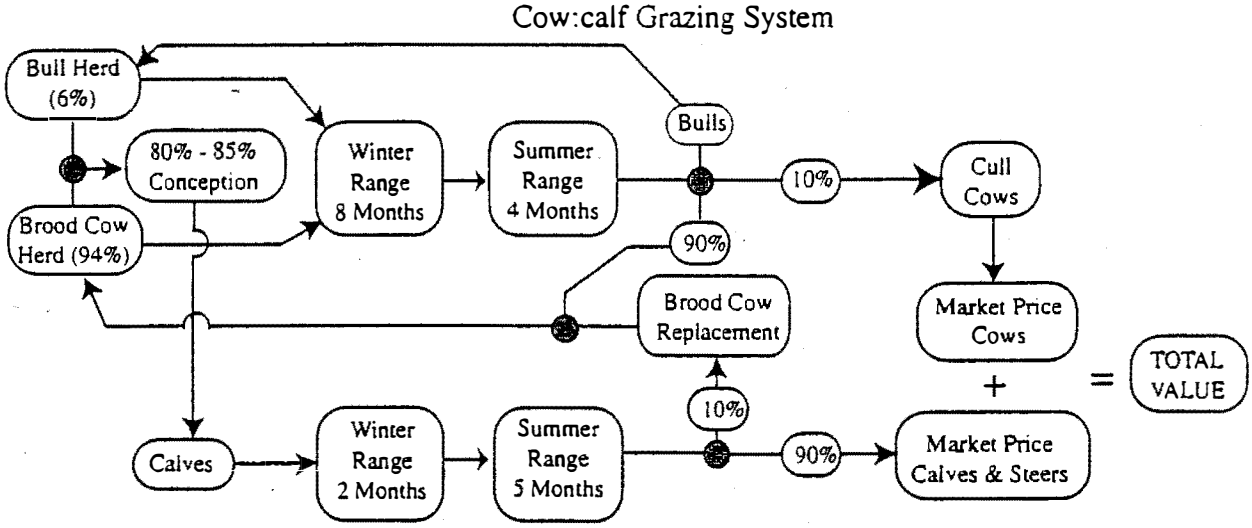
Value of Turkey Hunting in CWEMA (1996 Dollars)



The values generated from turkey hunting are directly related to the number of hunters and the length of time that they spend hunting. Local expenditures were calculated using Lee et al. (1993) per trip expenditures in the local area of the Kaibab Plateau. In constant 1996 dollars, these expenditures are estimated to average about $250,000 per year in the local area, and another $125,000 in the remainder of the state. The Arizona Game and Fish Department collects about $32,000 per year in turkey license tags for hunters in the Central Winter EMA.

III. Livestock Grazing

Most grazing on public lands in the southwest are cow:calf operations. In cow:calf operations, the marketable crop is the calves that are produced by mother's grazing, and who typically spend their first nine months on the range. A schematic of a typical cow:calf operation is shown in the figure below. In this section, values associated with the various components of a

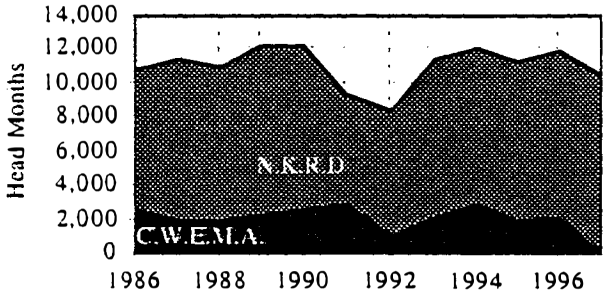


typical cow:calf operation will be explained, and placed in the context of livestock grazing occurring both within the Central Winter EMA as well as the North Kaibab Ranger District. Following the scheme for the other resources, livestock grazing values will be divided between those occurring locally—within the Arizona Strip—and those that occur regionally or state-wide.

Three factors typically go into determining the value of an AUM of forage in an operation where the primary product is calves. First, there is the size of the mother cow herd which is producing calves. These mother cows initially comprise the principle consumer of forage. After calves are born, they too consume forage but their consumption is combined with the mother's for the purposes of AUM calculation. Second, only between 80% and 85% of the mother cows successfully produce calves that live until market (due to infertility and death loss). During any given grazing year, generally about 10% of the mother cows are culled from the herd and sold. Third, each calf gains between 50 and 60 pounds per month on the range, rising from its birth weight of approximately 85 pounds. Thus, the ultimate value of an AUM of forage can be derived from the value resulting from this 50 to 60 pound per month weight gain. Values can be apportioned based on (1) the total number of AUMs for the livestock herd using the Central Winter EMA; (2) the grazing receipts received by the Forest Service (and divided among the District, County and U.S. Treasury); (3) benefits that the rancher receives from public forage above and beyond the fees paid; and the local and regional benefits

Use. Cattle use the Central Winter allotment from October 1 to May 31. The total AUMs permitted corresponds to about 295 head during the majority of the grazing season, from December through May. The number of animal unit months (AUMs) of forage allocated to domestic livestock in the Central Winter mule deer winter range decreased from about 8,600 AUMs in 1964 to about 2,204 today (McCullock and Smith, 1991). The figure at right shows head months (see discussion of conversion to AUMs) used from 1986 – 1997. No grazing has been allowed on the Central Winter EMA since July, 1996 because the Bridger Knoll Complex Fire destroyed many of the improvements required to control livestock. As the table below shows, the Central Winter and Central Summer allotments combined provide between 55% and 75% of the total livestock use on the North Kaibab Ranger District.

Livestock grazing on the District and Allotment



Livestock grazing use in Head Months on the North Kaibab Ranger District allotments.*

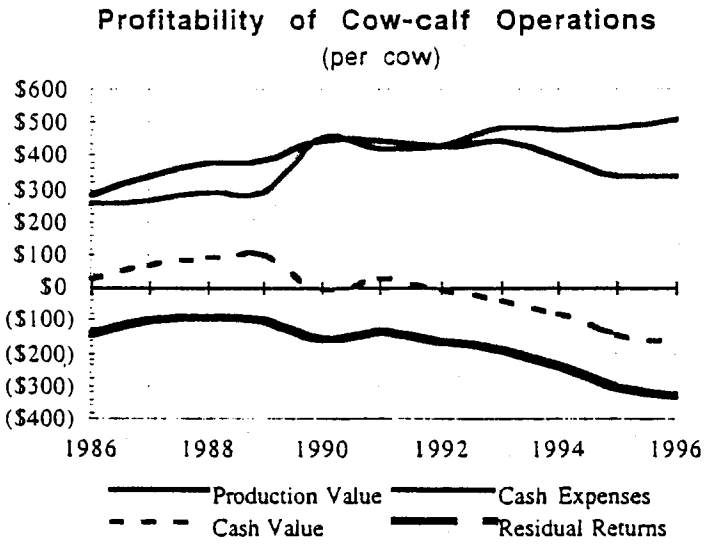
Fiscal Year	Central Winter	Central Summer	Kane	Kanab Creek	Ryan	Burro	Willis Canyon	House Rock	N.K.R.D. TOTAL
1986	2,604	4,779	1,060	246	No Data	715	Inc. Data	1,387	10,791
1987	2,004	4,779	648	60	1,704	240	1,406	548	11,389
1988	2,004	4,779	No Data	120	1,704	510	1,208	548	10,873
1989	2,316	4,779	289	174	1,704	650	1,674	717	12,303
1990	2,628	4,776	852	138	1,704	390	1,033	676	12,197
1991	2,873	2,291	852	120	1,819	510	835	No data	9,300
1992	886	4,779	367	120	1,200	42	742	184	8,320
1993	2,028	4,824	863	120	1,690	519	1,033	282	11,359
1994	2,874	5,213	569	156	1,289	414	2,047	354	12,916
1995	1,973	4,818	566	207	1,757	444	1,157	360	11,282
1996	2,037	4,818	948	208	1,643	516	1,280	492	11,942
1997	0	4,912	863	207	1,738	601	1,744	423	10,488

* Source: Grazing receipt files in the Kaibab National Forest Supervisor's Office, Williams, AZ.

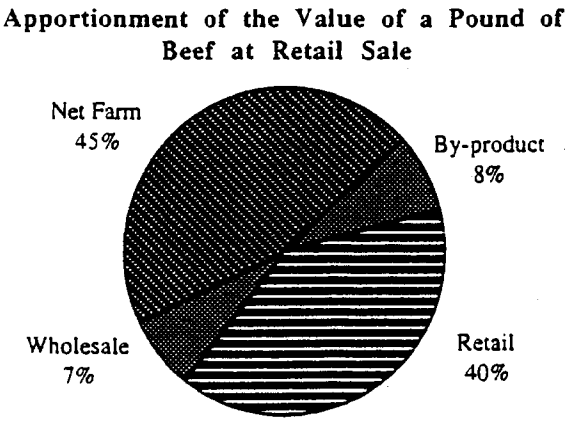
Demand. As can be seen in the figure above, the Central Winter EMA provides between ten to twenty-five percent of the permitted livestock use on the District, with the average being about 17% in the years prior to the Bridger Complex fire. However—at present—the same cattle move between the Central Winter and Central Summer allotments. Because of this, the absence of available forage in one allotment potentially affects the permittee's use of the other allotment. In other words, because of this linkage the two allotments can be considered as a single production unit.

Another way to characterize the demand for livestock forage is to consider the demand for the products produced from this forage. For cow-calf operations, this corresponds to calves. But the market for calves is regionally—if not nationally—determined based on the overlying demand for beef and calves and yearlings for the feedlot market. One proxy for this demand is the profitability of cow-calf operations. The profitability of cow-calf operations in the west also reflects, in addition to overall market conditions, the comparative advantage—or disadvantage—of western cow-calf operations relative to other regions of the country.

Information on the profitability of cow-calf enterprises on a regional basis is provided by the U.S.D.A. Economics Research Service in their "Costs of Production – Livestock and Dairy" annual reports (USDA-ERS, 1996b). The chart at right reports the profitability per cow for the western region over the period 1986 - 1996. First, the cash value of products produced, including calves, heifers, steers, and cull cows, are apportioned. This cash production value is compared to the cash costs involved in production. Over the last 11 years, net cash returns have been positive in five years, and negative in the other six years. Beyond simply cash returns, profitability is also reported when the operator's risk (involving return on capital investment) and management effort (including unpaid labor) are included (called "Residual Returns" on the chart). When this is done, the state of western cow-calf operations are even more tenuous: they have, on average, never been profitable over the past eleven years, and recent trends are becoming even more unfavorable.



Value. The economic values associated with grazing on the Central Winter EMA can be apportioned among those directly received by the U.S. Government in the form of grazing fees, the benefit to the permittee rancher from using forage in the EMA, and benefits received by others after calves and cattle are sold until the meat is purchased by the



consumer at retail. A first place to start is to apportion the value of a retail pound of beef among these various parties. This apportionment is shown in the figure at right. The average retail Choice grade of beef sold for $2.80 per pound in the third quarter of 1996 (US.D.A.-E.R.S., 1996a). This value reflects a weighted average price for all cuts sold by retail markets. This beef was purchased from a wholesaler, who received an average of $1.59 per pound from the retail store. But one pound of beef to the consumer is equivalent to 2.4 pounds of cattle weight "on the hoof" to the rancher or feedlot. Not all of the 1.4 pounds that is not cut into retail beef is waste: these "by-products" are sold, or used in the production of cattle, and have a value of $0.24. Thus the gross farm or ranch value from a pound of beef averages $1.61, with the net beef value equaling $1.37 after the value of the by-products is subtracted. However, this value reflects selling the beef carcass to the wholesaler or meat processor, and does not include the weight gain and value received when cattle are fattened in feedlots (this value is included in the gross farm value in the previous discussion).

The values for a pound of beef in the retail market can be converted to values per pound for the complete animal by dividing by 2.4. By doing so, the average retail value becomes $1.67 per, value to the wholesaler is $0.663, value of the by-products is $0.10, and value to the producer is $0.57 per pound. This conversion—and the values represented in it—allow the value of an AUM of forage to be apportioned among the various parties in a manner similar to that used for the other resources in the CWEMA.

Calculation of Weight Gain Resulting From an AUM of Forage

- One cow (1,000 lb.) is assumed to consume 26 lbs. of dry forage per day.
- One month (30 days) is assumed to require 780 lbs. of dry forage.
- Marketing weights for weaner calves are 450 lbs. for steers and 425 lbs. for heifers 200 days after birth.
- Birth weight is assumed to be 70 lbs.
- Net weight gain averages 367.5 lbs./200 days (50%:50% ratio steers to heifers).
- Thus a calf is assumed to gain 1.8375 lbs. per day from this forage.
- Total weight gain for calves is 55.125 per AUM.

The U.S.D.A. Economic Research Service provides information on cattle prices in markets throughout the western United States. Its information on prices in Arizona and Utah provide an indication of what the rancher is receiving for the calves and cull cows raised and marketed on the CWEMA. Because prices received by ranchers for both calves and cull cows fluctuate for year-to-year, an average of the last five years of U.S.D.A. prices received information was used to estimate values. The annual price data was adjusted for inflation using the Consumer Price Index (CPI-U), and then the individual 5-year averages for each state were averaged to obtain the prices per hundredweight (cwt.) used in the table at right. This procedure yielded an average price per hundredweight for calves of $86.95 (much higher than the $58.25 2-state average ranchers received in 1996). For cull cows, the 2-state, 5-year average price is $43.72/cwt.

The flow chart for a cow-calf livestock operation shown previously was used to estimate the value of livestock grazing—and consequently the value of an AUM of forage—on the CWEMA. Starting with the 296 animal herd permitted on the CWEMA, deductions were made for (1) the number of bulls servicing the herd (6%); (2) the yield of calves to market weight from the

cow herd (85%, including death loss); and finally the number of heifers from the calf crop that are commonly used to replace unproductive cows that are culled from the herd (10%).

Calf crops are generally equally distributed by sex; however, the replacements for the cull cows come only from the heifers (no replacement for the bulls is assumed). Steer calves are generally average about 25 lbs. heavier than heifer calves at market weight (450 lbs. versus 425 lbs.). This weight difference is taken into account in calculating the estimated total weight gain for the calf crop. Prices reported by the U.S.D.A. do not differentiate between steer and heifer calves, so the average price of $86.95/cwt. was multiplied by the number of cwt.'s produced (about 916). The marketed calf crop is then estimated to be worth about $80,000 annually for the 296 animal herd.

Again following the cow:calf operation flow-chart, the net value of the cull cows—after the imputed market value of the replacement heifers— can be determined. The annual replacement of 10% of the cows in the herd represents 28 animals. If each cull cow weighs about 1,000 lbs., then the gross value of the 28,000 lbs. is $12,242 at $43.72/cwt. However, the value of the replacement heifers (whether from within the herd or purchased outside) must be deducted from the price received for the cull cows. Because calves are twice as expensive per hundredweight as cull cows, there is little net monetary gain—approximately $2,000—received. The value of the calves is added to the net value of the cull cows to obtain an estimate of the total annual production value received from the 296 animal livestock herd: $81,512.

Calculation of CWEMA Grazing Value

Herd size	296
Cow proportion of herd	* 94%
Number of cows in herd	= 278
Calving success & death loss	* 85%
Number of calves produced	= 237
Deduction for 10% cow replacement	- 28
Calves marketed	= 209
Average weaner calf weight (425 lb. heifer/450 lb. steer)	* 438
Total weaner calf weight (90 heifers; 118 steers)	91,571
Average price per hundredweight (cwt.)	* $86.95
Value of calves marketed	**$79,617**
Number of cull cows	28
Average weight of cull cows (lbs.)	* 1,000
Total weight of cull cows	28,000
Average price per hundredweight (cwt.)	* $43.72
Market value of cull cows	$12,242
Number of cow replacement heifers	28
Average weight of replacement heifers	* 425
Total weight of replacement heifers	11,900
Imputed replacement heifer price (cwt)	* $86.95
Imputed value of replacement heifers	= $10,347
Net market value from cull cows	**$1,896**
Total annual value of herd	**$81,512**
Annual AUMs for Herd	÷ 3,552
Value per AUM	**$22.95**
Permitted AUMs on CWEMA	* 2,004
Annual value of CWEMA grazing	**$45,988**

The value of an AUM of forage can be imputed by dividing the net benefits, $81,152, by the 3,552 AUMs required to support the 296 animal herd for a year. The value of an AUM of forage for this herd is estimated to be $22.95. But the total value of the herd is received as a result of the herd grazing on both the Central Winter and Central Summer allotments. Based on the existing schedule for the Central Winter allotment, 2,004 AUMs of livestock grazing are authorized in the CWEMA. This 2,004 AUMs multiplied by the benefit of $22.95/AUM provides an estimate of the value of livestock grazing on the CWEMA: about $46,000 per year.

The distribution of this $46,000/year benefit is important for comparative purposes. Under the Public Rangelands Improvement Act, the U.S. Forest Service charges the livestock permittee $1.35 per AUM. This equals $2,705 per year for the 2,000 AUMs authorized for the CWEMA. This $2,700 is divided among three parties: (1) the counties receive 25%, or about $676/year as revenue sharing to support roads and schools; (2) the Forest Service receives 50%, or $1,353 in its Range Betterment Fund to rehabilitate rangelands and construct fences and water developments; and (3) the U.S. Treasury receives the remaining $675/year. Once the Federal grazing fee is subtracted, the permittee receives the remaining $43,000 in benefits; from which he has to pay his expenses and obtain any available profits.

Summary of Annual Livestock Benefits	
Herd size	296
Calves Marketed	209
AUMs of Livestock Forage	2,004
Estimated Total Benefits	$45,988
Grazing Permit Receipts	$2,705
County Revenue Sharing	$676
Range Betterment Fund	$1,353
U.S. Treasury	$676
Rancher Benefits	$43,283
Value per AUM of Livestock Forage	$22.95

IV. Fuelwood

Use. The fourth major resource in the Central Winter EMA for which economic values can be inferred is fuelwood, principally pinyon and juniper. Pinyon-juniper woodlands cover approximately 78% of the Central Winter EMA (Draft MSR, 1997). The Management Situation Report provides data about fuelwood permits for the period 1987 - 1996, however, only in 1993 were the permits likely to represent fuelwood harvested in the CWEMA.

Fuelwood permits and values, N. K. R. D.

Year	Permits	Fees	Receipts ('96$)	Benefits
1987	1,004	$5,020	$7,009	$70,280
1988	997	$4,985	$6,683	$69,790
1989	965	$4,825	$6,171	$67,550
1990	846	$4,230	$5,133	$59,220
1991	900	$4,500	$5,240	$63,000
1992	972	$4,860	$5,494	$68,040
1993	685	$3,425	$3,759	$47,950
1994	524	$2,620	$2,804	$36,680
1995	669	$3,345	$3,481	$46,830
1996	478	$2,390	$2,390	$33,460
5-yr. Avg.	666	$3,328	$3,356	$45,592

Source: N.K.R.D., Draft Management Situation Report, August, 1997.

Demand. The demand for fuelwood, as expressed in the number of permits sold, has decreased by over half in the last ten years. The Management Situation Report states that demand for fuelwood permits has been reduced as a consequence of the reduction in timber harvesting in the North Kaibab Ranger District. Timber harvest operations leave unsuitable logs and slash from their operations that are easily accessible to fuelwood gatherers. The underlying demand for fuelwood has probably not changed, but this demand has shifted to other locations as the difficulty in obtaining fuelwood on the North Kaibab Ranger District has increased.

Value. Fuelwood cutting and gathering permits are sold for $5.00 per cord. The fees collected have ranged from a low of about $2,300 per year to a high of slightly over $5,000 per year, averaging about $3,300 in nominal and real terms over the last five years. The fees that the Federal government receives are divided with 25% going to the County as revenue-sharing, and the remaining 75% going to the U.S. Treasury. Inflation-adjusted receipts, expressed in 1996 dollars,

show a real reduction in the value of receipts over the last 10 years of from about $7,000 per year in 1987 down to about $2,400 per year in 1996. Using a net imputed value of $70 per cord in 1996 (assuming that the replacement price for a cord of pinyon-juniper firewood would be $75 in the Fredonia-Kanab area), the social benefits of fuelwood from the North Kaibab Ranger District have averaged about $46,000 per year over the last 5 years, but have decreased from about $70,000 per year to about $33,500 per year, or a drop of over half.

DISCUSSION

The purpose of this study is to incorporate considerations of the benefits that society receives from wildlands into decisions that are made about their management. Readily available information can provide an indication of the relative values associated with various uses of wildlands, and that this information—while not perfect—is at least comparable in quality to the quality of other types of data relied upon to make decisions. The systems approach process used in this study looks at the quantity and quality of resources that provide public benefits, attempts to place a value on the yield of these resources, and by implication, provides evidence of effective ways to gain additional benefits. The following table provides a summary of the estimates of the values received from four uses in the CWEMA.

Summary of estimated values received annually in the Central Winter EMA.

Resource	Analysis Area	Estimated Benefits	Fee Receipts Distribution				Benefit Distribution	
			County	State	Treasury	N.K.R.D.	Local	Region
Dispersed Recreation	W. of S.R. 67	$6,400,000	$0	$0	$0	$0	$6,400,000	
Hunting								
Mule Deer	CWEMA	$922,604	$0	$51,649	$0	$14,757	$470,528	$452,076
Turkey	CWEMA	$401,655	$0	$20,375	$0	$0	$248,864	$132,416
Livestock Grazing	CWEMA	$45,988	$676	$0	$1,353	$676	$43,283	
Fuelwood	NKRD	$48,984	$839	$0	$2,517	$0	$45,492	$0

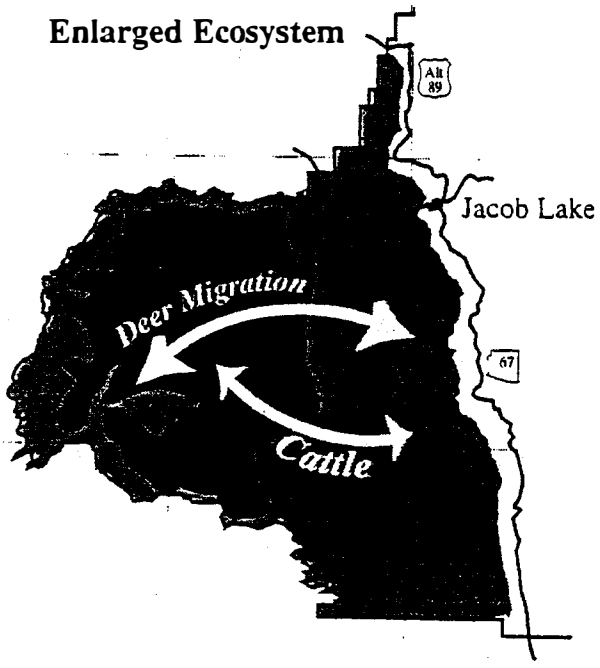
Sources: Information discussed in report.

It should be apparent from the information in the table above that the vast majority of public benefits, whether locally or regionally, result from recreation-related uses of the Central Winter EMA. While the area for the estimation of dispersed recreation benefits is greater than the CWEMA—and while the bulk of recreation use occurs outside the CWEMA—if only 3% of the dispersed recreation occurred in the area its value to the public would be almost $200,000 per year. Similarly, while the bulk of mule deer hunting in Unit 12A West occurs at elevations higher than the CWEMA, trophy hunting in the late seasons occurs within the CWEMA, and the herd is dependent upon the area for critical winter habitat.

In contrast, the benefits in terms of livestock forage from traditional grazing in the CWEMA represent about 5% of the value that forage in the CWEMA provides for mule deer. A

value of an AUM of forage for livestock compared to mule deer was derived for this study. The benefit received from an AUM of forage on the CWEMA for livestock was calculated to be $22.95; a similar calculation for the value of an AUM of forage for mule deer showed it to be worth $129.41, or approximately five times more valuable.

Economists frequently criticize agency managers because they do not balance benefits and costs of various management possibilities. Often, managers are not provided with effective "signals" to indicate where society desires management emphasis to be placed. One signal that if often used are funds that return to the agency based on its decisions. While necessarily an imperfect mechanism, examination of the summary valuation table includes columns representing receipts to various governmental entities, including the North Kaibab Ranger District. The relative lack of management emphasis on dispersed recreation may result from the lack of direct returns to the agency from these uses. However, this cannot explain differences in management intensity between hunting and livestock grazing. The North Kaibab Ranger District receives greater amounts of funding from the tag surcharge on hunting in the Grand Canyon Game Preserve than it does from the Range Betterment Fund generated from a portion of the grazing receipts.



It became apparent through the course of this study that the Central Winter Ecosystem Management Area is a sub-unit of a larger ecosystem, both biological and economic (see map at right). The boundaries of the CWEMA were based on a grazing allotment that provides winter range. The corresponding Central Summer allotment provides livestock forage for the remainder of the year, i.e., the same cattle move back and forth between the two areas. So from a livestock perspective, the two allotments are integrally united. A similar situation exists for the mule deer: the herd largely summers in the higher elevation areas in the Central Summer allotment and migrates to lower elevations in the CWEMA to winter. So for the deer the ecosystem is a combination of both areas. For dispersed recreational use, a case can be made that the types of use (visiting overlooks, auto tours, wildlife watching, wilderness access) are compatible with combining the two areas. This certainly makes sense when the available information is reported on the basis of the larger area.

The valuation approach used in this study certainly has limitations. Of particular concern is that the uses which can be easily valued are restricted, both conceptually and as a result of available information. A whole host of other values—such as the publics' desires for pleasing landscapes, the value that they place on intact ecosystems, and the value that ecosystems play in maintaining

biological diversity, and cleansing air and water—are not easily picked up from the survey information used for this study. Additionally, conflicts among uses—for instance, the competition for forage between mule deer and livestock, any effects (and whether they are positive or negative) between the presence of cattle and the enjoyment of the area by recreationists—have not been determined for this area.

Through the process of constructing this valuation, the limitations of available data became apparent. First, much of the information used to develop this study came from disparate sources, both within the Forest Service, and other cooperating agencies, such as the Arizona Game and Fish Department and Agricultural Extension. This highlights both the problem and the opportunity for studies of this type: there may be problems pulling data from agency sources, but also opportunities because a wealth of data exists that can be brought to bear on management decisions. Starting with studies of this type shows where information does not exist, and this knowledge can then be used to determine priorities for acquisition of additional data. For this study, additional site-specific information on dispersed recreation use, and visitors' perceptions of conflicts among uses would be valuable. For example, are visitors' enjoyment of wildlife viewing adversely or positively affected by the presence of livestock. Do they prefer dense, open or a mosaic of tree densities in pinyon-juniper vegetation? The information gained from asking these questions can be directly used to make management decisions.

Even with the limitations discussed above, the valuation study used as an example shows that considerable benefits are being received from uses other than livestock grazing on wildlands. Dispersed recreation and hunting provide orders of magnitude more societal benefits. Before decisions are made to continue investments in managing livestock, it would seem to make sense to determine whether the benefits received from this use outweighs its costs, both financially and in terms of the management effort required. Other uses, such as fuelwood gathering, generate comparable receipts and values compared to livestock grazing, but these uses inexplicably receive less management emphasis. If the purpose of public wildlands is to provide benefits to society, studies of this type can show where management emphasis and decisions can provide greater benefits.

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THE EFFECTS OF RANGELAND WATER DEVELOPMENTS ON SOIL AND WATERSHEDS

Rangeland Water Developments: Conservation Solution or Illusion?

Joseph R. McAuliffe,
Director of Research
Desert Botanical Garden

Abstract -- Scarcity of surface water greatly restricted livestock ranching in southern Arizona 100 years ago. Permanent sources of water were so few and widely separated that year-round grazing was largely limited to corridors along a limited number of perennial streams and springs. In the decades before the turn of the century, overstocking coupled with extreme drought caused severe degradation of these areas. At the time of this first wave of damage, range scientists recommended widespread construction of watering places to disperse livestock more evenly over the landscape in order to lessen such degradation. However, structures such as large earthen tanks were difficult to construct in this era of horse-drawn equipment. Furthermore, there was little economic incentive for an individual to invest deeply in construction of widespread watering places in an era of common use of the open range. The end of the open range era, signaled by the Taylor Grazing Act of 1934, coupled with the availability of mechanized earth-moving equipment and infusion of capital and labor from federal programs, initiated the widespread construction of livestock watering places in semi-arid grasslands throughout southern Arizona. However, these additional water sources did not have the ameliorating impact on range condition that range scientists had originally envisioned. Instead, water developments dispersed across the landscape led to a second, more pervasive episode of range degradation in southern Arizona that has continued in some places to this day. As a tragic reversal to the situation that existed in the late 1800's, the major limitation to livestock production in many semi-desert ranges of southern Arizona is no longer a shortage of watering places, but rather, the extremely reduced forage production on degraded landscapes. However, the semi-arid grasslands of southern Arizona have not all been equally affected. Depending on climate (precipitation input) and watershed and soil characteristics, some areas are far more sensitive to others and can be easily flipped from one hydrological/ecological state to a much less economically and environmentally desirable one. Understanding the natural ecological and hydrological constraints of these landscapes is an important key to planning the location of future water developments and managing the use of land around existing ones.

INTRODUCTION

An understanding of how southern Arizona's semi-arid grasslands have been used for livestock production and have changed requires knowledge about the history of the development of livestock watering places. Since the beginning of extensive Anglo-American ranching operations in southern Arizona over 125 years ago, two more-or-less distinct episodes of range deterioration occurred which are tied to very different situtations with respect to the distribution livestock watering resources. The first episode followed the initial cattle boom during the last decades of the 1800's when livestock use was focused near the relatively few sources of naturally occurring, perennial surface water. A second, more geographically pervasive episode of damage began between more recently when livestock watering places were widely constructed in areas that were originally little used by livestock due to the absence of natural surface waters. This second episode of range degradation continues in some places in southern Arizona.

In this paper I strive to assess some of the relatively recent ecological changes that followed the widespread construction of livestock watering places in upland, semi-arid ranges of southern Arizona. A careful assessment of these changes and the fundamental ecological and hydrogical behaviors of semi-arid rangelands is extremely relevant to the planning of future livestock water developments and the management of existing ones.

A Brief History: Water and Livestock Ranching in Southern Arizona

Beef cattle need water on a daily basis. A mature beef cow drinks about 10 gallons (38 l) of water every day. This daily need limits the distance cattle can travel away from watering places in order to forage to a few miles. As a consequence, in the days of pioneer ranching operations in southern Arizona, livestock use of the landscape was generally restricted to relatively narrow

corridors along widely separated streams or other naturally occurring water sources. Despite the limited availability of water, the number of cattle stocked in the region skyrocketed when railroads linked the region to distant markets and fattening of cattle on the "free grass" of southern Arizona's open range was widely billed as a highly profitable investment (Hastings and Turner, 1965). The decade of the 1880's experienced nearly 10-fold increases in the number of cattle stocked in southern Arizona. For example, estimates of the number of head of cattle in Pima County in 1880 versus 1890 were about 12,000 and 114,000 head, respectively (Wagoner, 1952). The heavy use of a relatively small portion of the landscpe led to severe range deterioration. By 1885, forage resources were severely depleted, causing heavy mortality of cattle during a summer drought of that year. Pronounced destruction of vegetation coupled with the even more severe, prolonged drought of 1892-93 led to the death of an estimated 50 to 75% of cattle on southern Arizona ranges (Wagoner, 1952).

These consequences of severe rangeland deterioration prompted critical scientific examination of the situation throughout the region. Biologists from the U.S. Department of Agriculture reported conditions they observed and offered recommendations for improvements. For example, Shear (1901) described general condition of rangelands in the region observed in 1895:

> "The ranges have been so heavily overstocked that the greater portion of the better perennial grasses have been entirely destroyed. This is particularly true of those portions of the range situated within easy distance of a more or less permanent water supply."

Similar observations were recorded by Griffiths (1901). Hastings and Turner (1965), Cox et al. (1983) and Bahre (1991) have chronicled the degradation that occurred during this period.

The same individuals that reported this severe range deterioration also observed that

extensive areas far removed from dependable water sources were not damaged:

> "Owing to the very scant and uncertain supply of water over large areas, it has been impossible to graze stock for a sufficient period to destroy the grasses." (Shear, 1901)
>
> "The pioneer stockman... located near the comparatively few permanent streams and springs... left unused abundant forage on the unwatered areas beyond..." (Talbot, 1926)

Cox et al. (1983) suggested that the extreme range deterioration during the last decades of the 1800's affected only about one-fifth of southern Arizona's landscape. The remaining areas escaped the ravages of overuse because they lacked surface water.

Management recomendations of USDA biologists at the turn of the century called for the widespread construction of livestock watering places in upland areas in order disperse cattle over wider areas, thereby lessening the damage caused by concentration of livestock:

> "One of the most serious mistakes made by the stockman of the Southwest is that of not making ample provision for an abundant supply of stock water... to obviate this deficiency, every stockman ought to build dams, tanks, or artificial ponds which may be filled by the natural drainage of the land... If the carrying capacity of the ranges is to be increased, it is necessary that provision be made in advance against a scarcity of water in times of drought." (Bentley, 1898)
>
> "Providing water, either in the form of tanks or wells, so that the stock will not be required to travel long distances and thus tend to the destruction of the grasses on the areas in the immediate vicinity of watering places, is urged." (Smith, 1899)

Despite calls such as these at the turn of the century, relatively few upland watering places were developed until another 30 to 40 years had passed. Several factors contributed to this lag. In uplands of this semi-arid region, groundwater is often found at great depth, making drilling of wells and construction of windmill-powered pumps difficult or infeasible. The labor required and

cost of excavating and constructing earthern dams across ephemeral drainageways were usually prohibitive. For example, a 1926 USDA publication cited costs of construction of a large earthen tank as high as $15,000 (1926 dollar amount) using horse-drawn equipment (Talbot, 1926). Such a capital investment on the part of most ranching operations at the time in southern Arizona would have been prohibitive, given the inherently low capacity and unpredictability of production in these semiarid settings and corresponding length of time that would be required for a rancher to recoup such an investment. Futhermore, lack of exclusive control of specified areas by individual ranchers on the unregulated public domain of the open range provided little incentive for a rancher to invest widely in such improvements.

The widespread construction of livestock watering places across upland environments of southern Arizona began after passage of the Taylor Grazing Act in 1934. One of the purposes of this federal legislation was to prevent overgrazing and further damage to rangelands in the public domain and provide a means for constructing range improvements such as fencing and watering places. Costly improvements were implemented through the influx of capital and labor from federal sources. Funds were provided, in part, from grazing fees; 25% of grazing fees were originally designated for range improvements (Wagoner, 1952). Other associated programs in this era, such as the USDA Soil Conservation Range Benefit Program, initiated in 1936, also provided funding for range improvements, including construction of watering places. The Civilian Conservation Commission (CCC) provided considerable labor needed to carry out construction efforts (Wagoner, 1952; Cox et al., 1983). Additionally, the increasing availability of mechanized earth-moving equipment, such as bulldozers, undoubtedly greatly facilitated the construction of sizable earthen tanks that could retain sufficient depths and volumes of water to last through

periods of lengthy drought.

Unfortunately, though, the widespread distribution of water developments in some parts of southern Arizona was not a panacea that led to better management and improvement of range condition. Instead, in many places it led to the subsequent overexploitation of forage plants and severe deterioration of upland ranges. This relatively recent episode of damage is most evident in the more arid range environments found below 4000 ft. (1220 m) elevation which generally receive less than 12 inches (30 cm) average annual precipitation. Grasslands in less arid, somewhat higher elevations in the southeasternmost part of the state have generally not experienced this severe damage.

A Case Study

An area I have studied in southern Yavapai County provides a case history of how the lack of natural surface water protected upland ranges from the catastrophic episode of landscape degradation in the late 1800's, but how subsequent development of livestock watering places eventually led to destruction of the original grassland vegetation within the last 50 years. The study area is on the broad, gently sloping alluvial piedmonts (or "bajadas") that flank the south side of the Date Creek Mountains, between 8 and 22 miles (13 -35 km) northwest of Wickenburg (Fig. 1). Highway U.S. 89 is the study area's eastern boundary area and the southern boundary is formed by a set of low mountains south of Sols Wash. The study area includes approximately 75 square miles (200 km ^{2}) of Arizona State Trust lands divided into grazing allotments used by four separate ranching operations (Date Creek Ranch, Moore & Moore Cattle Ranch, OX Ranch, Sols Wash Ranch). My research has focused on vegetation and soils and I have also drawn on

information from early maps, original land surveys, repeat photography (both ground and aerial), and studies of protected vegetation relicts to document the magnitude, timing, and causes of environmental changes that have occurred.

Today, the vegetation throughout most of the area consists principally of widely spaced woody plants, including mesquite (*Prosopis velutina*), catclaw (*Acacia greggii*), burroweed (*Isocoma* [=*Haplopappus*] *acradenia*), and broom snakeweed (*Gutierrezia sarothrae*) together with cacti, including staghorn cholla (*Opuntia acanthocarpa*) and pancake prickly pear (*O. chlorotica*). Creosotebush (*Larrea tridentata*) is abundant in some areas. Perennial plant canopies frequently cover less than one-quarter of the soil surface; in some places, less than 10% of the soil surface is covered. In the winter-spring season, especially during unusually wet years, ephemeral plants such as filaree (*Erodium cicutarium*) provide most of the cover for a brief period. The only sizable stands of perennial grass (tobosa grass, *Hilaria mutica*) are restricted to widely spaced, narrow swales that receive runoff from adjacent upland areas. These grassed swales, though, are limited to an area of about 12 square miles (30 km^2) in the southeastern part of the study area and in this small portion of the entire study area, tobosa-covered swales account for only 5-6% of the land area. With few exceptions, the slightly elevated uplands between swales lack perennial grasses altogether and are sparsely covered with woody plants as described above. Based solely on the composition of existing vegetation, the area is accurately described as a semi-arid shrubland.

Despite the present dominance of woody plants across the area, perennial grasses originally covered most of this landscape, including both well-watered swales and adjacent, drier uplands. An 1864 military map labels the area flanking the south side of the Date Creek

Mountains as "Grass Valley" (Fig. 2). One of the townships in the study area (T9N, R6W; see location in Fig. 1) was surveyed by the U.S. General Land Office in1897. Surveyors noted soil conditions and vegetation along all north-south and east-west boundaries of each of the 36 sections within the township. The summary of their descriptions indicated that the vegetation 100 years ago was considerably different from today's:

> "This township is level and gently rolling land, without timber, excepting a few paloverde and mesquite trees along washes and patches of scattering catclaw, mesquite, and cactus undergrowth. The land is nearly all of good quality and covered with good grasses. There is no water in the township." -- Philip Contzen, U.S. Deputy Surveyor

Because of the lack of water, this area clearly escaped the damage inflicted in the late 1800's on other Arizona ranges that contained natural surface waters.

Eventually, many earthen stock tanks were constructed to provide water for livestock in this and adjacent townships (Fig. 3). One tank in the area (Gibson Tank) was built just before the turn of the century (R. and K. Moore, personal communication, July 1997) and is shown on a 1903 USGS topographic map. Although a few more earthen tanks were built with animal-drawn equipment in the first few decades after the turn of the century, most of the tanks were built between the 1930's and the early 1950's. Aerial photographs taken in 1954 show that all but one of the tanks in the region had been constructed by this date. Many of the tanks have been substantially enlarged over time. Some of the tanks are extremely large with earthen dams up to about 16 ft. (5 m) tall and more than 650 ft. (200 m) in length. Two of the largest tanks when filled to capacity each impound around 10 acres (4 ha) of surface water and contain water during prolonged droughts. Many of the other tanks exceed 1 acre (.4 ha) in area. There are few places where livestock have to travel in excess of 1-1.5 miles (1.6-2.4 km) from any point to reach

water, except during extreme droughts when the smaller tanks may dry up.

A photograph taken in 1950 by Robert R. Humphrey at the north-central boundary of township T9N, R6W (photo location in Fig. 3) shows that tobosa grass provided most of the cover and woody plants were rare in a well-drained upland site (Fig. 4A). Despite the predominance of perennial grass, Humphrey (1950) accurately viewed this scene as a grassland at risk of degradation. He assigned range condition of the area shown in the photograph as "fair" (in a ranking system with four condition classes: excellent, good, fair, and poor) and commented that "there is not enough vegetation to control erosion" and "grass seedlings are not becoming established here to replace the old plants that have died." The 1950 photograph shows heavy use of grasses with well over half of the earlier season's growth consumed by livestock. The slight pedestalling of individual grass plants indicates loss of soil in areas not protected by plant canopies. The "fair" ranking indicated that Humphrey estimated the site was producing only 25-50% of all the forage it could potentially produce. Humphrey (1950) recommended that grazing of ranges in this condition should be deferred every other summer until they improved at least one condition class. For ranges in poor condition, he recommended deferring summer grazing every summer until they showed improvement.

I located the site of Humphrey's 1950 photograph and rephotographed the scene in 1992 (Fig. 4B). Tobosa grass has been completely eliminated from the area and woody plants, primarily small mesquites, cover only about 10% of the soil surface. This kind of dramatic change has generally occurred in upland areas throughout the study area. Comparisons of repeat aerial photography from 1963, 1977, and 1995 taken across the entire area show the widespread elimination of grass cover from upland areas and replacement with a sparse cover of woody

vegetation within a few decades (Fig. 5).

Causes of vegetation changes. Determining the fundamental cause(s) of these undesirable vegetation changes is more difficult than merely documenting their extent and timing. The changes occurred soon after the widespread construction of watering places made the area more readily available for use by livestock. Nevertheless, there have been claims that livestock grazing was not the principal cause of change, but rather other factors, such as diminished summer rains, set the process of vegetation change in motion. Some way is required to unequivocally separate the effects of livestock grazing from other purported causes of change. Three areas within the study areas where livestock use has been either minimal or excluded provide references that allow the assessment of the extent to which livestock grazing has been responsible for the widespread vegetation change.

The first of these reference areas is located on the eastern side of the study area within a narrow corridor of land between U.S. Highway 89 and the Atchison, Topeka, and Santa Fe Railroad tracks in the eastern part of the study area (location in Fig. 3). The northern part of this corridor is extremely narrow (approx. 80 ft. [25 m] wide). This narrow portion is not fenced from the railroad tracks and consequently is not used by livestock. The southern portion broadens to about 820 ft. (250 m) and is fenced both from the highway and railroad tracks to allow use by livestock. Nevertheless, this southern area has been little used by livestock because it lacks watering places and is completely separated by the railroad from watering places west of the tracks. One very small tank with a 40 m (125 ft.) long, 1.5 m tall earthen dam was constructed in this corridor but has apparently not impounded water for over 30 years. A 1964 aerial photograph shows the earthen dam forming the tank was cut through by a gully (probably

due to excessive runoff channeled in roadside ditches along Highway 89). Examination of the tank in 1997 shows the dam apparently was never repaired and does not retain water.

This corridor contains a variety of soil types matching those found throughout the rest of the study area, including fine-textured, clay-loam soils of swales and sandy clay loam to sandy loam upland soils. Exceptional examples of grass-dominated areas exist throughout the corridor. Tobosa is the dominant grass on clayey soils both in well-drained upland areas and swales. Big galleta (*Hilaria rigida*) predominates on upland soils with somewhat coarser textures, often with several other native perennial grass species, including small amounts of black grama (*Bouteloua eriopoda*; Figs. 6A, B; Table 1). Large bunches of bush muhly (*Muhlenbergia porteri*) are found growing in the open and show no sign of use by livestock. Although perennial grass cover within the protected area is patchy and woody plants predominate in some places, the abundance of perennial grasses in upland soil environments of this area exceeds anything found on comparable soils found to the west side of the railroad tracks.

The second reference area is found in the western part of the study area in a fenced livestock exclosure. The fenced area measures 200 ft. (61 m) on a side, enclosing nearly 1 acre (.37 ha) and is located south of Alamo Road, 2.5 mi. (4 km) west of the intersection with highway U.S. 93 (location in Fig. 3). The establishment date of the structure is unknown, but many other similar, one-acre exclosures were built throughout west-central Arizona during the 1950's and 1960's by various federal and state land management agencies (Turner et al., 1980). The considerably weathered condition of the fence also suggests the exclosure was constructed at least several decades ago.

The exclosure contains two soil types. The eastern half contains fine-textured soils of a

swale and is dominated by tobosa (Fig. 7). The western half contains slightly calcic, loamy upland soils and supports big galleta. In October, 1997, approximately three-quarters of the soil surface within the exclosure was covered by canopies of perennial plants; tobosa and big galleta provided most of this cover (Table 2). Outside of the exclosure, only one-quarter to one-third of the soil surface was covered principally by the sparse, open canopies of creosotebush with minor amounts of other shrubs and succulents. In swale environments outside of the exclosure, tobosa is extremely rare, not contributing more than a few percent total canopy cover and big galleta is essentially absent from adjacent, well-drained loamy upland soils. Extremely sharp fenceline contrasts between the interior and exterior of the exclosure demonstrate the effects of grazing by domestic stock (Fig. 8). The difference between vegetation cover within versus outside of the exclosure is apparent in a high-altitude aerial photograph taken after the end of the 1992 summer rainy season (Fig. 7). The substantially darker area inside the exclosure reflects the abundant production of tobosa, big galleta, and ground-covering perennial forbs within the fenced area versus the nearly complete elimination of these plants from the surrounding area. This nearly complete elimination of effective ground cover from the original mixed grass-shrub plant community and corresponding baring of the soil surface has undoubtedly greatly increased the amount and intensity of runoff generated by the landscape. Gullying has become widespread across this part of the study area and incision of swales threatens the existence of the little tobosa grass that remains. A gully has recently cut into the swale on the east side of the exclosure (this gully was absent in 1992; personal observation of the site) and threatens to undermine and destroy a portion of the fence on the eastern boundary. Even if the fence is not damaged or destroyed, the rapid exit of water through the gully rather than slow infiltration into soils of the swale

threatens the survival of the tobosa stand within the exclosure.

The relatively steep, rocky slopes of Saguaro Hill, located in the eastern part of the study area (location in Fig. 3) provide another reference area since it has been little used by cattle in comparison to the surrounding terrain. Livestock avoid the slopes because of both its steepness (up to 35% slope inclination) and rockiness. Examinations of this hill since 1991 rarely yield any sign (i.e., dung) of cattle on the slopes, despite heavy use of the surrounding, relatively flat terrain. Clayey soils underlie the rocky surfaces of this basaltic hill and tobosa forms a dense cover beneath widely spaced canopies of foothills paloverde, and on southern exposures, saguaros (Fig. 9). Following summer rains when tobosa experiences a marked flush in growth, individual tobosa grass plants that are occasionally found on level ground at the base of the hill are typically cropped to the ground by cattle whereas those on the slopes remain untouched. The clayey soils on this hill differ considerably from those that have formed in the fine granitic alluvium of the rest of the study area, hence direct comparison with other areas cannot be made as can be done with the first two reference areas. Nevertheless, the presence of the dense cover of tobosa over the entirety of Saguaro Hill attests to the ability of this grass to persist and provide a substantial soil cover, even on relatively xeric, south-facing slopes.

These reference areas provide strong evidence that protection from livestock use has allowed perennial grasses to persist as dominant components of the vegetation and conversely, *livestock have been a direct cause of the undesirable vegetation changes in surrounding areas.* Perennial grasses were lost from upland environments because they were preferentially consumed by livestock. Woody plants such as mesquite and creosotebush which were infrequently encountered in the 1897 land survey and remained uncommon until the 1950's and 1960's

dramatically increased in abundance (Figs. 4, 5). Mesquite probably increased so rapidly because cattle avidly consume the sweet fruits and widely disperse viable seeds in their dung (Brown and Archer, 1989). Survival of mesquite seedlings is enhanced when perennial grass cover is substantially depleted (Glendening and Paulsen, 1955).

The overexploitation of the original grass-dominated vegetation by livestock apparently set futher landscape degradation in motion. The dramatic elimination of perennial grasses from upland environments substantially changed the hydrologic behavior of the landscape. Soils in the area are formed in relatively fine-grained, sandy to gravelly alluvium derived from the Date Creek Mountains. Most of these soils contain substantial, clay-enriched subsurface horizons with relatively slow infiltration capacities [see McAuliffe (1995) for more detailed descriptions of these soils]. The ability of these soils to absorb rainfall undoubtedly plummeted once grass-dominated vegetation in uplands was essentially eliminated. Increased intensities and amounts of runoff have caused widespread and severe gullying. Broad swales draining upland areas originally supported dense, tremendously productive stands of tobosa that were originally located througout much of the area (Figs. 5, 10). In the semi-arid climate of this area, extremely dense stands of tobosa such as these require the receipt of runoff derived from the surrounding landscape. However, once the surrounding uplands were denuded of perennial grass cover, increased runoff intensity began cutting deep, vertical-walled gullies through most of the larger swales, causing the rapid loss of water through these channels rather than storage of moisture in the soils of the swales (Fig. 11A). The dewatering of these soil environments rather than grazing *per se* has caused the widespread mortality and loss of tobosa grass from these once-productive swales (Fig. 11B). Humphrey (1960) also recognized that gullying of swales occupied by dense tobosa stands often caused

death of this grass. The more limited number of small swales in the southeastern part of the study area that have not been so seriously gullied retain stands of tobosa grass (although diminished from those present in 1963 aerial photos), despite the heavy grazing pressures that have existed.

Other human-caused alterations also contributed to landscape degradation and vegetation change. Many unpaved roadways with compacted, rutted surfaces (some dating to the late 1800's) have altered overland flows, concentrated and speeded the loss of runoff, and contributed to the demise of some of the dense tobosa stands of swales (Fig. 12). Widespread soil erosion and gullying in the area have also been blamed on a number of other factors, including construction of the highway 93 corridor in the early 1960's and unusual floods associated with extreme climate events such as the 1983 El Nino year. Nevertheless, it is fundamentally the greatly reduced capacity of uplands *producing the runoff* to absorb precipitation rather than characteristics of drainageways *receiving the runoff* that has caused the severe biological and physical degradation of this environment.

The actions of human beings and domesticated livestock have desertified this former grassland. Forage production in this area is now a pitiful fraction of what it originally must have been when perennial grasses predominated. There is very little recharge of soil moisture on this denuded landscape by intense thunderstorms of the warm season; most of warm-season precipitation is quickly lost as runoff. In late summer-early fall at a time when warm season rains produce a flush of growth in perennial grasses in the ungrazed reference areas (e.g., Figs. 6, 8), very little high-quality forage is produced in the degraded areas and cattle subsist largely on browsing foliage and fruits of mesquites. The area is managed as an ephemeral range where winter ephemeral plants such as filaree provide most of the forage base (personal

communications, P. Boles, Ariz. State Land Department). Despite this recognized limitation of production, cattle are nevertheless stocked year-round throughout the area. In some places, cattle have been provided supplemental feed on small, inholdings of private property while they continue to have free access to use surrounding state-owned grazing allotments. Such supplemental feeding of free-ranging livestock in situations when inadequate natural forage is produced causes further range deterioration and is economically counterproductive in the long run (Holochek, 1992, 1996). In addition to continued use by cattle, sheep have been stocked in winter-spring to use ephemeral forage (personal observations, 1992).

The area is considered "an extreme problem area; the amount of soil that moves with every storm is alarming" (personal communication, D. Smith, USDA Natural Resources Conservation Service, Prescott, December 1992). Until vegetative cover is restored on runoff-producing areas, attempts to stop erosion of gullies and deepening of channels will probably be unsuccessful. Unfortunately, the prospect of restoration of perennial grass cover on exposed, compacted soils of uplands is poor, probably even if livestock were to be removed for a long period. The likelihood of natural re-establishment of perennial grasses has been essentially eliminated since no seed sources remain across wide areas. Efforts to reseed with perennial grasses, including the non-native Lehmann lovegrass (*Eragrostis lehmanniana*), have failed (D. Smith, personal communication, 1992). Unfortunately, the compacted soils and highly altered surface hydrology will undoubtedly persist for a long time, thereby impeding the establishment of perennial grasses, regardless of technological inputs. These kinds of ecological changes in semi-arid grasslands are typically self-reinforcing and difficult, if not impossible to reverse (Schlesinger, et al., 1990; Grover and Musick, 1990). As a consequence of the damage that has been inflicted,

the inherent value of these lands and their long-term prospects to generate revenue from grazing fees has greatly diminished.

The direct, damaging impacts of this degradation extend far beyond the boundaries of the ranch properties and grazing allotments. The majority of the drainage basin of Sols Wash is included within the degraded area. Sols Wash is an ephemeral stream that empties into the Hassayampa River at Wickenburg. Increased intensity and amount of runoff from the degraded landscape have increased the likelihood of damaging floods on Sols Wash at Wickenburg. For example, a tropical Pacific cyclonic storm (Hurricane Nora) produced 4 inches (10 cm) of rainfall in the Wickenburg area throughout the night of 25-26 September, 1997. Flooding of Sols Wash threatened and closed a major bridge crossing of Highway 93 and flooded several homes in early morning of 26 September. The width of the channel beneath the bridge is approximately 125 ft. (38 m) and floodwaters rose to touch the lower side of the bridge, a maximum flood depth of 10 ft. (3 m). The severe erosion of reddish, clay-enriched soil horizons across the degraded watershed produced the "thick, churning, deep-reddish colored water" of the flood (Swift, 1997). Hurricane Nora actually produced far less rainfall than anticipated. Larger storms will inevitably occur in the future. The severely diminished water retention capacity of the entire watershed will one day likely cause a much more damaging flood in Wickenburg.

Inherent Behaviors of Semi-Arid Environments and Land Use

Livestock watering developments in themselves obviously did not cause the undesirable environmental changes that have occurred throughout the area. However, relatively dependable water supplies have allowed overexploitation to occur. Management allowing sustainability

requires a much better understanding of the how these semi-arid systems respond to various perterbations, including the removal of vegetation by grazing animals. The biological characteristics of plant species and physical attributes of the terrain and its soils are principal determinants of the sensitivity of these landscapes. These particulars must be understood in order to better *predict* the susceptibility of various landscape to degradation and to foster better land-use decisions. Present-day range management strategy relies to a great extent on a trial-and-error approach of monitoring the impacts of use and adjusting land use on the basis of observed trends in range condition. Knowledge we have of plant ecology, soils, landscape geomorphology, and fluvial hydrology could be used to far greater advantage to better *predict* behaviors of landscapes and thereby help make management decisions before environmental deterioration begins.

Ecological responses of perennial grasses. The dominant warm-season, perennial grass species of the more arid semi-arid grasslands in southern Arizona differ greatly from those of less arid regions in terms of their manner of growth. The familiar warm-season grasses of less arid ranges including cane beardgrass (*Bothriochloa barbinoda*), side-oats grama (*Bouteloua curtipendula*), hairy grama (*B. hirsuta*), blue grama (*B. gracilis*), and many others, die back almost all the way to the soil surface at the end of the growing season, storing carbohydrate reserves needed to initiate regrowth from buds located at or below the soil surface. Their above-ground canopies are replaced during the next favorable growing season. The dominant grasses of the more arid desert grassland ranges of southern Arizona, principally big galleta, tobosa, bush muhly, and black grama, store carbohydrates and initiate regrowth in a very different manner. During periods of drought and in winter, much of the above-ground plant remains alive but

dormant, and the stems (culms) are the principal place where carbohydrate reserves are stored. Growth in the following season is initiated from buds located on the dormant stems. The storage of food reserves in above-ground, living stems allows more rapid leaf production and regrowth at the beginning of the next growing season than in grasses that have to regrow completely from basal sprouts. Consequently, these kinds of grasses (called "suffrutescent" grasses) can rapidly and effectively use the relatively small, unpredictable supplies of summer rain received in arid environments (Schmida and Burgess, 1988; Burgess, 1995).

Storage of carbohydrate in dormant, above-ground stems is also what makes grasses like black grama and bush muhly so valuable as forage during either drought or winter. Livestock water developments substantially lessen the short-term economic impacts of drought on a ranching operation by allowing cattle to remain on the range and consume dormant vegetation. However, heavy use of these kinds of grasses when they are dormant constitutes a *loss of resource capital* that translates into a reduced capacity for future regrowth and production and reduces the plant's ability to survive should drought conditions persist. Consequently, *grazing during the non-growing season has a more deleterious impact on suffrutescent, warm-season grasses than on the "typical" grasses found on less arid ranges*. Excess use during the growing season which fails to allow sufficient development and storage in above-ground plant parts has the same deleterious effect. The *absolute amount* of this essential resource capital that must be annually retained on these semi-arid grasslands in order to maintain the persistence of these grasses and sustained range productivity has long been underestimated by land-use managers. For example, typical BLM management recommendations for semi-arid rangelands in the region generally stipulate a 50% utilization rule (the amount of the current year's growth allowed to be

removed by grazing before livestock are removed). Similar recommendations are given by the USDA (e.g. Wendt, et al. 1976; p. 65: loam upland range sites). Yet perennial grasses such as black grama cannot sustain this level of utilization in the more arid grasslands of southern Arizona and New Mexico (Martin and Cable, 1964, Holechek, et al. 1994). A more conservative approach in levels of forage use yields better range condition, higher forage production, and ultimately, greater livestock production and higher economic returns in the long run. For example, in black grama ranges of southern New Mexico, conservatively grazed ranges (30% average utilization) produced more forage and ultimately supported higher stocking densities than on ranges where utilization averaged 50% (Holechek et al., 1994).

For the suffrutescent grasses of semi-arid grasslands, even conservative levels of percent forage utilization do not leave sufficient quantities of stored plant reserves in dry years to insure persistence of the plants should drought persist. Management strategies based solely on allowing a constant level of *relative* utilization leave *decreasing* absolute amounts of living, dormant plant tissue behind in periods of low productivity during droughts. Consequently, productivity and range condition can be inexorably and rapidly racheted downward through maintenance of a constant, relative utilization level in years of below-average production. Considerable, hard-to-reverse harm can be done in a relatively short time if sufficient plant reserves are removed during these stressful periods. The importance of leaving a minimum *fixed* quantity of standing plant material to insure sustained range productivity in semi-arid ranges is increasingly recognized (Holechek et al., 1995; Holechek, 1996).

Variable responses of landscapes and soils. Just as different grasses vary in their growth characteristics, different soils and physical landscapes respond variably to removal of

vegetation. Some soils are are inherently susceptible to erosion whereas others are not. For example, soils formed in fine-grained, gravelly alluvial materials like those flanking the south side of the Date Creek Mountain have experienced rapid and widespread erosion. The fine-grained materials alone are easily displaced and transported by runoff. Consequently, vegetation plays an essential role in moderating the erosive power of runoff. Terrains with these kinds of soils in semi-arid regions are inherently unstable and excess removal of vegetation is one trigger that can readily flip the system from one hydrological/ecological state (i.e., an unincised, grass-dominated landscape) to a far less environmentally and economically desirable one (an erosionally incised terrain with reduced or highly altered vegetation cover)(Bull, 1997). The onset of such landscape degradation typically occurs rapidly once the system is moved across a threshold where the power of runoff (stream power) exceeds the landscape's ability to resist the erosive power of runoff (resisting power). Once that geomorphic threshold is crossed, the strong, reciprocal interdependence of vegetation and hydrological dynamics typically produces self-enhancing feedbacks that promote continued and worsening landscape alteration: vegetation removal leads to increased runoff; with increased runoff, moisture storage in soils diminishes, less plant-available soil moisture contributes to futher vegetation declines which in turn aggravates the situation by further increasing the intensity and volume of runoff and accompanying soil erosion and landcape incision (Bull, 1991). The inherent instability of these kinds of semi-arid landscapes requires that they be used *very conservatively* in order to prevent the initiation of episodes of degradation that once begun, may be difficult or impossible to reverse until they have run their course.

In contrast, soils formed in alluvial fan deposits of coarse, extremely rocky materials of weathering-resistant lithologies (rock types) are far more resistant to erosion because the coarse

materials are not easily moved by runoff (Bull, 1991; McAuliffe, 1995). Such terrains are often physically armored by the coarse parent materials and are relatively less dependent on the maintenance of vegetation cover to reduce the power of runoff below the threshold necessary to move the large-sized materials (e.g., large cobbles and boulders). Although selective erosion of fine soil materials from the surface can occurr, rapid erosional incision is prevented by the physical nature of the soil's extremely coarse parent materials.

For example, a large, distinct alluvial fan (Antelope Creek Fan) located to the immediate east of the study area at the same elevation (location in Fig. 3) is composed largely of cobbly to bouldery deposits of weathering-resistant volcanic rocks. The soils that have formed within these coarse parent materials contain very strongly developed, clay-enriched subsoils (Bt horizons). These soils have required a very long time to develop and indicate the surface deposits of the alluvial fan may date to the earliest Pleistocene (2 million years old; see McAuliffe, 1995 for discussion of other similar deposits and their soils). The coarse materials of the fan's surface were originally delivered and deposited long ago by Antelope Creek which has a drainage basin of approximately 16 mi.^{2}(41 km^2). Antelope Creek subsequently cut a channel through these deposits, leaving the most of the ancient fan's surface elevated above any voluminous discharges contained in Antelope Creek. The fan's surface has been hydrologically severed from the large Antelope Creek watershed. Consequently, any runoff flowing over the fan's surface is derived exclusively from precipitation falling on the fan surface. This amount of runoff is but a small fraction of the flows derived from the entire Antelope Creek drainage basin that originally transported and deposited the coarse, rocky materials. These relatively less voluminous and energetic flows can selectively remove fine soil materials, but are incapable of widely and rapidly

entrenching the surface of the ancient alluvial fan. The coarseness of the weathering-resistant materials that comprise the fan deposit literally armor this landscape, protecting it from the effects of runoff across the surface.

The greater resistance of this landscape to erosion has contributed to the persistence of grass-dominated vegetation despite heavy use by livestock. Most of the land contained in the Antelope Creek Fan is property of the Arizona State Land Department and has been subject to use similar to the state-owned lands south of the Date Creek Mountains. Tanks and other water sources are distributed across the fan surface. Tobosa grass is typically very heavily cropped; far greater than 50% utlization commonly occurs (Fig. 13A). Continual, heavy utilization during the growing season has unoubtedly substantially reduced the total overall cover provided by this perennial grass. In most places, less than 25% of the soil surface is covered by perennial grass, and typically 50% or more of the rocky soil surface lacks any vegetation cover. Examination of soils in areas that now lack grass cover shows the presence of darkened, organic-matter enriched surface horizons (mollic A horizons) which clearly indicate the former presence of considerably more extensive and dense perennial grass stands. Even though total vegetation cover has undoubtedly been substantially reduced, the "armor" of coarse stony materials protects this surface from the kind of rapid gullying and severe hydrological alterations as have occurred on the fine-grained alluvial deposits south of the Date Creek Mountains (Fig. 13B). Consequently, the potential of the Antelope Creek Fan and to support tobosa has not fundamentally diminished because surface hydrological characteristics are principally controlled by the nature of the coarse, stony alluvium rather than by vegetation. The physical nature of this terrain make it far more resilient and capable of sustaining relatively heavy use.

Although attempts are made to include knowledge about the potential for soil erosion in range management decisions, unfortunately the only information typically available to land managers does not contain the most up-to-date advances in the understanding of how these systems operate. For example, classifications of runoff characteristics and erosion hazards for the clayey, cobbly soils of Antelope Creek Fan (Rimrock cobbly clay soil series) versus soils where severe erosion has occurred on the south side of the Date Creek Mountains (Vekol and Mohave soil series) contained in the soil survey for the area (Wendt, et al., 1976) provide a case in point. Runoff is listed as "very slow" and "slow" and erosion hazard is identically listed as "slight" in the two highly contrasting sets of soils. The classification of erosion hazard is one factor that contributes to the USDA *land capability classifications* used in making land management decisions. *Range Site* classifications based on the inferred potential plant community composition of a given soil and climate are used to make livestock use recommendations but do not adequately consider the marked differences in landscape behavior (i.e. susceptibility to erosion) despite their similarities in vegetation. An underestimation of the inherent vulnerability of some of these systems to erosion combined with an overestimation of their ability to produce usable forage (discussed in the previous section) have contributed to unsustainable use and degradation of semi-arid ranges. Knowledge about the intrinisic, variable behaviors of coupled geomorphic/ecological systems of semi-arid regions is essential to making land management decisions, including those regarding the placement of livestock water developments and managing the intensity of use around existing ones.

Outlook on Future Rangeland Water Developments

Today, renewed calls are heard for providing additional livestock water developments in upland ranges in order to remove livestock impacts in ecologically sensitive riparian corridors. However, it is mistaken to believe that provision of alternative watering areas and the transfer of livestock onto adjacent upland ranges will be without consequences to any particular riparian corridor. A riparian ecosystem cannot be considered separately from adjacent uplands since the uplands are the source of runoff and sediments delivered to stream bottomlands. The streams that we intend to protect are on the receiving end of whatever we and our livestock do in the uplands. A century ago, livestock water developments in uplands were touted as the panacea for improving range conditions along overused riparian corridors. It was a panacea that simply didn't pan out. It will take much better management derived from knowledge about the biological and physical behaviors of entire landscapes to make sure episodes of degradation are not repeated, despite our best conservation intentions.

ACKNOWLEGEMENTS

I thank the many persons who have helped me in this work. Patrick Boles (State Land Department, Prescott) shared much information about the study area, including the 1864 military map, and accompanied me in fieldwork in the area in summer, 1997. Gary Irish (State Land Department, Phoenix Office) and Charles Deutschlander (Arizona Department of Roads, Photogrammetry and Mapping Dept.) located aerial photographs of the study area. David Smith (USDA Natural Resources Conservation Service, Prescott) shared his knowledge of the area and allowed use of aerial photographs. Librarians Dianne Bean of the Desert Botanical Garden and

Fay Freed (Phoenix Public Library) located and obtained a copy of the1864 military map. The University of Arizona Library archives provided a copy of the 1950 Humphrey photograph. Roy and Kathleen Moore, owners of Moore & Moore Cattle Ranch graciously shared their knowledge about the area's history and the changes that have occurred. Personnel at the Phoenix, Arizona BLM office provided access to original land survey notes. My wife, Carla, digitally copied and processed aerial photographs for use in analyses of vegetation changes and edited the original manuscript. Dianne Bean reviewed the final manuscript. Jim Purvis provided an original copy of the 1903 USGS topographic map. Fieldwork with Tony Burgess in other semi-arid grasslands of southern Arizona has contributed immensely to my understanding of the ecology of these systems. Work and interaction with Les McFadden has broadened my ecological perspective through the inclusion of knowledge about soils and geomorphology. This research was supported by the Desert Botanical Garden.

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Table 1. Composition of upland, grass-dominated stands located in protected corridor between Highway U.S. 89 and the Atchison, Topeka, and Santa Fe Railroad. Data collected 8 October 1997.

	Percentage canopy cover, estimated visually on 8 October 1997	
	Area 1 (Fig. 6A)	Area 2 (Fig. 6B)
Perennial grasses:		
Big galleta (*H. rigida*)	65	20
Bush muhly (*Muhlenbergia porteri)*	0	5
Purple three-awn (*Aristida purpurea*)	1	5
Black grama (*Bouteloua eriopoda*)	0	< 1
Tobosa (*Hilaria mutica*)	0	< 1
Desert fluff grass (*Erioneuron pulchellum*)	1	1
Woody and suffrutescent plants		
Goldenhead (*Acamptopappus sphaerocephalusi)*	1	5
Mesquite (*Prosopis velutina*)	2	2
Catclaw (*Acacia greggii*)	0	2
Whitethorn (*A. constricta*)	1	1
Creosotebush (*Larrea tridentata*)	1	0
Burro-brush (*Hymenoclea salsola*)	2	1
Foothills paloverde (*Cercidium microphyllum*)	0	1
Mormon tea (*Ephedra* sp.)	1	1
Paperflower (*Psilostrophe cooperi*)	0	1
Wolfberry (*Lycium andersonii*)	1	1
Turpentine bush (*Thamnosma montana*)	1	< 1
Succulents:		
Staghorn cholla (*Opuntia acanthocarpa*)	0	2
Christmas cholla (*O. leptocaulis*)	0	1
Pancake prickly pear (*O. chlorotica)*	<1	0
Banana yucca (*Yucca baccata*)	0	< 1

Table 2. Comparison of vegetation inside and outside of the Alamo Road livestock exclosure.

	Total percentage canopy cover, estimated visually on 10 October 1997	
Plant species	Within exclosure	Outside of exclosure
Perennial grasses:		
Tobosa (*Hilaria mutica*)	50 (eastern half)	< 1 in swales
Big galleta (*H. rigida*) upland soils	30 (western half)	< 1 in loamy
Bush muhly (*Muhlenbergia porteri*)	< 1	absent
Purple three-awn (*Aristida purpurea*)	< 1	absent
Lehmann lovegrass (*Eragrostis lehmanniana*)	< 1	absent
Woody plants:		
Creosote bush (*Larrea tridentata*)	5-10	25-30
Catclaw acacia (*Acacia greggii*)	1	1
Mormon tea (*Ephedra* sp.)	1	1
Mesquite (*Prosopis velutina*)	1	1
Succulents:		
Staghorn cholla (*Opuntia acanthocarpa*)	5 (swales)	2-5 (swales)
Joshua tree (*Yucca brevifolia*)	2	1-2
Banana yucca (*Y. baccata*)	1	1
Perennial forbs:		
Desert holly (*Perezia* sp.)	10	< 1
Creeping ragweed (*Ambrosia psilostachya*)	10	< 1

Figure Captions

Figure 1. Map of the study area in southern Yavapai County, Arizona. Areas of exposed bedrock of mountains and hills are shaded. The remainder of the terrain consists of alluvial fan deposits. Elevation contours in meters.

Figure 2. Portion of "Map of the Military Department of New Mexico" (Anderson, 1864). Pictured is the southwestern part of Arizona, the Colorado River, and a small strip of southern California on the west side of the Colorado River. The town name "WICKENBERG" is shown on the right center. "CAMP ON DATE CREEK", a U.S. military camp was located on the north side of the Date Creek Mountains. The words "Grass Valley" are located on the other (south) side of the Date Creek Mountains. Photograph of map provided by Phoenix Public Library.

Figure 3. Distribution of earthern stock tanks and other features discussed in the text. Tanks east of highway 89 are not plotted. Three tanks that have either been cut by channels or have been filled with sediment and cannot impound water are shown with open symbols. The location of R.R. Humphrey's 1950 photograph is indicated along the northern boundary of township T9N, R6W. The small, shaded rectangle in the southwestern part of this township is the area shown in the repeat aerial photographs of Figure 5. Three reference areas that receive little or no grazing from domestic livestock are indicated by arrows.

Figure 4. A. Photograph by Robert R. Humphrey on 2 February1950 southwest of Congress, looking northeast with the Date Creek Mountains in the background. Tobosa grass predominates. Filaree, a winter-spring ephemeral, forms the dark, irregular mottling on the soil surface. Only a few mesquite canopies are present. **B.** Matched photograph taken 20 September 1992. The few small shrubs in the foreground are broom snakeweed. Small mesquites are the dominant plants over the rest of the view. Perennial grasses are completely absent. The fenceline present in the 1950 photograph is hidden from view in 1992 by the brushy canopies of mesquite. The original 1950 photograph was originally published in Humphrey (1950). The matched pair of photographs was previously published in McAuliffe (1995) by the University of Arizona Press.

Figure 5. Aerial photographs showing changes between 1963 and 1995 in a portion of the study area (see Fig. 3 for location). The road along the lower margin is Highway 93, under construction in the 1963 photograph. The lighter-colored "upland" areas between dark-colored swales contain the same kinds of soils as the site shown in Figure 4A and originally supported grasslands in which woody plants were few (isolated canopies of small mesquites apparent as dark dots in 1963). The darker swales contained dense stands of tobosa, such as those shown in Figure 10. By 1977 the density of small mesquites had markedly increased. Drainage channels increasingly cut into swales, leading the the disappearance of tobosa from many of these environments. In 1995, only small remnants of tobosa cover remain in limited parts of swales that have not yet been incised. Perennial grasses have been almost entirely eliminated from upland areas and shrubby mesquites predominate. In the upland soil environments, areas between

mesquite canopies generally lack perennial plant cover, with the exception of small, short-lived shrubs such as broom snakeweed. The arrow indicates the vicinity of the advancing headcut shown in Figure 11.

Figure 6. Relict grasslands between railroad and highway right-of-ways located 1 mile (1.6 km) due east of the peak of Saguaro Hill. **A.** View north in of well-drained upland site dominated by big galleta. **B.** View south of mixed grass stand in upland, well-drained site with big galleta, bush muhly, and a few black grama plants. Railroad tracks in upper right. Species compositions for both stands listed in Table 1 and soils of both areas contain slightly calcic, sandy loam surface horizons. The stands are both located in the SW 1/4 of Sec. 13, T9N, R6W. Photographs taken 8 October 1997.

Figure 7. Much enlarged area of aerial photograph showing the livestock exclosure along Alamo Road. A broad swale borders the eastern (right) side of the plot. Adjacent uplands are covered by creosotebush.

Figure 8. Fenceline contrasts at Alamo Road livestock exclosure. 10 October 1997. **A.** Facing directly north toward interior of fenced plot from the plot's southeastern corner. Tobosa is the dominant perennial grass within a swale in this portion of the plot. **B.** View south of the area open to livestock from the plot's southeastern corner. Tobosa have been nearly eliminated except for a few heavily used plants located in refuges beneath staghorn cholla (right foreground). **C,D.** Easterly views from the southwestern corner fencepost of the exclosure. The protected area (left of fence, **C**) contains big galleta in this more xeric, upland environment but this grass has been totally eliminated from upland areas outside of the exclosure **(D)**.

Figure 9. View of the southern slope of Saguaro Hill, 9 October 1997. Tobosa predominates in the foreground. The small trees are foothills paloverde (*Cercidium microphyllumi*) and the cacti are pancake pricky pear (*Opuntia chlorotica*). Total perennial plant canopy cover on the southern exposures is over 50% and tobosa provides most of this cover.

Figure 10. Dense stand of tobosa in a swale that has not been incised by gullies (E 1/2, Sec. 29, T9N, R6W). Photograph taken 10 October 1997.

Figure 11. A. View south of headcut advancing into a swale that was formerly occupied by tobosa. Location of headcut shown in aerial photograph (Fig. 5, 1995). This headcut is one a pair that branch from a single channel located a short distance downslope. The headcut position was marked with stakes in 1991 and by July, 1997 had advanced 28.5 ft. (8.7 m) from the position marked by the hat . The eastern fork of the headcut (not pictured to the left) advanced headward a distance of 92 ft. (28 m) during the same time period. The channels immediately below both headcuts are approximately 3 feet (1 m) deep. **B.** View north taken 65 ft. (20 m) directly upslope from advancing headcut in zone of converging flows and increased runoff velocity. More rapid movement of water is causing sheet erosion and pedestalling of tobosa

plants. Grass plants in the foreground are dead, dying, or in poor condition, whereas the rest of the tobosa stand in the background has not yet suffered from the effects of rapid loss of runoff. Photograph taken on 18 July 1997.

Fig. 1

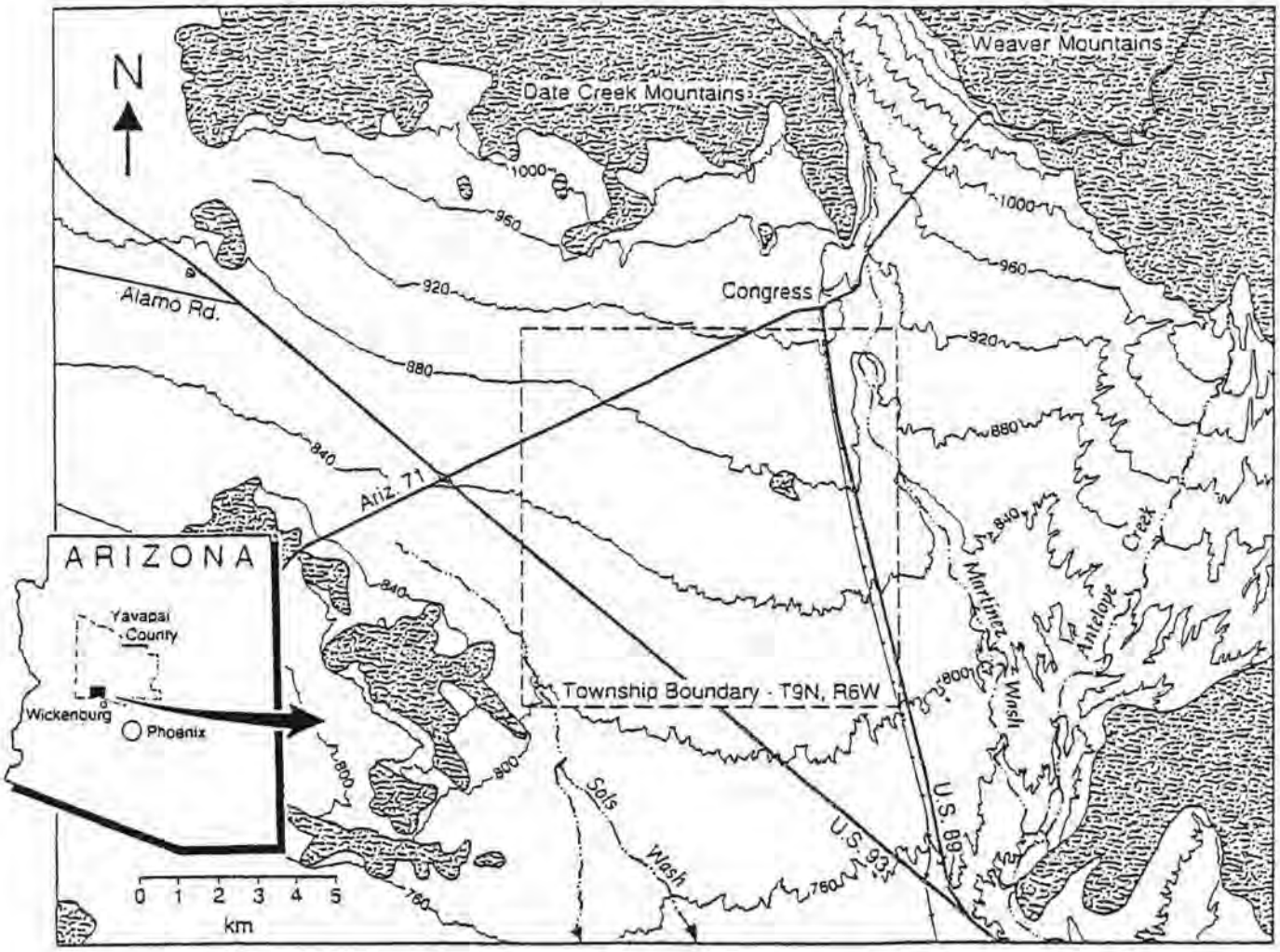

Fig. 2


MAP
OF THE
MILITARY DEPARTMENT
OF
NEW MEXICO
Drawn under the direction of
Brig. Gen. JAMES H. CARLETON
BY
Capt. ALLEN ANDERSON, 5th U.S. Infantry.
Acting Engineer Officer.
1864.
PRINCIPAL LATITUDES AND LONGITUDES
ASTRONOMICALLY DETERMINED.
LATITUDE. LONGITUDE. AUTHORITY.
Albuquerque 35° 05' 31" 106° 37' 30" Capt. A. W. Whipple.
Santa Fe 35° 41' 00" Maj. W. H. Emory.
Doña Ana 32° 17' 14" 106° 48' 35" " "
El Paso del Norte 31° 44' 18" 106° 29' 00" " "
Azotea Chico 31° 11' 11" 105° 09' 15" Capt. A. W. Whipple.
Persia 34° 30' 57" Maj. W. H. Emory.
CAPTL
BLACK
PRESCOTT
HUALAPAI
GREAT
SANTA FE
CASTLE
DOME
FORT YUMA
Gila Station

Fig. 3

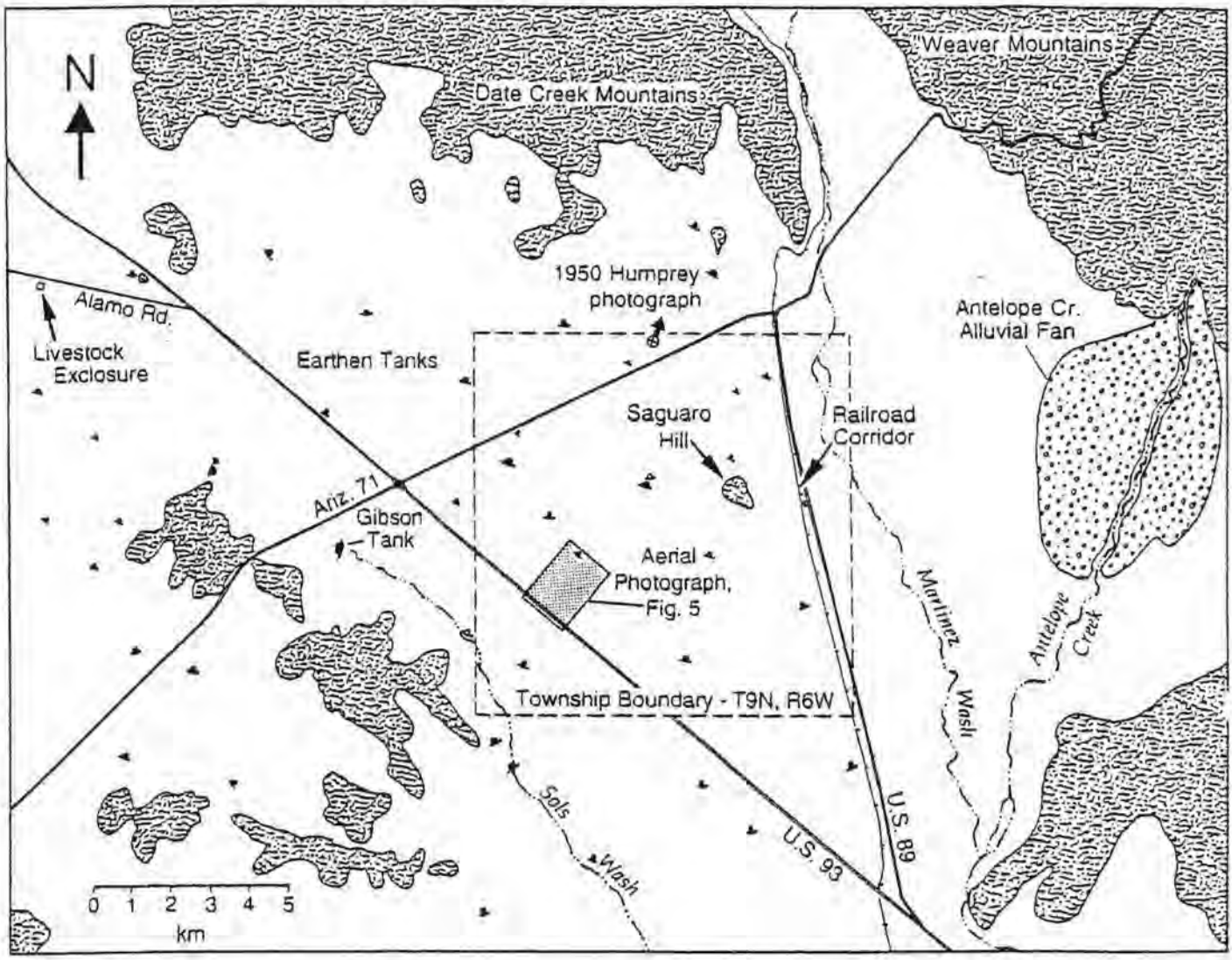
N
Date Creek Mountains
Weaver Mountains
1950 Humprey photograph
Alamo Rd.
Livestock Exclosure
Earthen Tanks
Antelope Cr. Alluvial Fan
Saguaro Hill
Railroad Corridor
Ariz. 71
Gibson Tank
Aerial Photograph, Fig. 5
Martinez Wash
Antelope Creek
Township Boundary - T9N, R6W
Sols Wash
U.S. 93
U.S. 89
0 1 2 3 4 5
km

Fig. 4

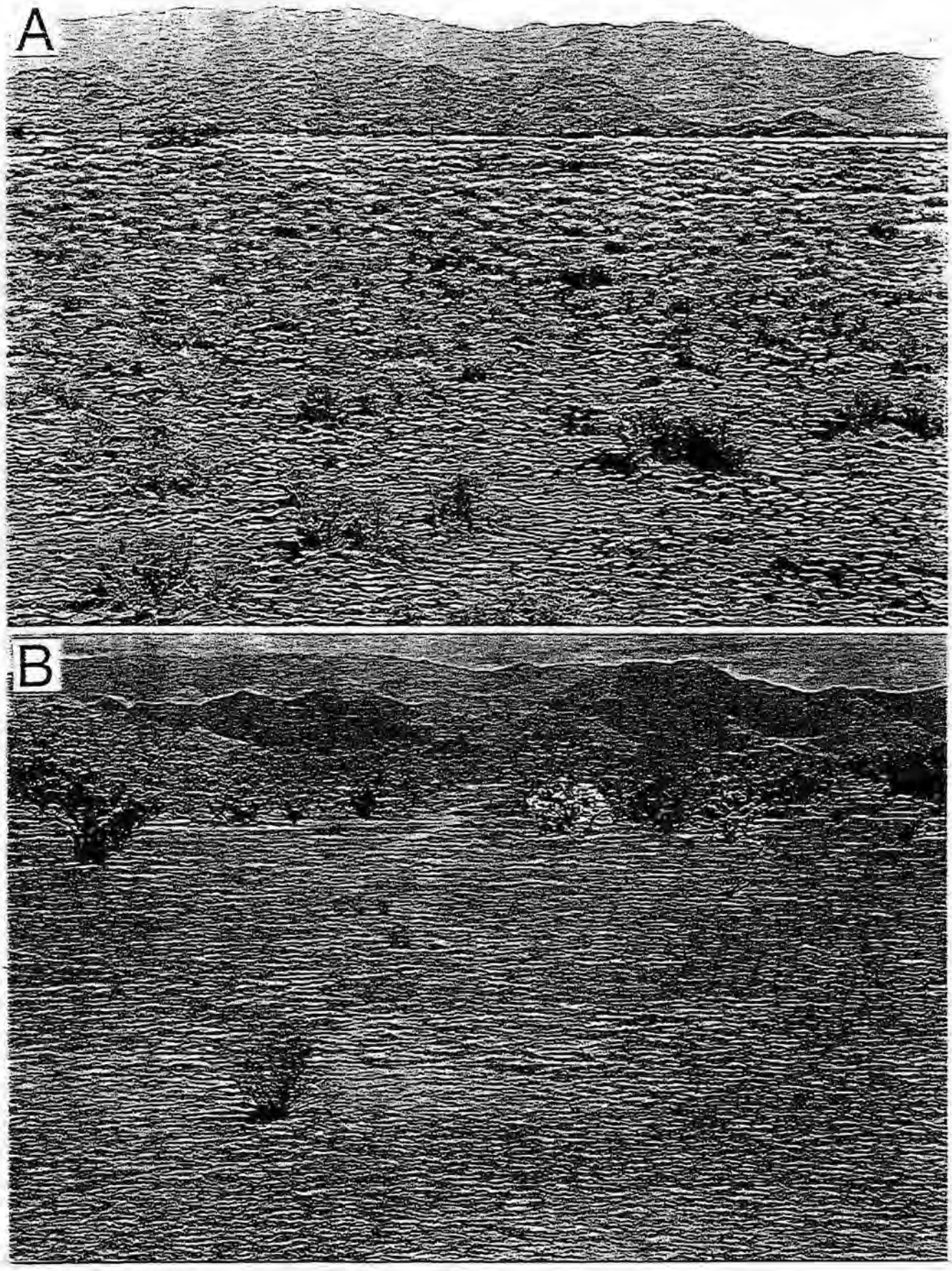

Fig. 5a

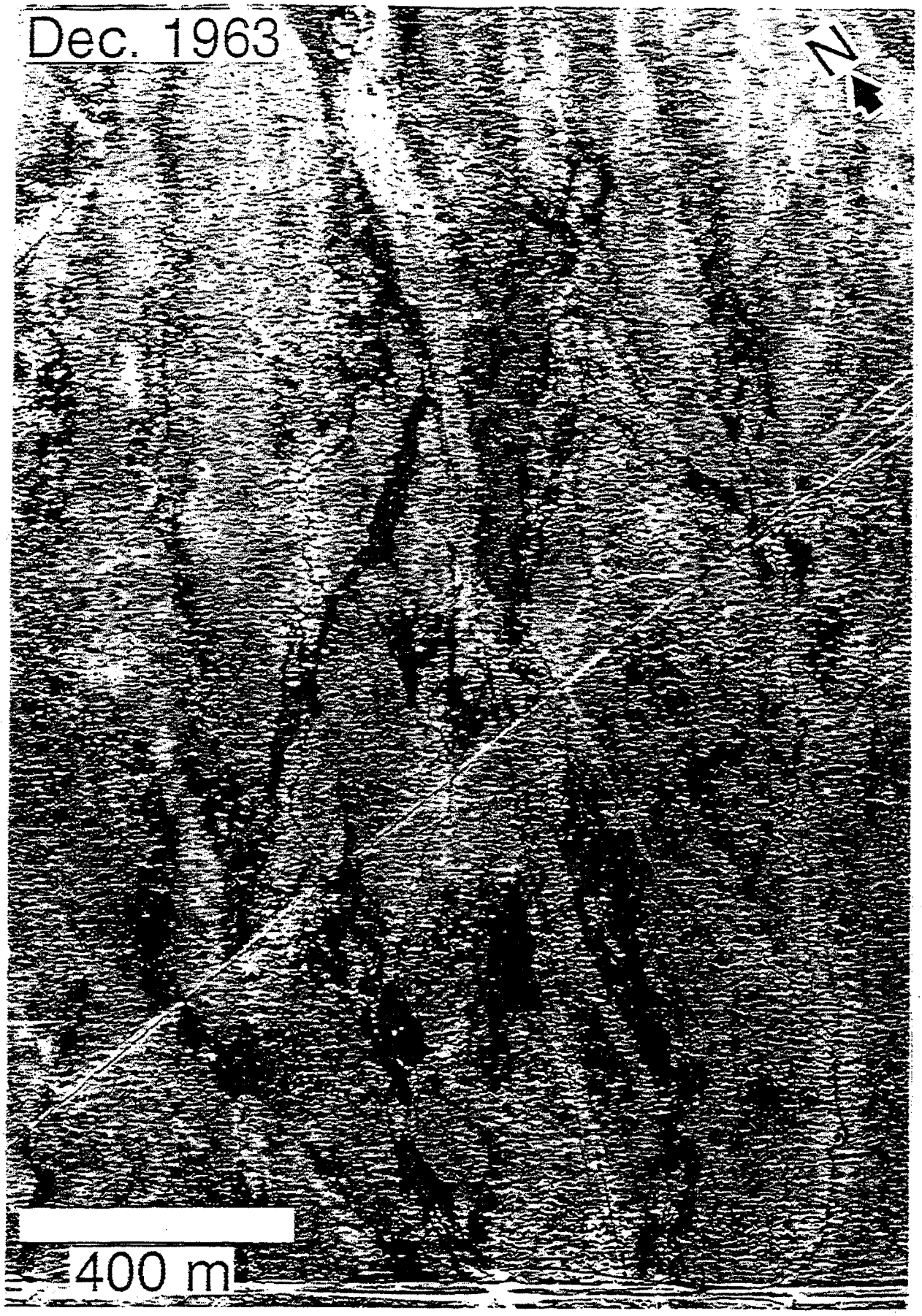

Fig. 5b

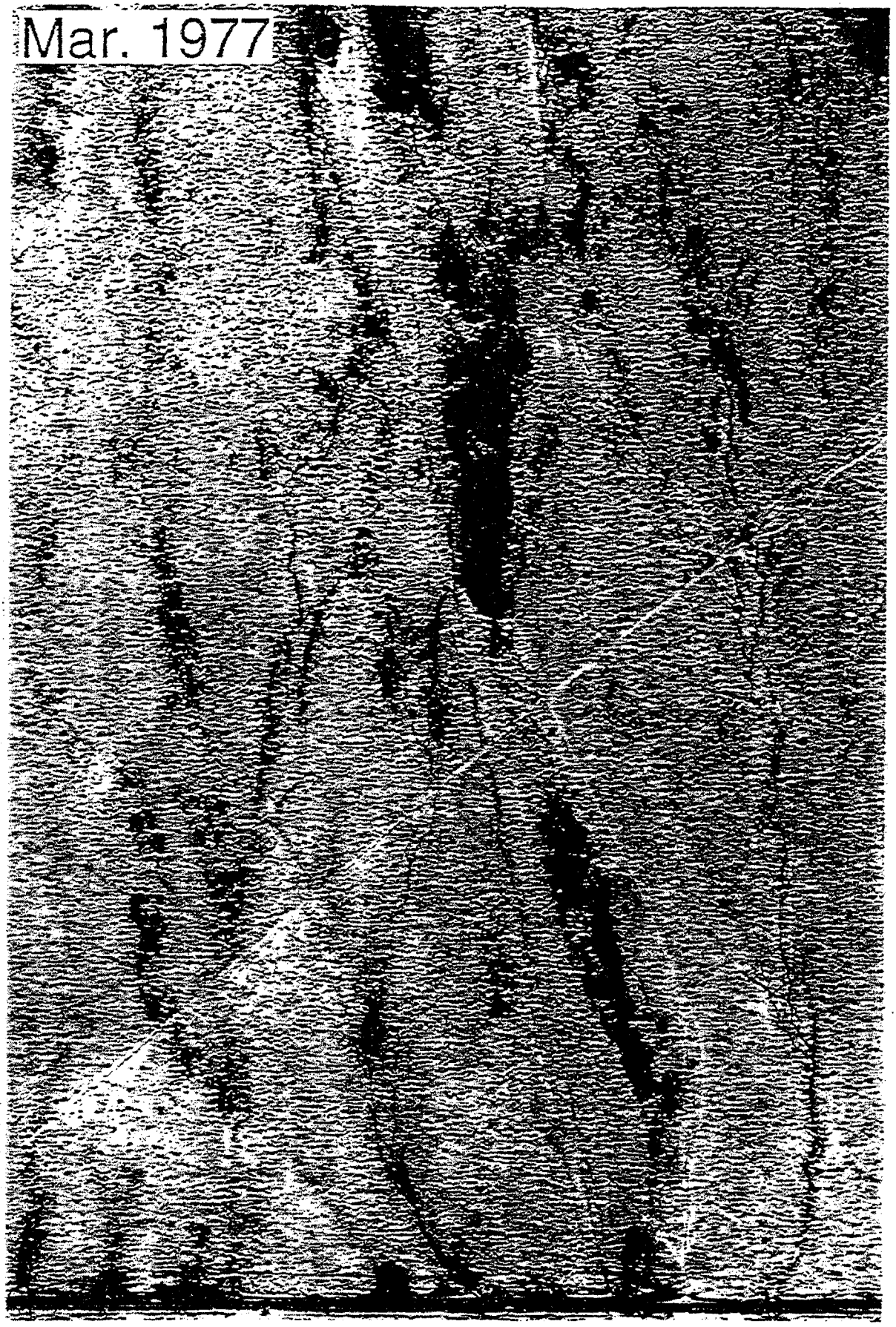

Fig. 5c



A



B

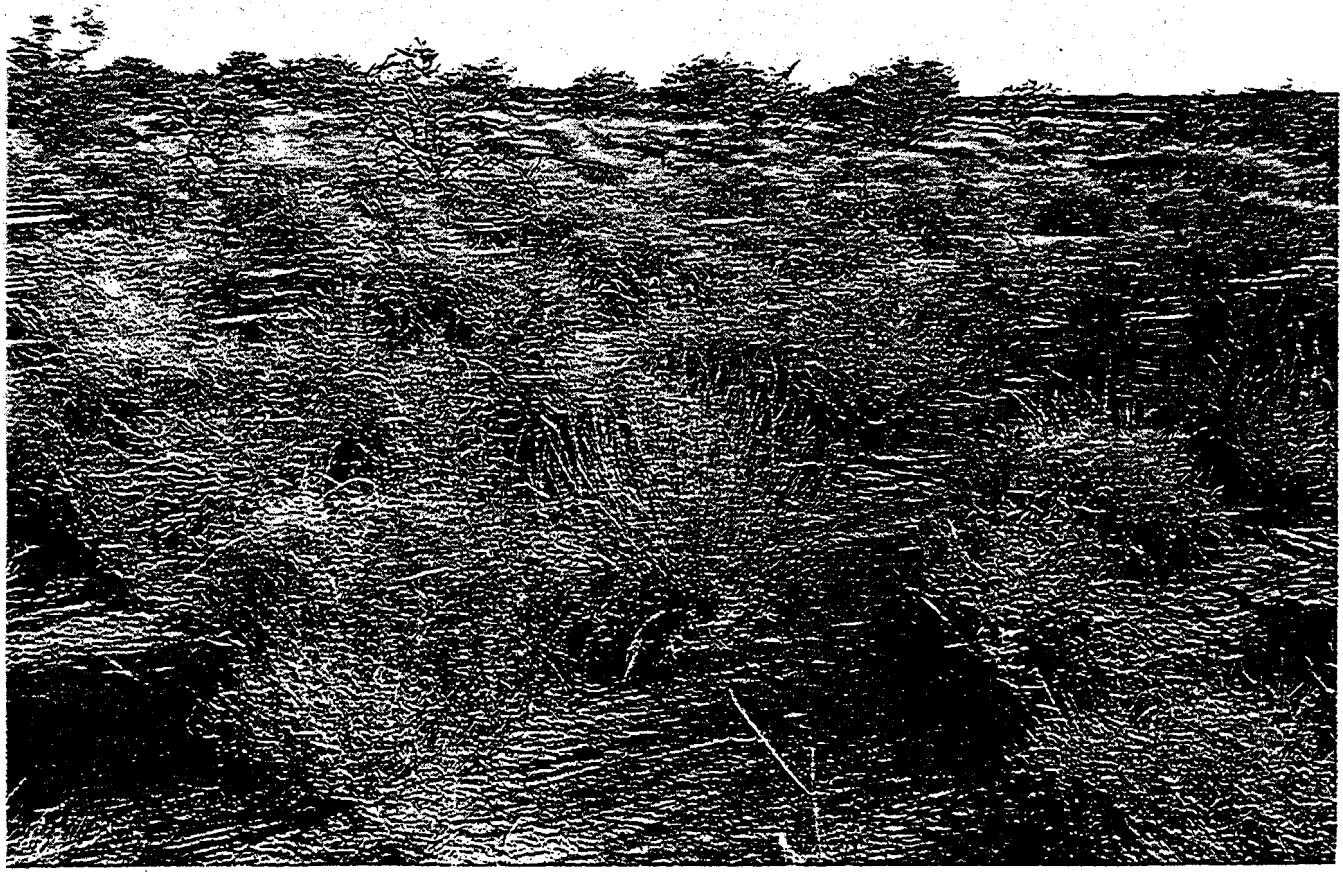

Fig. 7

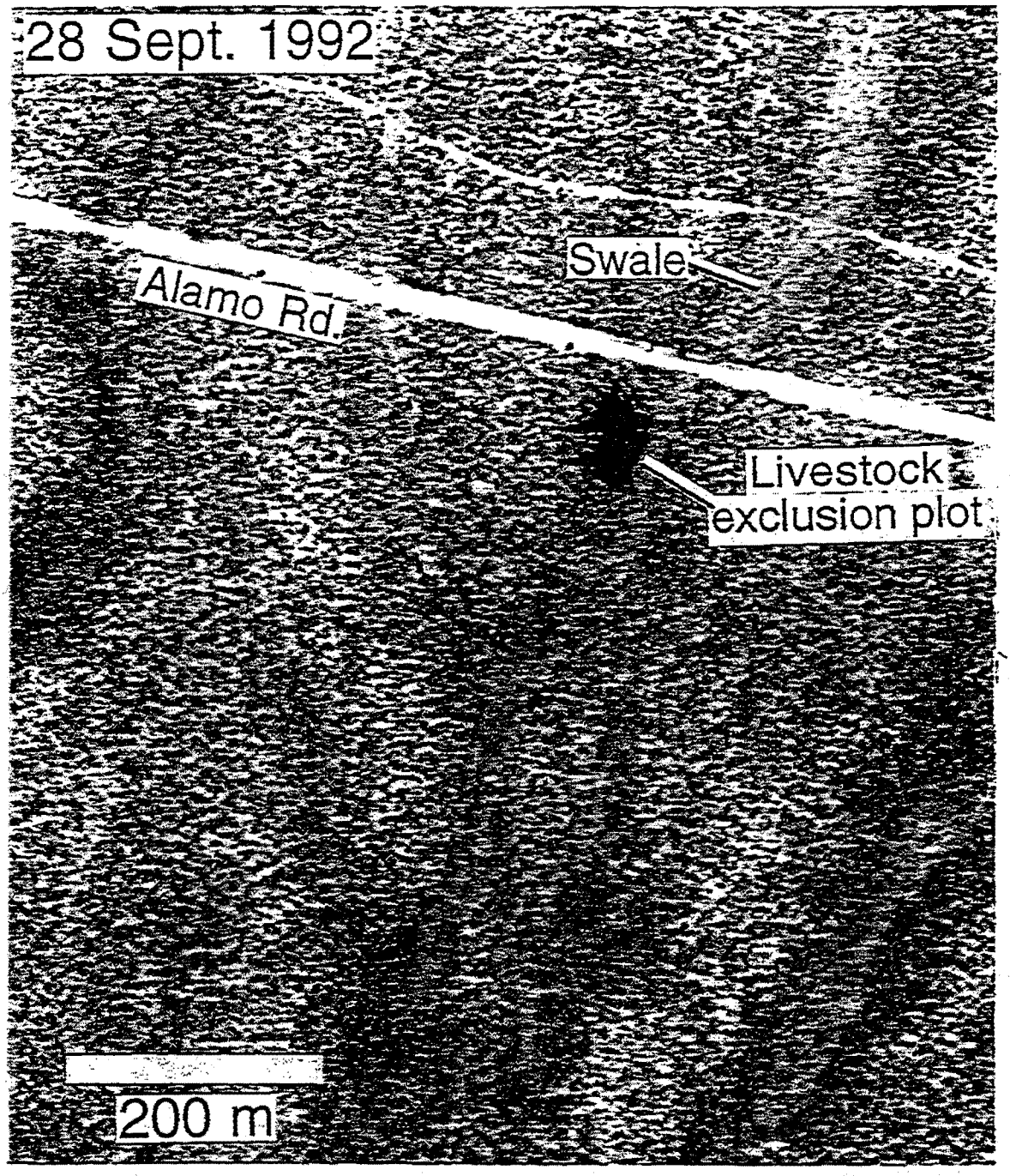

Fig. 8a and 8b

Fig. 8c and 8d

Fig. 9

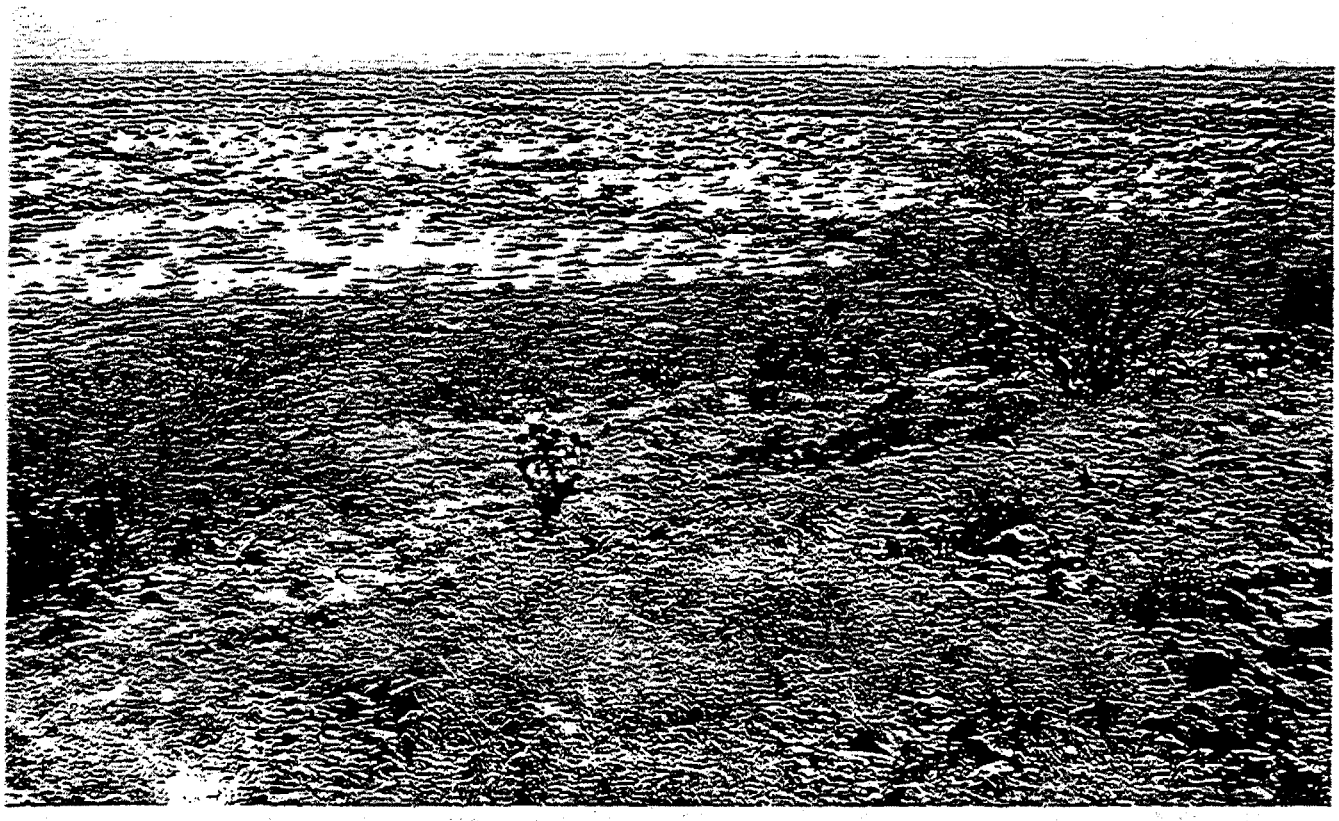

Fig. 10



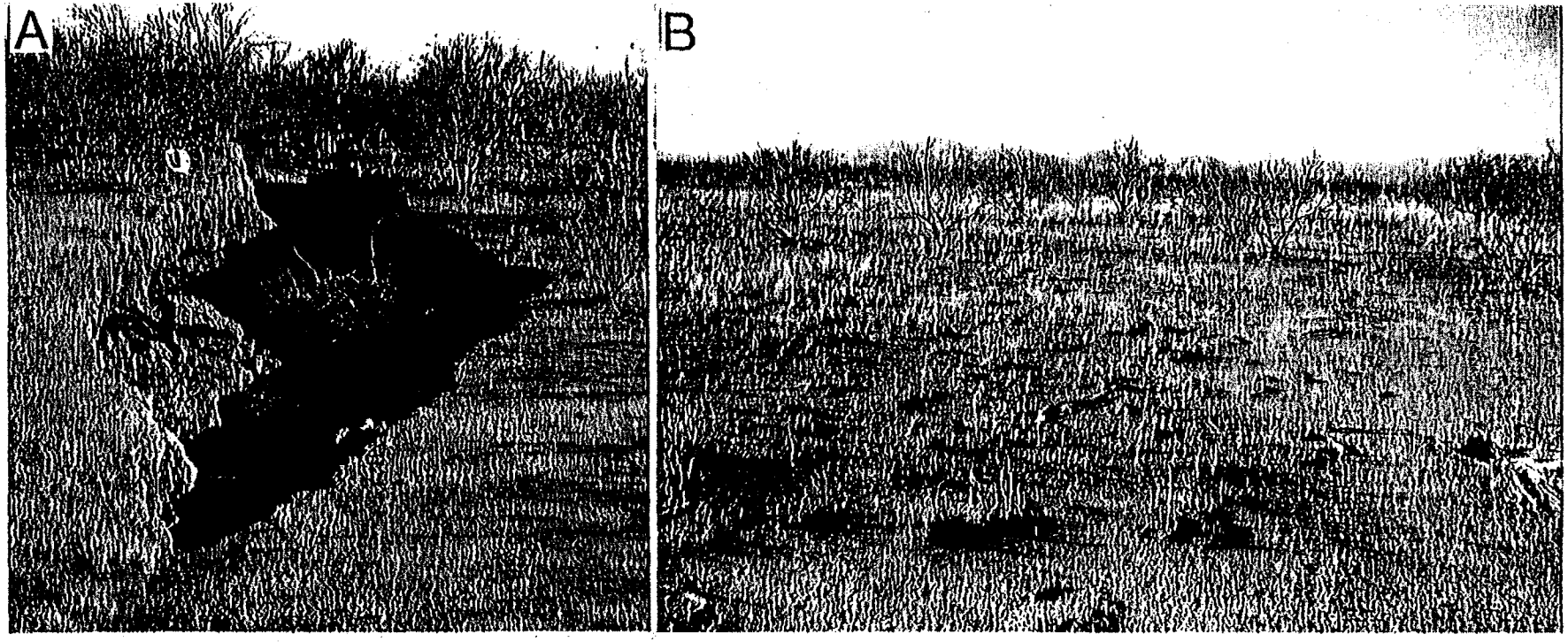

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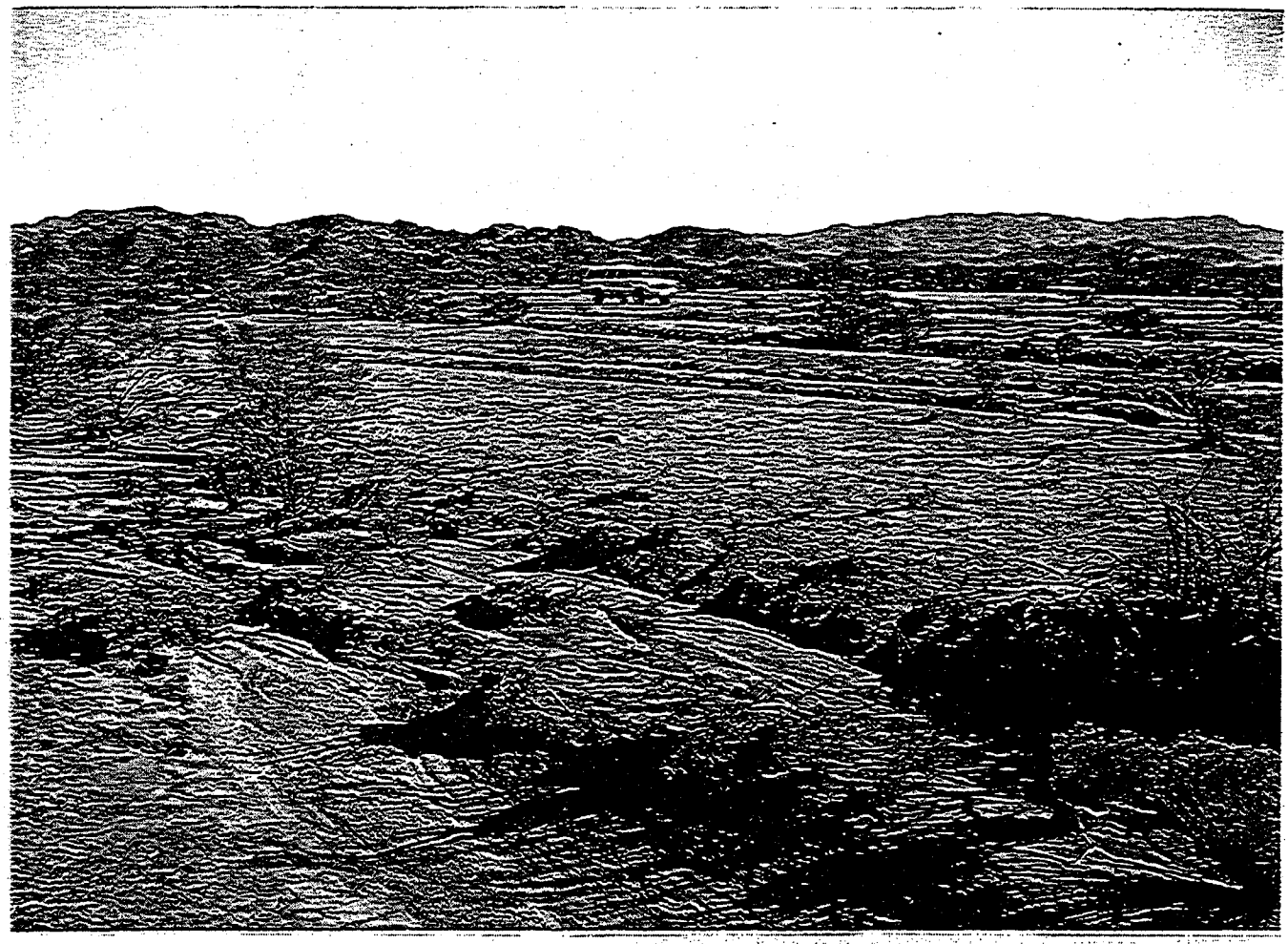
Fig. 11

Figure 12. Four rutted, abandoned roadways in foreground located in NE 1/4, Sec. 12, T9N, R6W, 0.4 mi. (.64 km) south of Henderson Tank. The vehicle is parked on a fifth, parallel roadway. Rutted roads like these rapidly remove water from the landscape rather than allowing recharge of soil moisture.

Fig. 13 A. Overview of Antelope Creek Fan, SE 1/4, Sec. 3, T9N, R5W, approximately 300 ft. (91 m) due east of Earis Tank, a large earthern cattle tank. **B.** Soil surface of the Antelope Creek Fan, armored by weathering and erosion-resistant, coarse parent materials.

Fig. 12



A

B

Fig. 13

Dirt is Not Cheap: Livestock Grazing and a Legacy of Accelerated Soil Erosion on Organ Pipe Cactus National Monument, Arizona

Susan Rutman[1]

Abstract - Active sheet and gully erosion is a management problem at Organ Pipe Cactus National Monument, Pima County, Arizona. Sheet erosion has removed up to 25 cm of sediment in places and in other places gullies are 1 - 2 meters deep. To determine when the accelerated erosion began and to identify possible causes, an environmental history of each erosion site was constructed by compiling the scattered information located in books and the files, archives and libraries of the Monument and the National Park Service-Western Archeological and Conservation Center, Tucson, Arizona. Observations regarding current conditions and land uses on adjacent properties contributed to the interpretation of historical material. Of the six actively eroding areas in the Monument, two sites are addressed in this paper. The Dos Lomitas site was located on the south (International) boundary of the Monument. Accelerated erosion rates were most likely triggered there by poor grazing management practices and channelization of the Rio Sonoita. Accelerated erosion at the Armenta Ranch site was most likely triggered by poor livestock grazing practices. Water developments, livestock grazing and fine soil texture were the three common denominators at all six erosion sites in the Monument. The Monument, having permanently lost many thousands of cubic meters of soil, now must try to minimize additional losses.

INTRODUCTION

Organ Pipe Cactus National Monument (Monument), Arizona, was designated by presidential proclamation in 1937 to protect a unique part of the Sonoran Desert containing organ pipe cactus (*Stenocereus thurberi*). Since the early history of the Monument, the problems of managing livestock and accelerated erosion attracted a great deal of management attention and concern. References to six erosion sites appear repeatedly in National Park Service (NPS) written materials starting in the 1940s and continuing to the present. These six sites and their locations in the Monument (in parentheses) are: Dos Lomitas (south boundary east of Lukeville), Kuakatch Wash near Armenta Ranch (north-central Monument), East of Growler Canyon (east of the Bates Mountains in the western Valley of the Ajo), Cherioni Wash (southern Valley of the Ajo), Growler Valley (west of Bates Well, Bates Mountains) and Palo Verde Camp (northwest corner of the Monument).

This paper reports on an interdisciplinary study undertaken to identify areas on the Monument

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[1]Plant Ecologist, Organ Pipe Cactus National Monument, Route 1, Box 100, Ajo, Arizona 85321.

that have experienced accelerated erosion, to describe land uses that might have triggered accelerated erosion cycles, to investigate and document attempts to control erosion and to assess the current status of these sites. This paper highlights two of these case studies.

One of the case studies was the Dos Lomitas erosion site, located along the south boundary of the Monument, east of Lukeville, between the Gachado line camp and Dos Lomitas. This erosion site was the focus more erosion control construction work than any other site in the Monument. References to it appear frequently in the historic written and photographic record. The second case study and of more recent concern was the active gully erosion occurring mostly west of the historic Armenta Ranch, along one branch of Kuakatch Wash.

METHODS

Organ Pipe Cactus National Monument is located in southwestern Pima County, Arizona. It is bounded to the south by the State of Sonora, Mexico, to the west by Cabeza Prieta National Wildlife Refuge, to the north by Federal lands managed by the Bureau of Land Management and to the east the Tohono O'Odham Reservation.

The Dos Lomitas erosion site was located east of Lukeville, Arizona, adjacent to the International Border between the U.S. and Mexico. The eroded area was mostly contained within Township 18S, Range 5W, sections 9, 10, 14 and 15. The site is in the Rio Sonoyta watershed.

The Armenta Ranch erosion site was located in the Valley of the Ajo near the northern boundary of the Monument. The eroded area was mostly contained within Township 14S, Range 6W, sections 23 and 24. The site is in the Gila River watershed.

The Monument was fortunate to have archival materials that document (albeit incompletely) historic land use, the progress of erosion problems and activities associated with erosion control. These materials allowed the author to locate sites with ongoing or historic accelerated erosion in the Monument. To determine when accelerated erosion began and to identify possible causes, an environmental history of each erosion site was constructed by compiling the scattered information located in books and files in the archives and libraries of the Monument and the National Park Service (NPS)-Western Archeological and Conservation Center, Tucson, Arizona. Observations regarding current conditions and land uses on adjacent properties contributed to the interpretation of written and photographic historical material.

RESULTS AND DISCUSSION

The Soil and Moisture Conservation Program

No discussion of accelerated erosion and its management in the Monument would be complete without reference to the Soil and Moisture Conservation (SMC) program. Under this program,

the U.S. Department of Agriculture Soil Conservation Service (SCS, now the Natural Resources Conservation Service) worked cooperatively with the NPS. The SCS provided funding for soil conservation projects that were developed and reviewed by the two agencies and were carried out by the NPS. Annually during the 1940s through the 1960s, the Monument proposed projects to the SCS and reported on their implementation. To meet SCS funding requirements, proposed projects had to be clearly tied to soil conservation.

The first SMC project to be funded was the construction of the barbed-wire fence along the south boundary of the Monument. Superintendent William Supernaugh justified using SMC funds to construct the boundary fence by stating that the fence would exclude Mexican livestock, which were contributing to overgrazing and the erosion problem (Memoranda #1, 2, 10, 11, 12, 13 and 14; Document #3). After this section of the fence was completed in December 1947 (Memorandum #21), the flow of trespass livestock from Mexico was slowed or stopped. By 1948, the eastern, northern and western boundaries were also completely fenced.

The early 1950s marked the beginning of nearly twenty years of SMC program construction to control erosion in the Monument. The first of these projects was constructed near Dos Lomitas in 1951 (Memorandum #4). Construction methods were based on work the SCS had carried out on the Tohono O'Odham Indian Reservation near Santa Rosa (Memorandum #11). Over its sixteen-year history in the Monument, the SMC program funded the construction of water spreaders (shallow ditches backed by berms), check dams, catchments, detention dams, overflow aprons, retention furrows, rock-filled wire baskets, and diversion dams, as well as seeding projects.

SMC construction work was primarily focused on the eroded areas along the south boundary, east from near the Gachado line camp to Blankenship Ranch. Work was also conducted at the following sites: west of Bates Well (Growler Wash), Kuakatch Wash near Armenta Ranch, east of Bates Well near the confluence of Cherioni Wash and Cuerda de Lena, and in an unspecified area along Cherioni (Five Mile) Wash. The last of the erosion control structures funded by the SMC program was constructed in 1967 at Dos Lomitas (Memoranda #16, 17).

Twenty to forty years later, many of these erosion control structures remain clearly visible from the ground and on aerial photographs. Specific effects to the plant and animal communities, soil nutrients and the hydrology of local areas remained undetermined, although aerial photographs and ground observations clearly indicated that the projects have had a long-lasting effect on the plant community. Plant distribution was non-randomly patterned by the structures and cryptobiotic soil crusts have not yet recovered completely from the soil disturbance or loss.

The Dos Lomitas Erosion Area

Dos Lomitas are two small hills located in the southern Sonoyta Valley, an expansive, low-elevation desert plain located to the west of the Sierra Santa Rosa and east of the Puerto Blanco Mountains. The southern boundary of the Monument bisects the southern end of the Sonoyta Valley, where there are rolling, rocky hills separated by wide flats with deep soils.

Accelerated erosion has occurred on the flats, where the soil is a Gilman loam or silt loam thicker than 2.4 m (8 ft) (USDA Soil Conservation Service 1972, Great Western Research 1989). The most pronounced gully erosion has occurred within 0.8 km (0.5 mi) to the east and west of Dos Lomitas. Sheet and rill erosion have occurred in a broader area along the south boundary, extending east from Lukeville to east of Dos Lomitas.

Creosotebush *(Larrea tridentata)* and desert saltbush *(Atriplex polycarpa)* dominated the vegetation on the fertile, deep loams of the flats. Associated species included linear-leaved saltbush *(Atriplex linearis)*, saguaro *(Carnegiea gigantea)*, Christmas cactus *(Opuntia leptocaulis)*, barrel cactus *(Ferocactus* sp.) , hedgehog cactus *(Echinocereus* sp.), and chain-fruit cholla *(Opuntia fulgida)*. The washes dissecting these flats supported a rich riparian community composed of creosotebush, velvet mesquite *(Prosopis velutina)*, blue palo verde *(Cercidium floridum)*, white-thorn acacia *(Acacia constricta)*, grey thorn *(Ziziphus obtusifolia)*, and desert hackberry *(Celtis pallida)*. Above the flats on the coarser and less fertile soils of the low hills, a sparse creosotebush/triangle-leaf bursage *(Ambrosia deltoidea)* association occurred.

Historic Background

Pinpointing the time when the accelerated erosion cycle at Dos Lomitas began was impossible. Evidence indicated that soil loss probably began before the establishment of the Monument in 1937. As early as 1947, sheet and gully erosion due to livestock grazing were reported (Document #3). By the 1950s-- only 13 years after the Monument was created-- photographs documented a progressed state of gullying (Photograph Accession #1624, 1629, 1642, 1644, 1646). If erosion predated the establishment of the Monument, it seemed reasonable to conclude that land uses predating 1937 might have contributed to the accelerated erosion problem. The two major land uses that occurred in the Dos Lomitas area prior to 1937 were livestock grazing and truck farming.

The truck farming occurred near the Sonoyta River, not far (about 3.2 km or 2 miles) south of Dos Lomitas. The town of Sonoyta was founded on a natural cienega (swamp) on the Sonoyta River sometime around 1850 (Hoy 1970). During this time, the Sonoyta River flowed ". . . in a narrow channel . . . without embankments . . ." (Lumholtz [1912] 1990). The residents raised fruits and vegetables on fields irrigated with artesian well water and water diverted from the cienega. Livestock roamed freely in and around the Sonoyta River and its cienega.

In 1891, floods destroyed the cienega and channelized the river (Lumholtz [1912] 1990). Afterwards, river downcutting progressed fairly rapidly. When Lumholtz saw the river in 1909, he noted that the trench was about 6.1 m (20 ft) deep. By 1943, Monument Custodian William Supernaugh examined the river two miles east of the current town of Sonoyta and noted that ". . . floods had cut a channel fifty feet deep" (Memorandum #23). The entrenchment of the Sonoyta River destabilized the watershed and headcutting most likely began to work upstream.

The first known livestock rancher to occupy the south boundary/Dos Lomitas area was Lon Blankenship, who ran about 100 head of cattle until selling to Robert Gray senior in 1929 (Hoy

1970). Blankenship and, later, Robert Gray and his sons (the Gray Partnership) provided water for livestock at the Blankenship (Dos Lomitas) Ranch house and Gachado line camp. After purchasing the ranch, the Gray family added about 500-600 head of cattle to Blankenship's 100. By 1942, there were over 1,673 head of cattle, well over the NPS permitted amount of 1,050 head (Schultz et al. 1971; Hoy 1970).

Because there was no fence separating the U.S. from Mexico until 1947, the Gray's herd ranged freely into Mexico for nearly two decades. The reverse was also true; livestock from Mexico (including cattle, goats, horses, mules and burros) ranged into the Monument (Memoranda #1, 2). In June 1942, the NPS estimated that 1,000 head of wild burros and horses from Mexico were grazing in the southern half of the Monument (Hoy 1970). The Grays estimated that there may have been as many as 3,000 cattle on the Monument at one time (Schultz et al. 1971).

The saltbush communities along the International Boundary probably provided suitable forage for livestock, at least for a while. By 1948, Paul Balch, NPS Soil Conservationist noted that:

> "Everything edible and within reach of stock was eaten and the stock were all in poor condition. The vegetation cannot endure this over utilization [*sic*] and continue to maintain its vigor." (Document #3)

Despite Balch's recommendation, the pleas of Superintendent Supernaugh, and numerous permit violations, the Gray family did not decrease the stocking rate. The Gray Partnership successfully fought any changes in grazing fees and stocking rates by enlisting the assistance of an attorney and by appealing to U.S. Senator Carl Hayden, the NPS Regional Office and the Office of the Department of the Interior Secretary (Hoy 1970). The relationship between the Gray Partnership and the NPS was a long and stormy one, documented by years of frequent correspondence.

While mired in politics, the Monument continued to issue a grazing permit to the Gray Partnership. Eventually, the year-long use and overstocking resulted in soil erosion, the reduced density and vigor of plants and the development of cattle trails (Memoranda #1 and 2, Document #3, USDI Bureau of Land Management 1966, Schultz et al. 1971). Along the south boundary, these problems were most pronounced around water sources, such as Gachado Well, Dos Lomitas and Blankenship Ranch. The BLM noted in 1966 that the ". . . most severe use exists around the Blankenship Well, where dead remnants of saltbush are found" (USDI Bureau of Land Management 1966). That same year the BLM estimated the carrying capacity of the range within the service area of water to be 314 cattle yearlong on the Monument. More than four times the carrying capacity were actually grazing on the Monument.

The BLM returned to the Monument in 1970 to report on the range conditions (Schultz et al. 1971). Along the south boundary east of Lukeville they reported:

> Very severe use on desert saltbush is evident throughout this area. There are many dead plants and those living are very decadent and show a lack of vigor. Many plants have

dead branches and centers. Trampling damage has occurred throughout. Age ratio is not proportionate. Young plants, when found, were severely hedged. The entire saltbush types have a mowed appearance.

Mesquite around Blankenship has been high-lined. Many paloverde trees show damage by cattle. Perennial grasses, though not prevalent along arroyos, were severely grazed except where protected (Schultz et al. 1971).

Unaccessioned photographs of the Gachado Well and Dos Lomitas areas in 1965 showed virtually no plants more than a few inches tall. Where the plant community was in poor condition, surface erosion accelerated because the density and cover of vascular plants and cryptobiotic soil crusts decreased, raindrop impact was increased, sheetflow volume and velocity was increased and percolation was reduced. The entrenched cattle trails and roads directed and concentrated flows. Sheet erosion, rilling, gullying and channelling resulted.

The Monument issued the last grazing permit to the Gray Partnership in 1968. Undaunted, the Gray Partnership continued grazing livestock in the Monument without a permit until their deaths in 1974 and 1976. Approximately 1,500 head of cattle, a few dozen wild horses and several hundred burros were removed from the Monument by 1979.

Erosion Management at Dos Lomitas

The Monument's efforts to control erosion began in 1947 with the construction of the barbed-wire fence across the south boundary to stop Mexican livestock from drifting into the Monument. The next attempts to control erosion along the south boundary were more ambitious.

In 1951, the SMC program provided $2,000 for the purchase of grass seed and construction of 25 check dams and overflow aprons. Two photographs taken in 1952 (Photograph Accession #1642 & 1643) showed structures that may be the check dams or overflow aprons that were built in 1951. The grasses Arizona cottontop *(Digitaria californica)* and Plains bristlegrass *(Setaria macrostachya)* were seeded into the soil disturbed by construction. In addition, ". . . one large wash was diverted back to its original channel" (Memorandum #4). Unfortunately, records did not indicate exactly where this work was done. Encouraged by the success of the structures (Memorandum #4), Superintendent Supernaugh decided to continue the rehabilitation project.

In 1952, fifteen diversion dams with a total length of 2,415 m (7,920 ft) and containing 2,061 cubic m (2,700 cubic yd) of material were constructed in the Sonoyta Valley (Memorandum #5; Photograph Accession #1628, 1641). These structures were also seeded with Arizona cottontop and Plains bristlegrass (Memorandum #5). Paul Balch, NPS Soil Conservationist, was somewhat disappointed with the success of these structures, reporting that only three of the dams were completely "successful" while flooding damaged the others. He attributed the lack of success to underestimating the size of the watershed (Memorandum #6).

The SMC program provided about $100 to purchase and spread grass seed in the Sonoyta Valley

during the summer of 1952. Almost 7 kilograms (15 lb) of Arizona cottontop, Plains bristlegrass, and side-oats grama *(Bouteloua curtipendula)* seed was planted in freshly disturbed ground and covered with brush to keep cattle off. The seeded area was in the basins of catchments constructed earlier in 1952. A "considerable portion" of the seeds sprouted during that summer (Memorandum #7). Again, the project reports do not specify the location of these construction actions.

A plan to construct 450 earthen dams (water spreaders) covering 518 ha (1,280 ac) was proposed for fiscal year 1956 (Memorandum #8). Reality was less ambitious than the plan and by February 1956, water spreaders covering approximately 130 ha (320 ac) were constructed north and west of Gachado Well (Memorandum #20).

In fiscal year 1957, Superintendent Mullady reported that water spreading dams were added to previously contoured areas so that the structures were no more than 30.5 m (100 ft) apart (Memorandum #9). He also reported that the projects had been expanded beyond their existing limits (Memorandum #9).

In 1958, contour furrows were constructed across 304 ha (750 ac) in the Dos Lomitas area (Memoranda #10 and 18). Furrows that followed the natural contours were placed at 15.2 m (50 ft) intervals. A large retention furrow or dam was also constructed across the center of the project. This project was documented photographically (Photograph Accession #3264 - 3276, 3277, 3280). Work on the Dos Lomitas project was continued in 1959, when check dams with intervening water spreaders were constructed (Memorandum #14).

During the 1960s, SMC work along the south boundary continued. Wire fencing intended to collect debris and decrease flow velocity was placed across washes in 1962 (Memorandum #15). These "wire contours" were documented photographically (Photograph Accession #1637 & 1639). In 1964, an erosion dike was repaired and wire rock baskets and fill were placed in a wash one mile east of Blankenship Well (Memorandum #22). That same year, a two hectare (5 ac) livestock exclosure/study plot was constructed near Dos Lomitas (Memorandum #24).

The last SMC construction project was the construction in 1967 of rock-filled wire baskets in two washes where erosion ". . . has reached a very serious stage" (Memoranda #16 and 17). A single undated photograph (Photograph Accession #2757) showing a wire basket "to prevent erosion in arroyo-fence crossing" might be depicting this project.

1997 Status

The eroded gullies at Dos Lomitas were now entrenched about 1 - 2 m (3.3 - 6.5 ft) below the current soil surface, which has dropped at least 20 - 30 cm (8 - 12 inches). Channel erosion and headcutting was continuing. Data from permanent study plots established by North Central Illinois College have shown that between 1977 and 1997 headcuts had progressed upstream (Marsh 1981, Marsh unpublished data). Using aerial photograph comparisons, Warren (Letter #25) documented that the headcuts of existing gullies at Dos Lomitas had progressed upstream in

the 7 - 8 years between 1976 and 1983. As these headcuts move upstream, newly established plants are undercut and killed.

Fortunately, the older vertical cutbanks had begun to round off as soil slumps off the banks and builds along the sides of the wash. Plants were actively establishing on this newly deposited soil and will help decrease channel flow velocity and retain soil. More recently (within the last decade or so), plants have also begun to establish in the denuded areas between gullies.

By March 1996, plant populations near Dos Lomitas had higher densities of new recruits in areas unaffected by SMC erosion control work or where soil deposition had occurred than in areas that had lost soil or had been disturbed in the past. To the north of the westernmost hill (lomita), plant density and cover was low and recruitment was not occurring or was occurring very slowly. Recruitment was occurring along water spreaders generally on top of the berms, not in the trenches where water accumulates. South of the easternmost hill, where no water spreaders were apparent (from the air or on the ground) in 1996, recruitment of saltbush and creosotebush was actively occurring and plant cover was surprisingly high. Compared with the area north of the hill, the area south of the hill was more actively recovering (S. Rutman, pers. observ. 1995).

Near the Gachado line camp, plant density and canopy cover has been increasing slowly since livestock were removed. As at Dos Lomitas, the water spreaders and larger structures were still visible and were affecting distribution of newly establishing plants. Recovery was set back in 1983 and 1984 when two non-overlapping fires killed many of the perennials in areas where water spreaders had been installed.

It may be no coincidence that the areas along the south boundary that had been severely overgrazed, eroded, and manipulated by SMC projects were also the areas where native and non-native weedy annuals have been very successful and fire has been a problem. Mediterranean grass *(Schismus barbatus)*, an exotic species, was abundant (>80% cover) near Gachado Well and Dos Lomitas during the winter of 1995. This species provided a fine, continuous fuel that could easily have carried a fire through the recovering site. Other weedy species such as amaranth *(Amaranthus* sp.), annual globemallow *(Sphaeralcea* sp.), feather fingergrass *(Chloris virgata)* (non-native) and buffelgrass *(Pennisetum ciliare = Cenchrus ciliare)* (non-native) occurred in these disturbed areas and in some years provided dense and continuous enough fuel to have carried a fire.

Armenta Ranch Erosion Area

Armenta Ranch was a homestead located in the north-central part of the Monument. The erosion area was mostly west of Armenta Ranch, centered around one branch of Kuakatch Wash (Figure 3). The erosion area was near the center of the Valley of the Ajo, where the topography is flat and drainages are shallow and overlay deep alluvium. Overland flow of water is common during flood events. The soil is Gilman very fine sandy loam (USDA Soil Conservation Service 1972).

Description and classification of the potential vegetation of the area was difficult because very little of the area was undisturbed. In the center of the valley, shallow groundwater and overland flood-flows between the several channels of Kuakatch Wash supported a velvet mesquite bosque, which no longer exists in the Valley of the Ajo. In 1997, the xeroriparian areas lining the channels had canopies of blue palo verde, velvet mesquite, ironwood *(Olneya tesota)*, crucifixion thorn *(Castela emoryi)*, and grey thorn with a prominent vine component that included Texas virgin's bower *(Clematis drummondii)*, climbing milkweed *(Sarcostemma cynanchoides)* and indian root *(Aristolochia watsonii)*. Shrub species in the riparian zone included brittlebush *(Encelia farinosa)*, canyon ragweed *(Ambrosia ambrosioides)*, cheesebush *(Hymenoclea salsola)*, rayless encelia *(Encelia frutescens)*, four-wing saltbush *(Atriplex canescens)*, sandpaper plant *(Petalonyx thurberi)* and desert honeysuckle *(Anisacanthus thurberi)*. Small washes were lined with galleta grass *(Pleuraphis rigida)*, Arizona cottontop and bush muhly, occasional trees and a rich array of shrubs. Areas between washes in this part of the valley supported tall-stature creosotebush, bush muhly (a grass) and annual plants.

Historic Background

Historic references to the Armenta Ranch erosion area were difficult to find and sketchy. The first record of gully erosion at Armenta Ranch was a collection of photographs taken in 1963 (Photograph Accession #3285 - 3288 and 3290 - 3292). These photographs show a progressed state of deep gullying, indicating that the erosion had begun long before 1963.

Early memoranda, maps, and letters about erosion in the Monument mentioned the Dos Lomitas and Bates Well erosion areas, but did not mention Armenta Ranch as a critically eroded area. A 1952 map of erosion produced for a contemporary Master Plan for the Monument included the gullied area west of Armenta Ranch in the "serious erosion" category, not the more serious "critical erosion" category. The 1952 map did include East of Bates Well and Dos Lomitas sites as "critically eroded." Collectively, these observations implied that the erosion cycle might have been triggered or at least expressed slightly later at Armenta Ranch than at Dos Lomitas. Exact timing remains unknown. During historic times, land uses in the area included livestock grazing, truck farming and woodcutting. Of these uses, livestock grazing was the longest lasting and most widespread.

The truck farming era was short-lived. The Armenta family moved to "The Temoral" (now known as the Armenta Ranch) in the 1920s and raised corn, squash and watermelon on irrigated fields (Hoy 1970). A hand-dug well pumped water from 12.2 m (40 ft) below the surface. The well soon went dry and the Armentas abandoned the farm by 1935 after digging a well 73 m (240 ft) deep that never reached water. The runoff from the devegetated farm field for decades has delivered unnaturally large flows to the channel, contributing to downcutting.

Woodcutting occurred along the wagon trail that went through the Armenta Ranch area and connected the small mining camp of Ajo to points south (Hoy 1970). The faint shadow of this road could still be seen on aerial photographs taken in 1987. This old trail became entrenched and impassable and by 1917 was abandoned in favor of the newer "Ajo-Sonoyta Road" a few

miles to the west. The old trail and the newer road provided access to the Monument for woodcutters seeking heating and cooking fuel and building materials for the then-burgeoning mining town of Ajo. Advertisements for "local mesquite" appeared in the Ajo Copper News in the 1910s and 1920s. Local ranchers were also cutting wood for building, heating, livestock corrals and other uses. "Woodcutting is one of our biggest problems on the Monument," stated the November 1939 Superintendent's Monthly Report. Complaints about woodcutting continued to appear in the Superintendent's Monthly Reports through the 1940s, particularly during World War II when home heating fuels were rationed. In 1997, numerous cut tree stumps were still visible near these two abandoned roads, providing modern evidence of historic woodcutting.

Livestock grazing was the first commercial use of the area. Rancher Ruben Daniels had about 1,000 head of cattle headquartered at Bates Well by 1913 (Hoy 1970). The herd ranged across the Ajo Valley via Cherioni Well to Alamo Canyon in the Ajo Mountains. Daniels' ranch and what remained of his original herd eventually passed to the Gray Partnership. The Grays continued to graze livestock yearlong in the Bates Well area. These cattle ranged freely and trailed from Bates Well to Rasmussen Tank, about 7 miles away near the Armenta Ranch. Livestock access to Rasmussen Tank was cut off in 1948, when the NPS constructed the fence along the north boundary of the Monument. The Grays then hauled water to a small charco (a small impoundment that captures overland or channel flows) about 0.5 km (150 yards) from the Armenta's abandoned house. The remains of this charco were still present in 1997 but surrounded by deep gullies.

Although there are no records of the early stages of erosion at Armenta, a 1948 description of an erosion site near Cherioni Wash (about 10 miles south of Armenta) probably accurately describes the erosion that was to happen later at Armenta Ranch. The two sites have the same soil type, similar topography and similar position in the watershed. The amount of soil loss and the array of dead trees and shrubs that remain standing at Armenta in 1997 seemed similar to that noted by Paul Balch at the Cherioni Wash erosion site in 1948 (Memorandum #27):

> There is an estimated 2560 acres of land . . . in this condition. Overgrazing has continued until all grass has been extinguished. This exposed the soil to advanced sheet and rill erosion which has removed all the top sandy loam soil down to a fairly heavy clay soil. There has been a loss of up to 12 inches of this top soil from relatively flat country.
>
> The mesquite and creosote bush have been dying in this vicinity during the past few years. I believe this to be due to a lack of water, since first, the area has been overgrazed until vegetation is destroyed, second, sheet and rill erosion have developed into an advanced stage, third, infiltration capacity is lowered to practically zero with loss of top soil and the sealing effect of the remaining soil, fourth, the runoff with nothing to hold it back rapidly flows off into gullies . . . which in the end lowers the water table.

A 1965 study of range conditions on the Monument (USDI- Bureau of Land Management 1966) briefly mentioned the erosion problem at Armenta. An expanded description appeared in a

follow-up study of range conditions (Schultz et al. 1971). They reported:

> Water is available at Bates Well. Although Armenta Well is approximately seven miles to the east-northeast of Bates Well . . . cattle continue to trail between the two. Water is not available at Armenta Well and palatable forage species are extremely rare yet cattle trail here, possibly to harvest the annual grama production (page 11)."
>
> The Armenta area is severely cut up by cattle trails, of which many have become water courses and are developing into gullies and headcuts. The area around the buildings is severely cut by gullies and head cuts that are deep (4 to 5 feet) . . . (page 14)."

Despite the overuse, the Gray Partnership resolutely continued grazing above their permitted stocking rate of 1050 head of cattle and 6 horses. They continued grazing even after the National Park Service did not issue them a grazing permit. The NPS began removing livestock after the last Gray brother passed away in 1976. By 1978, about 1500 head of cattle, several hundred burros and an unspecified number of mules and horses were removed from the Monument.

Livestock overuse was continuing to affect the Monument in 1997. Two Bureau of Land Management grazing allotments were immediately adjacent to the Monument to the north of Armenta Ranch. The poor condition of these lands has undoubtedly contributed to the erosion problem at Armenta Ranch. Aerial photographs taken in the 1960s and 1970s showed the area near Rasmussen Tank was denuded or nearly denuded and this condition remained in 1997. This situation has resulted in unnaturally large flows of water being delivered to Cuerda de Lena and Kuakatch Wash in the Monument.

A 1989 study of the Armenta erosion problem cited the north boundary road as one of the triggers for accelerated erosion (GWR 1989). It is unlikely that this road was an early trigger of erosion because the section of road along the northern boundary approximately between Cuerda de Lena and Armenta Ranch was not constructed or at least did not appear on road maps until after the 1960s. In 1997 the road had become deeply entrenched in certain areas and had begun contributing to the erosion problem by diverting surface flows away from natural channels..

Erosion Management at Armenta Ranch

The 1968 Range Management Report (Letter #19) suggested seeding the non-native species buffelgrass (*Pennisetum ciliare*) and Lehmann's lovegrass (*Eragrostis lehmanniana*) in the erosion area to stabilize the site. There were no records indicating whether or not this seeding was carried out. The two species did not occur at Armenta Ranch in 1997.

In late July and early August of 1984, the Monument constructed a rock dam (gabion) across the main channel where the Armenta Road crosses it just west of the ranch buildings. Unfortunately, some velvet mesquite trees were destroyed in the construction process. The loss of these trees probably further destabilized the channel banks. Also constructed in August 1984 were thirteen wire-and-brush weirs in several side channels.

Shortly after the 1984 construction of the dam and weirs, a flash flood washed out three of the thirteen weirs. An unknown number of weirs remained in 1997. The project was documented with unaccessioned photographs and line drawings (Monument files).

Current Status

In 1997 the gully of the main channel was about 2 - 3 m (c. 6.6 - 9.8 ft) deep. The headcut has moved upstream during the last decade and in the summer of 1995 captured the north boundary road. Active erosion has been continuing in some but not all areas, but no recent data have been collected. Dr. Terry Marsh and students from North Central Illinois College established permanent study sites in this erosion area in 1977 and reported headcutting had occurred between 1977 and 1997 (Marsh 1981 and unpubl. data).

The SCS visited the Armenta Ranch erosion area in 1989. They thought the watershed was healing and given enough time the erosion problem would resolve itself (Memorandum #26).

Observations made in 1996 support the SCS's conclusion. The vertical sides of the main and side channels had collapsed in many areas and native plants such as mesquite, creosote bush, three-awn *(Aristida* sp.), globemallow, and triangle-leaf bursage were growing in this newly established margin.

Site conditions in 1997 remained harsh, however. Few plants have been able to establish in the flat, devegetated areas between the gullies, where the soil surface was a clay hardpan. Recruitment in these areas was probably poor for a number of reasons. The top layer of soil, which formerly contained the stored seed bank and other beneficial organisms such as cyanobacteria, was gone. Seeds migrating into the eroded area from surrounding areas were blown or washed off the soil surface. Cryptobiotic soil crust was absent. Moisture infiltration was so poor that seedling survival was unlikely. Nurse plants were at low density or absent. Seedling plants were unprotected from herbivorous animals. In summary, physical and biological conditions on devegetated areas needed to be mitigated to improve plant survivorship and growth.

CONCLUSION

Although the Dos Lomitas and Armenta Ranch erosion areas have different land use histories, their similarities have provided compelling evidence that livestock overgrazing has permanently affected soil resources and has had long-lasting effects on plant distribution and density on the Monument. This conclusion was further supported by evidence from the other four erosion sites on the Monument.

The six erosion areas were alike in that they were all centered around livestock water developments-- wells, tanks, charcos or water hauls. Livestock congregated around these water sources and locally devegetated the area.

A second similarity was that the areas surrounding the erosion sites were overgrazed. Starting in at least the 1920s and continuing through the 1970s, livestock numbers exceeded a sustainable stocking rate. By 1965 livestock were travelling 7 - 8 miles away from water sources to obtain sufficient forage (USDI- BLM 1966). With significantly reduced plant density, cover and vigor over most of the Monument, unnaturally high runoff was occurring. Overland flows were channeled by livestock trails, which were embedded up to 30 cm (12 in) on Gilman sandy loams. Wash channels not large enough to carry the unnaturally high flows became entrenched. The sheet, gully and channel erosion that continues today is a manifestation of this historic watershed disruption. Only after the affected watersheds stabilize will the biotic communities begin to stabilize. The natural processes of achieving equilibrium in both the physical and biological systems will take many more decades to resolve.

A third similarity among the erosion sites was that they all occurred on Gilman Series sandy loams. Livestock concentration areas that occurred on less erodable soils experienced some soil movement but did not experience catastrophic soil loss. Unfortunately, livestock distribution and forage availability determined the location of livestock waters and not soil erosion potential. Developing a water source where livestock will congregate on fine-textured, erodable soil has significantly different consequences than developing water on more erosion-resistant soil types.

The construction of erosion control structures in the 1950s and 1960s compounded the disturbance caused by livestock grazing and accelerated erosion. These structures did little or nothing to stop erosion, but did have long-lasting effects on plant distribution, natural drainage patterns and other aspects of the physical and biological environment. If the erosion control projects of that era remain visible and still affect the environment nearly fifty years after they were constructed, then full site recovery may take tens or even hundreds of years more.

The long-term damage caused by livestock grazing on the Monument could have been avoided had the warning signs been heeded. Local land managers, biologists and visitors repeatedly reported resource damage caused by livestock and ranching-related activities (e.g. off-road driving). The livestock operators either did not recognize or did not care about such resource damage. The NPS for decades was ineffectual at managing the resource misuse. The desire of one family to commercially produce livestock on public lands prevailed. The result has been the permanent and continuing loss or redistribution of thousands of cubic meters of soil and long-term loss in plant productivity.

The ineffectualness of public land managers when dealing with irresponsible land users is not a new story nor is it peculiar to the NPS. Seldom are records available to document a long-term resource problem, however. National Parks and Monuments are perhaps uniquely equipped, given their archived material and currently ungrazed landscapes, to evaluate the effects of humans on the environment.

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LEGAL ISSUES RELATED TO RANGELAND WATER DEVELOPMENT

Recent Legal Developments Regarding Water Rights on Rangeland Water Developments - No One is Completely Right!

David A. Brown[1]

In 1978, the United States Supreme Court held that water rights arising from cattle grazing by permittees on the forest should be adjudicated to the permittee under the law of prior appropriation. *United States vs. New Mexico*, 438 U.S. 696 (1978). In the last seven years in Arizona, this proposition has been tested in court, by the legislature and by the Clinton administration and the issue of ownership of water rights on public lands is at best murky. The answer to the question of who owns the water rights on rangeland water developments depends on many factual and legal scenarios, including the nature of the land ownership, (i.e. forest service, BLM, state, private) and the facts and background surrounding the development and appropriation of the water. Rangeland water rights issues is becoming the subject of more scrutiny as competition for other uses increases on rangelands.

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[1] Attorney, Pinetop and St. Johns, Arizona - with emphasis in water rights. Portions of this paper were originally drafted by Paul Orme, Esq., and other portions are from various briefs filed in the Gila or Little Colorado adjudications.

PREAMBLE

Prior to the 1970s, the development of rangeland water facilities occurred in a fairly simple, non-controversial manner. Prior to 1919, a water right was perfected by the recording of a Notice of Appropriation or by beneficial use of the water, or both. After 1919 if a user of public land wanted to develop a stockwater facility on federal or state lands, a mechanism was in place through the 1919 Arizona Water Code to apply for and obtain a certificate of water right. Certificates were routinely issued in the name of the applicant, the majority of which were ranchers, but also from time to time included the public land agency. In most respects, the public land agencies and the ranchers cooperated in the development of and legalization of the respective water rights.

In the 1970s, two general stream adjudications began in Arizona: The Gila River Adjudication covering the southern and central portion of the state, and the Little Colorado River Adjudication covering the northeastern portion of the state. These two cases involve approximately 75,000 claims to water asserted by individual users, as well as municipalities, industrial users, and irrigation districts in the State of Arizona, and the federal government on behalf of National Forests, National Parks, wilderness areas, and numerous Indian tribes. Despite years of cooperation between public land managers and private grazing lessees, permittees, and allottees, water right ownership disputes have arisen in the Gila and Little Colorado River stream adjudications. These proceedings require a legal determination of all attributes of every appropriated right on a watershed. However, experience in the first cases demonstrated that it was prohibitively expensive to determine stockwatering rights through adversarial proceedings on a case-by-case basis. The cost of the proceedings in the Silver Creek watershed sub-basin of the Little Colorado and the San Pedro sub-basin of the Gila adjudications was ruinous for small claimants. Furthermore, the controversy between the public land agencies and the ranchers was exacerbated by a policy issued by the Arizona Dept. of Water Resources in 1992 (DWR) which is discussed at length in this paper.

As a result of the cost of the litigation associated with the adjudication of small water rights, including the attempted determination of water rights on public lands, the Arizona legislature formulated a study committee which studied issues which resulted in legislation in 1995 referred to as House Bill 2276 and House Bill 2193. On April 17, 1995, several Apache tribes filed a Petition for Special Action in the Arizona Supreme Court seeking to stay of all proceedings in the Gila and Little Colorado General Stream Adjudications and a decision that House Bill 2276 and subsequently 2193 violate the U.S. and Arizona Constitutions and other federal laws. Subsequently, the United States, on behalf of several of its public land agencies also objected to certain provisions of the new legislation. The State of Arizona did not object.

This paper attempts to set forth the history behind water rights for stockwatering on public lands to demonstrate why the events and litigation of the last twenty years seems to drag on forever. Meanwhile, any further development of rangeland water projects is clouded by the specter of continued litigation. The answer to the question of who owns the water rights on

any given rangeland water development depends on many factual and legal scenarios. However, this paper concentrates on the vast body of law which protects the right of an individual to own water rights on public lands.

I. INTRODUCTION

On August 12, 1992, DWR issued a Statement of Policy ("Policy"). The Policy essentially stated that DWR had interpreted the law of the State of Arizona to be that surface water rights are appurtenant to the land on which they are used and that a valid surface water right can only be held by a person or entity who has an ownership interest in the land where the water is to be used. This position was not necessarily new as DWR had adopted rules and regulations in 1982 (A.A.C. R12-15-301 *et.seq.*) which required that stockpond certificates for stockponds on public lands be issued to the public landowner for the benefit of the private lessee or permittee. Additionally, DWR had taken the position that assignments between private individuals or entities of water rights certificates, permits, applications and statement of claims involving public lands would be issued in the name of the public agency landowner rather than the new private assignee or purchaser. This procedure was vigorously opposed by ranchers and others and led to various legal entanglements which led to the 1995 legislation.

Based on DWR's interpretation of the law of the State of Arizona as it applies to surface water rights on public lands, it had adopted the following policies and procedures as set forth in the Policy:

A. When a private party holding a water right or evidence of a claim to water on public land reports the assignment of the right or claim to another private party, DWR would reissue the right or claim to the public agency landowner for the benefit of the private party;

B. DWR would consider Statement of Claims for a pre-1919 water right filed by a public agency landowner even though there is a conflicting right already held by a private party; and

C. DWR would hold hearings before issuing a stockpond certificate to a public agency landowner on conflicting claims to stockpond water rights with private parties on public lands but would be guided by the principles enunciated in the Policy.

These policies and procedures were at the heart of several issues before the Special Master in the Silver Creek watershed adjudication on the Little Colorado River System relating to who owns surface water rights on public lands when such rights were originally perfected under a prior appropriation system by private individuals or entities. It is the premise of this paper that these rights are owned by the private individual or entity who perfected these rights (or their valid successor) and that the DWR Policy misstated Arizona law. The Special Master issued a ruling in the Silver Creek case dated April 20, 1994, in which he agreed with the ranchers that water rights could be held in the name of the rancher on public lands in appropriate cases where the filings were correct. Due to length constrictions, this paper concentrates on the DWR policy and the law in existence prior to the determination by the Special Master.

II. HISTORICAL BACKGROUND

For the most part, the western United States follows the prior appropriation doctrine as it relates to surface water rights. The most fundamental and distinctive feature of a prior appropriation system is that the surface water belongs to the public and is to be utilized on a priority basis by the one who first and continuously puts the water to beneficial use ("first in time is first in right"), irrespective of whether an individual owns land on which the water is utilized or from where it is diverted. The doctrine of prior appropriation was established in contrast to a riparian water rights system which is based on land ownership. Arizona specifically rejected the riparian doctrine in favor of its prior appropriation doctrine (Article XVII, Section 1, Arizona Constitution), and its utilization of the prior appropriation system dates back to early territorial days. Most of the western states adopted the prior appropriation system in one form or another. The distinction between riparian rights based on land ownership and prior appropriation rights is fundamental and has been described by one commentator as follows:

> The water right consists of a right to the use of the water, the right to use the flow of a stream, and is not a private ownership of the corpus of the water, whether the right is based on ownership of riparian land or on a right of appropriation . . . .
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> The water right acquired by priority appropriation is not dependent upon the location of the land to which it is applied. Nor does the appropriation right necessarily exist in connection with ownership or use of particular land.[2] (Emphasis added).

The early homestead laws, adopted by the United States' Congress in the second half of the 19th century, fully recognized and confirmed the prior appropriation doctrine in the West particularly as to the separation of ownership of water rights from the ownership of land. The Mining Act of 1866 set forth the rule with respect to private rights on the public domain:

> Whenever, by priority of possession, right to the use of water for mining, agriculture, manufacturing, or other purposes, have vested and accrued, and the same are recognized and acknowledged by the local customs, laws, and the decisions of courts, the possessor and owners of such vested rights shall be

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[2] *Waters and Water Rights*, Robert Emmet Clark, Vol. One, Sections 53.2 and 53.3, pp. 349, 353-354 (1967).

maintained and protected in the same.[3]

The 1866 Act was amended in 1870[4] to make it clear that prior appropriation rights on federal lands have priority over subsequent government claims rights, as well as the rights of federal grantees of such land.

Following the Mining Act of 1866 and its amendment in 1870, Congress adopted the Desert Land Act of 1877[5] which further confirmed the existence of private rights on the public domain. The United States Supreme Court discussed in detail the impact of these acts with respect to water rights in the case of *California Regional Power Co. v. Portland Beaver Cement Co.*[6] as follows:

> The effect of these acts is not limited to rights acquired before 1866. They reach into the future as well, and approve and confirm the policy of appropriation for a beneficial use, as recognized by local rules and customs and the legislation and judicial decisions of the arid states, as the test and measure of private rights in and to non-navigable waters on the public domain.[7]

The Court noted the effective result of the Desert Land Act of 1877 as follows:

> . . .it effected a severance of all waters upon the public domain, not theretofore appropriated, from the land itself.[8]

The United States Supreme Court left it undeniably clear that surface water rights on federal lands were not attached to those lands in any way, shape or form. The Court unilaterally rejected the concept that because title to the land was held in the United States, or ultimately the patentee of the United States, surface water rights utilized on or from the land must also be appurtenant to the ownership of the land:

As the owner of the public domain, the government possessed the power to

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[3] 14 Stat. 253, 43 U.S.C. § 661.

[4] 16 Stat. 218, 43 U.S.C. § 661.

[5] 19 Stat. 377, 43 U.S.C. §321, *et seq.*

[6] 295 U.S. 142, 55 S.Ct. 725, 79 L.Ed. 1356 (1935).

[7] 295 U.S. at 155.

[8] 295 U.S. at 158.

> dispose of land and water thereon together, or dispose of them separately. The fair construction of the provision now under review is that Congress intended to establish the rule that for the future the land should be patented separately; and that all non-navigable waters thereon should be reserved for the use of the public under the laws of the states and territories named. The words that the water of all sources of water supply upon the public lands and not navigable 'shall remain and be held free for the appropriation and use of the public' are not susceptible of any other construction. The only exception made is that in favor of existing rights; and the only rules spoken of is that of appropriation. It is hard to see how a more definite intention to sever the land and water could be advanced.[9] (Citation omitted) (Emphasis added).

Consequently, federal land patents in the West conveyed no surface water rights and such allocations were left to the discretion of the states.

The upshot of these early acts of Congress and court decisions was to create a "split estate" wherein land ownership with respect to the federal domain was separated from various rights incident to the use of the lands for agricultural, timber, mining, and other purposes.[10]

The importance of this principle in the Special Master's decision and the 1995 Arizona legislation cannot be underestimated because all water rights developed on these federal lands pursuant to the early laws of the Arizona Territory remained the property of the private individuals and entities who continued to hold these rights at the time of statehood. Article XVII, Section 2 of the Arizona Constitution recognized this key principle of Arizona water law by providing that:

> All existing rights to the use of any of the waters in the State for all useful or beneficial purposes are hereby recognized and confirmed.

Because these early federal homestead laws, the United States rarely asserted rights for surface water uses on federal domain but many private individuals and entities established such rights on the federal lands of the West, including Arizona.

Congressional recognition of privately developed rights on federal lands was also set

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[9] 295 U.S. at 162.

[10] *Storm Over Range Lands, Private Rights and Federal Lands*, Wayne Hage, Free Enterprise Press (1989).

forth in the passage of the Taylor Grazing Act in 1934.[11] This Act not only gave preference to those who had existing rights on federal lands but also recognized that future water rights could be appropriated on federal lands by private water users.[12]

Consequently, long before Arizona statehood, there was a well recognized and accepted tradition in the prior appropriation western states of privately owned water rights on the public domain. Arizona followed this tradition and recognized all such rights at statehood. Only in recent years has this well established legal principle been challenged with respect to all surface water rights in Arizona despite continual recognition of such private rights by the United States.

III. ARIZONA LAW - HISTORICAL PERSPECTIVE

It is clear that in all situations involving Arizona state trust lands, and in the vast majority of situations involving federal lands, the issue of who owns and controls the surface water rights on those lands is determined under state law. If the law of Arizona was that only the owners of lands may hold title to surface water rights which are utilized on those lands, then Arizona would be adopting a rule of law based on riparian concepts which is contrary to the vast majority of western states, as well as to the practices employed in the State of Arizona since early territorial days. Such a broad and drastic departure from the prior appropriation principles and laws of the various western states was not intended by the Arizona Supreme Court when it issued the *Tattersfield*[13] decision despite some confusing dictum set forth in that decision. Nevertheless, an overview of the Arizona law is critical for understanding why DWR's 1992 interpretation of Arizona law was incorrect.

A. Constitutional and Enabling Act Provisions

There is little question that Arizona follows the prior appropriation doctrine and has fully rejected the riparian water rights doctrine. Article XVII of the Arizona Constitution provides for the following:

> Section 1. Riparian Water Rights
>
> The common law doctrine of riparian water rights shall not obtain or be in any force or effect in the State.

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[11] 43 U.S.C. §315.

[12] 43 U.S.C. §315b.

[13] *Tattersfield v. Putman*, 45 Ariz. 156, 41 P.2d 228 (1935).

Section 2. Recognition of Existing Rights

All existing rights to use of the waters of the State for useful or beneficial purposes are hereby recognized and confirmed.

Because protection of early vested water rights established under territorial law was fundamental, this Article was approved by unanimous vote of the delegates to the Arizona Constitutional Convention.[14] As originally introduced, however, it was somewhat longer and included the following language in part:

> The common law doctrine of riparian rights having never heretofore obtained within the territory included with this State, shall not hereafter obtain or be of any force or effect in this State. . . .
>
> The water of every river, creek, and running stream in this State is hereby declared to be public property and no individual or corporation can ever acquire any right to the same except the right to appropriate the same to beneficial uses. The beneficial uses for which appropriations of water may be made are domestic purposes, irrigation, stock raising, mining, manufacturing, and the development of water power. . . .
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> ***
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> Appropriations of water for purposes of irrigation shall apply to the particular land which the appropriators either own or possess, and shall be appurtenant to such land. Provided, that nothing in this measure shall effect existing rights or systems growing out of the decisions of the courts or recognized customs now or heretofore existing. . . Subject to the limitations herein prescribed in the case of appropriations of water in the future, all existing rights to the use of the water in this State for beneficial purposes are hereby recognized and confirmed.[15] (Emphasis added).

Even though much of this language did not ultimately find its way into Article XVII, most of the concepts became part of Arizona's statutes and remain today.[16] It is interesting to

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[14] *The Records of the Arizona Constitutional Convention of 1910*, Edited by John S. Goff, The Supreme Court of Arizona, p. 962.

[15] *Ibid.*, pp. 1171 and 1172.

[16] Section 75-101, *et.seq.* 1939 Arizona Code; A.R.S. §§ 45-141, *et.seq.*

note that at the time of the Arizona Constitutional Convention the requirement for appropriation of irrigation rights was ownership or possession of the land to be irrigated. This concept is key because this was the sole basis on which the *Tattersfield v. Putnam*[17] decision was decided which is the case exclusively relied upon in the DWR Policy for tying ownership of surface water rights to ownership of and. In *Tattersfield*, the Arizona Supreme Court specifically held that for an irrigation surface water right, the party who claimed ownership of the right must either "own or possess" the land to which the right was appurtenant. This holding was based on cases decided in Territorial days for irrigation rights exclusively. It is logical to assume that, if the drafters of the Arizona Constitution desired to apply such a standard to other surface water rights, it would have been so stated in the earlier version of Article XVII or in the early statutes as it was with respect to irrigation rights. This was not their intent because such a rule of law would have been contrary to Territorial law as well as the general prior appropriation doctrine of the West.

It is also important to note that much of the discussion and concern expressed by the members of the Constitutional Convention was over the protection of prior vested rights under Territorial customs and judicial decisions. This fact is borne out by a statement made by the author of the water rights bill at the Constitutional Convention on November 26, 1910. At that time, John P. Orme stated the following:

> In drawing this bill, I went to the legal lights of the territory, the men who have passed upon all the cases of water rights in the territory, Judge Kent for one, and other judges. They drew these articles as you see them, according to every decision that has been rendered in this territory. We have never had any statutes covering the water appropriations in this territory, and it is these decisions that we wish to protect and forever bar such litigation as that which we have been burdened for years and years. To break up the general judicial decisions concerning water rights would be one of the greatest injustices that could be perpetuated, and I am opposed to any amendment to that section.[18]

Both Section 28 of Arizona Enabling Act and Article X, Section 10 of the Constitution, recognize that water rights may be held and protected as improvements on state trust lands by the lessees of those lands. Specifically, Article X, Section 10, provides the following:

> The Legislature shall provide for proper laws for the sale of all state lands or the lease of such lands, and shall further provide by said laws

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[17] 45 Ariz. 156, 41 P.2d 228 (1935).

[18] *The Records of the Arizona Constitutional Convention, supra.*, p. 695.

> for the protection of the actual bona fide residents and lessees of said lands, whereby such residents and lessees of said lands shall be protected in their rights to their improvements (including water rights) in such manner that in the case of lease to other parties the former lessee shall be paid by the succeeding lessee the value of such improvements and rights and actual bona fide residents and lessees shall have preference to a renewal of their leases at a reassessed rental to be fixed as provided by law. (Emphasis added).

The Enabling Act provision utilizes similar language. Neither of these provisions may be interpreted to suggest that previously vested private water rights on federal lands (which were ultimately conveyed to the state by the United States under the Enabling Act) were extinguished or no longer to be considered a reimbursable improvement for lessees on the state's trust land. To suggest otherwise, ignores the intent of Article XVII, Section 2 which recognized and confirmed all previously existing water rights prior to statehood. The intent of the drafters of the Arizona Constitution is clear -- all such water rights appropriated and perfected under the Territorial laws were to be effective upon statehood, including those rights on state trust lands.[19]

B. Statutory Provisions

The appropriation statutes found in A.R.S. §§ 45-141 and 45-175 deal with how surface water appropriations are made in the State of Arizona and contain many of the same concepts embraced by Territorial customs and decisions as originally codified in 1919. However, the 1919 Code did introduce a more formalized process for appropriating surface water rights than had been in place in the Territorial days and in the first few years of statehood. These procedures mostly remain in place today and none of these statutes require land ownership as a basis for filing a statement of claim (pre-1919 water right), an application to appropriate (post-1919 water right), or holding a stockpond certificate or other permit or certificate. Additionally, A.R.S. § 45-171 clearly recognizes the validity of surface water appropriations made prior to these procedures established under the 1919 Code:

> Nothing in this chapter shall impair vested rights to the use of water. . . . The right to take and use water shall not be impaired or affected by the provisions of this chapter when appropriations have been initiated under and in compliance with prior existing laws and the appropriators have in good faith and in compliance with such laws commenced the construction of works for applications of the water so appropriated to a beneficial use and prosecuted the work diligently and continuously, but the rights shall be adjudicated as provided in this chapter.

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[19] *Ibid.*, p. 705.

The only surface water appropriation statute which even hints that such surface water rights are appurtenant to land ownership is found in A.R.S. § 45-172 dealing with sever and transfer. However, this statute makes it clear that the appurtenancy to land applies to irrigation rights and no other form of surface water right. Specifically, A.R.S. § 45-172 begins with the following statement:

> A water right may be severed from the land to which it is appurtenant or from the site of its use if for other than irrigation purposes and with the consent and approval of the owner of such right may be transferred for use for irrigation of agricultural lands or for municipal, stock watering . . .purposes . . . . (Emphasis added).

This statute obviously makes it clear that only the irrigation rights are appurtenant to the land and not necessarily to the ownership of the land. In the case of a non-irrigation surface right, the consent and approval for such transfer must come from the owner of the right and not necessarily the owner of the land to which the right is not appurtenant (unlike an irrigation right) since the transfer is from the site of use. Recognition that the land appurtenancy requirement for irrigation rights is limited only to irrigation rights is also supported by the language of earlier versions of A.R.S. § 45-172. Specifically, Section 75-135 of the 1939 Code set forth, in part, the following:

> Water to remain appurtenant to land - Transfer of water where not practicable to continue use - Water use for irrigation purposes shall remain a right appurtenant to the land upon which it is used . . . the right may, with approval of the Commissioner, be severed from the land and simultaneously transferred and become appurtenant to other land. . . . (Emphasis added).

Consequently, a stockwatering right is not nor has it ever been required to be appurtenant to the land. As will be discussed in more detail, DWR in 1992 in interpreting *Tattersfield* failed to distinguish between irrigation rights and other surface water rights and between water rights being appurtenant to land versus being appurtenant to land ownership.[20] This ultimately lead to the incorrect premise in the DWR Policy that all surface water rights may only be held by the owners of the land to which the rights are appurtenant.

The water rights registration statutes (A.R.S. §§ 45-182 through 45-190) also make no mention of land ownership as a basis for filing a statement of claim to surface water rights perfected prior to the 1919 Code. They merely set forth statutory procedures for seeking to

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[20] Another common example of a water right which is not appurtenant to the land is a municipal surface water right.

identify and ultimately quantify surface water rights perfected under prior law. A.R.S. § 45-184 does require that such filings be on a timely basis or the rights will be lost. Additionally, A.R.S. § 45-185 makes clear that the mere filing of a statement of claim does not constitute the adjudication of rights between private individuals or entities or the State.

The stockpond registration statutes contained in Article X of Title 45 also contain no land ownership requirement as a basis for holding the stockpond right. However, when DWR promulgated rules and regulations implementing the Stockpond Registration Act of 1977[21] it did introduce the concept of land ownership as a requirement for the ultimate holder of the right as it applies to public lands. R12-15-301 required issuance of such certificates to the United States for stockponds located on National Forest Service lands. For BLM lands, the certificates were to be issued to the United States "on behalf of the United States and present and future permittees, lessees or allottees."[22] With respect to state lands, the certificate was to be issued to "the lessee by and for the State of Arizona" in all cases where the actual state grazing lease provided that the issuance of the certificate to the lessee was an authorized improvement. In all other cases, the certificate was to be issued directly to the State of Arizona.[23] The legal basis for these regulations was questionable.

C. Arizona Caw Law

A number of Arizona cases have dealt with issues relating to private water rights on public lands. Early cases recognized the existence of such rights under Territorial and early statehood laws.[24] In the case of *Hamlin v. Wooley*[25] a rancher developed a water right between 1850 and 1919 for domestic and stockwatering use of federal lands. In 1938, he sought to quit claim his pre-1919 right to the plaintiff. Subsequently, he filed an application to appropriate under the 1919 Water Code and he ultimately received a certificate in 1939 with a 1938 priority date. He then sought to assign this right under the certificate to the defendant. In determining who actually held the water right, the Arizona Supreme Court recognized the validity of the pre-1919 right owned by the original rancher on the federal lands as follows:

> Brown [rancher], by settlement and making improvements on the public domain and in actually developing and putting water to use, had an

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[21] A.A.C. R12-15-301, *supra.*, p.1.

[22] A.A.C. R12-15-301.A.1.

[23] A.A.C. R12-15-301.A.2.

[24] *Miller v. Douglas*, 7 Ariz. 41, 60 P. 722 (1900); *Gila Water Co. v. Green*, 27 Ariz. 318, 232 P. 1016 (1925).

[25] 64 Ariz. 152, 167 P.2d 100 (1946).

interest which was subject to conveyance....

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> The permit and certificate of water rights secured in Brown's name were based upon his prior possession, development and use of the water. These rights were capable of sale....[26]

Another important Arizona case is *Parker v. McIntyre*.[27] In this case, the plaintiffs filed applications for permits to appropriate stockwater from two springs located on federal lands. The plaintiffs did not complete the diversion works necessary for full utilization of the water for several years and subsequently assigned the applications for permits to appropriate to their successors. The successors were denied access to construct the necessary diversion works by the defendants who had sought a patent on the federal lands on which the springs were located and, consequently, contended that they owned the underlying water rights. The trial court ruled in favor of the defendants on the theory that laches applied because the original plaintiffs had failed to complete their appropriation in a timely manner.

Despite the fact that *Parker* was decided one year after the *Tattersfield* decision, the Arizona Supreme Court reversed the trial court and held that the waters of the spring were subject to appropriation by the original ranchers for stockwatering purposes. The court also determined that the original ranchers had complied with the necessary statutory requirements to appropriate without constructing diversion works. In so holding, the court stated:

> It also appears that the lands on which they were located were, at the time the application was made, open, unoccupied government lands. The federal government has for many years recognized the right of residents to appropriate the waters found in the public lands of the Western States, in accordance with local statutes and customs, and that any entryman of such lands took them subject to all valid, prior water rights.[28] (Emphasis added).

On this basis, the Court determined that the original water rights of the private ranchers on the federal lands were valid as against the interest of the United States (as the current owner of the land) and the defendants who were to be the ultimate title holders of the land. The Court's ruling clearly rejects the proposition that only the holders of title to the lands could

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[26] 167 P.2d at 103.

[27] 47 Ariz. 484, 56 P.2d 1337 (1936).

[28] 56 P.2d at 1340.

own the water rights emanating from the lands even though this was the same court which decided *Tattersfield* a year earlier.

Perhaps the premiere Arizona case in this area is *England v. Ally Ong Hing*.[29] This case involved water rights on 16,000 acres of public land and 80 acres of deeded land. The plaintiff cattle ranchers acquired surface water rights on federal lands in 1947 from several springs. The defendant developers placed dikes across the springs which hindered the traditional cattle movement of the plaintiffs. The plaintiffs sought to have the springs restored on the theory that they had a right to cross the defendant's property for watering their cattle based on a right-of-way acquired through adverse possession.

The Court held that the grazing of cattle did not support a claim of adverse possession but that the plaintiff ranchers did have a valid pre-1919 appropriation on the public land controlled by the defendants. The Court set forth the following:

> In its finding of fact, the [trial] court states that since 1910 the cattle on the Battle Cove Ranch have 'watered from the various natural water sources in the area' - included in the natural water sources are the water flows in Walnut Grove Canyon. Therefore, we conclude in light of the *Parker* decision, the plaintiff has made a valid appropriation of these waters, even though no notice was posted, by applying these waters to beneficial use since 1910.[30]

In fully understanding the *England* case, it is important to consider the lower court cases involving the same matter. In the first case,[31] the Arizona Court of Appeals discussed in detail Arizona's repudiation of riparian water rights and acceptance of the prior appropriation doctrine as established under Article XVII, Section 1 of the Arizona Constitution.[32] The Court of Appeals cited *Parker* for the following proposition:

> It is the recognized law in Arizona that <u>when a person acquires land he takes it subject to any water rights which might have been initiated according to the law</u>. Of course, these rights must not have lapsed nor

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[29] 105 Ariz. 65, 495 P.2d 498 (1969).

[30] 495 P.2d at 504. The Arizona Supreme Court further recognized that surface water appropriation rights for cattle grazing could and should be held by the rancher even though the place of use and the source of the water emanated from public land.

[31] *England v. Ally Ong Hing*, 8 Ariz. App. at 374, 446 P.2d 480 (1968).

[32] 446 P.2d at 484.

become void for some other reason.[33] (Emphasis added).

Obviously, this statement is completely contradictory to the view that ownership of the water right must follow ownership of the land as contended by the DWR Policy.

The Court of Appeals took a second look at the *England* case[34] on review due to confusion over language in the first case that suggested a spring on a landowner's property could be destroyed by that landowner to the detriment of a downstream appropriator. The Court clarified its position on the basis that the spring was actually determined to be percolating groundwater which was not subject to appropriation and that the prior ruling was not an effort to erode the prior appropriation doctrine as it applied to surface water rights. Specifically, the court addressed the issue as follows:

> Such language may give some persons the impression that we advocate that a riparian owner has the right to destroy a spring in violation of the rights of a prior appropriator or the state. Through this supplementary decision, we wish to clear up any such erroneous impression. An analysis of the Arizona case of *Parker v. McIntyre* and the State Water Code, A.R.S. §45-101 *et.seq.*, definitely shows that springs are appropriable and that such appropriable waters belong to the state and not the riparian landowner. The appropriable waters may not be destroyed at will or whim of the riparian owner.[35] (Citations omitted).

The lesson of the *England* cases is that the Arizona Court of Appeals on two occasions and the Arizona Supreme Court on one occasion dealt with the factual situation involving private stockwater rights on public lands and never once suggested that this situation was inconsistent with Arizona law despite the existence of *Tattersfield* and the other irrigation cases decided many years earlier.

D. Distinguishing *Tattersfield*

Tattersfield v. Putnam[36] merits special attention since it was almost exclusively relied upon in the 1992 DWR Policy. Simply put, *Tattersfield* was merely a case involving irrigation rights which relied on the law of the day which held that such rights must belong to the "owner or possessor" of the land. This was a long recognized standard in Arizona case

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[33] 446 P.2d at 484.

[34] 8 Ariz. App. 558, 448 P.2d 128 (1969).

[35] 45 Ariz. 156, 41 P.2d 228 (1935).

[36] 45 Ariz. 156, 41 P.2d 228 (1935).

law exclusively for irrigation surface water rights. The case may not be utilized as a basis for contending that no surface water right on public lands may be held by private individuals or entities. Nor did it involve any public policy pronouncements to the effect that any water rights which have been perfected on public lands by private individuals and entities were done so by the private individual or entity acting as the agent of the public owner as is suggested in the DWR Policy.[37]

Tattersfield v. Putnam, which is also cited as *In Re Determination of Relative Rights to Use of Water of Pantano Creek in Pima County*, involved a fact situation where the original homesteader of certain federal lands irrigated 32 acres of federal land which he mistakenly believed to be part of his homestead. His successor continued this practice and ultimately field a notice of appropriation on the 32 acres. Ultimately, the Court determined that the original appropriation was not valid because it was not made by the "owner or possessor" of the subject land. However, the individual who initially applied the water to the land was not a lessee or permittee of the federal government as he mistakenly believed the 32 acres were part of his homestead.

Based on the specific facts of the case, as well as the well recognized law of the day, *Tattersfield* should be interpreted as follows:

1. *Tattersfield* is an irrigation case which reflects the rule of law of its time that irrigation surface water rights must be appurtenant to the lands on which the rights are utilized.

As discussed earlier in this paper, the early law in Arizona was that irrigation surface water rights must be appurtenant to the land. This concept evolved from Territorial case law and was introduced in at the Arizona Constitutional Convention as follows:

> Appropriations of water for purposes of irrigation shall apply to the particular land which the appropriators either own or possess and shall be appurtenant to such land.[38] (Emphasis added).

The *Tattersfield* court specifically held as follows:

> We hold, therefore, that in order to appropriate the right to use water for irrigation the appropriator must be the owner or possessor of land which is susceptible of irrigation, and that the appropriation once made attaches permanently to such land and none other, and cannot be transferred

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[37] See DWR Statement of Policy at pages 6 and 7.

[38] *The Records of the Arizona Constitutional Convention, supra.*, p. 1172.

> therefrom, except when through natural causes and no fault of the owner it becomes impracticable to use the water economically or beneficially on the land to which it is appurtenant.[39]

It is this same standard which the *Tattersfield* court utilizes when it relies on the early irrigation cases of *Slosser v. Salt River Valley Canal Company*[40] and *Gould v. Maricopa Canal Company*.[41] One early case which set forth this rule is not cited in the 1992 DWR Policy. In *Biggs v. Utah Irrigation Ditch Co.*[42] the Arizona Supreme Court held the following:

> We hold that our statutes, while recognizing the ownership and possession of land as essential to the acquisition and enjoyment of a water right for purposes of irrigation, and while limiting its use to the particular lands to which it is attached, do not deny the rights of alienation, and the transfer of such right from one particular tract of land to another, except under the limitations that the transferee is of the class of persons entitled to make a valid appropriation by virtue of being the owner or possessor of arable and irrigable land, and such change does not injure another having rights which have accrued at the time of such transfer and change of use.[43] (Emphasis added).

In some of these irrigation cases, the pronouncement of this law does not always reference irrigation uses. However, the fact situations of all these cases involve only irrigation rights and the "owner or possessor" rule was clearly recognized as only applying to such rights. Therefore, the clear conclusion is that the *Tattersfield* court was relying on the well recognized law of the day to reject an irrigation water right claim involving 32 irrigable acres which had not been owned, leased or possessed by the individual claiming the appropriative right.

2. The private claimants on the public lands in *Tattersfield* had an interest in the lands which was far short of the interest of a true lessee or permittee on state or federal lands.

The claimants in *Tattersfield* mistakenly believed that they owned the federal

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[39] 45 Ariz. at 171.

[40] 7 Ariz. 376, 65 P. 332 (1901).

[41] 8 Ariz. 429, 76 P. 598 (1904).

[42] 7 Ariz. 331, 64 P. 494 (1901).

[43] 64 P. at 500.

land on which they sought the irrigation surface water rights because they had homesteaded adjacent lands. In no way were the original water users actual lessees or permittees on public lands with the same type of possessory rights which accompanies such status. Consequently, the most that *Tattersfield* can stand for is the proposition that one who is mistakenly in possession of land to which he could never become the "owner or possessor" may not make a valid appropriation for an irrigation surface water right under Arizona law.

There is also an argument that a "possessor" of land under *Tattersfield*, and the early territorial cases applicable to irrigation surface water appropriations, can have an interest in the land which is substantially less than an ownership interest. Again, the DWR interpretation of *Tattersfield* suggests that only an ownership interest is sufficient to support any surface water right claim on lands and this was never the holding of the *Tattersfield* court or the law at the time that *Tattersfield* was decided. This paper does not seek to carefully analyze this issue as it is unnecessary to do so since only irrigation surface water rights were involved and the interpretation of *Tattersfield* must be limited accordingly. Nevertheless, the ". . .or possessor" standard might ultimately justify a long term lessee's claim to an irrigation surface water right on public lands in Arizona.

3. *Tattersfield dicta* is meaningless and has never been followed by the Arizona Courts.

In one or two references, the Court in *Tattersfield* cites the "owner or possessor" requirement without the qualifying language that this rule applies only to irrigation surface water rights. However, the actual facts of the case, and the clear statement of the Court's holding, render these other statements meaningless *dicta*.

The *Tattersfield* case only been cited three times in 57 years in Arizona courts. It has never been cited for the proposition that a temporary possessor of lands (or a lessee of lands) may not appropriate any surface water rights on the lands on which he is leasing or temporarily possession because he is not the owner of the lands. It has only been cited for the irrigation surface water right rule.[44] During this 57 year period, the Arizona courts have repeatedly recognized situations where lessees of land, or their predecessors, have validly perfected water rights claims on such lands which, in most cases, have been public lands.

IV. FEDERAL LANDS

The acquisition of private water rights on federal lands was part of a grand design of the federal government in the last half of the 19th Century to settle the West. In recent years,

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[44] *Gillespie Land & Irrigation Co. v. Buckeye Irrigation Company*, 75 Ariz. 377, 257 P.2d 393 (1953); *Salt River Valley Water Users Association v. Kovacovich*, 3 Ariz. App. 28, 411 P.2d 201 (App. 1960).

these rights have further been recognized in acts of Congress, as well as through various judicial decisions on different types of federal land.

A. United States Forest Service Lands

There are no federal reserved rights for stockwatering on United States Forest Service lands. Under the Organic Administrative Act of 1897[45], the National Forests were reserved for the following specific purposes:

1. improving and protecting the forest;
2. securing favorable conditions and water flows; and
3. furnishing a continuous supply of lumber.

These original reservation purposes were broadened under the Multiple Use Sustained Yield Act of 1960[46]. A key case interpreting water rights for grazing purposes on Forest Service lands is the New Mexico case of *Mimbres Valley Irrigation Company v. Falpek*[47]. This case involved the general adjudication of water rights on the Rio Mimbres River and its tributaries. The United States claimed reserved rights for instream flows and recreational purposes, which rights were granted by the New Mexico Special Master. Also involved was the issue of whether the grazing permittees on the Forest Service land (whose predecessors had actually perfected the surface water right through grazing) should be considered the owners of the rights or whether the rights belonged to the United States under its reservation authority. The New Mexico Supreme Court stated the issue as follows:

> An additional matter raised in this appeal is whether the water rights used by permittees of the United States Forest Service should be adjudicated to the permittee under the State law of prior appropriation or outright to the United States. The prior discussions in this opinion reveals that the United States does not have reserved water rights in the forest for these permitted uses.[48] (Emphasis added).

The New Mexico Supreme Court arrived at this conclusion by strictly interpreting the purposes for which the Forest Service lands were reserved and determining that such purposes

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[45] 16 U.S.C. §475.

[46] 16 U.S.C. § 528.

[47] 564 P.2d 615 (N.M. 1977).

[48] 564 P.2d at 619.

do not include stockwatering. The court relied heavily on the *Caeppert v. United States*[49] decision for the principle that a reservation of federal lands is only for the limited purposes for which the reservation was primarily created. In applying this doctrine, the New Mexico Supreme court recognized that "secondary uses such as grazing, mining or recreation" were not part of the original purposes of the 1897 reservation under the Organic Administrative Act and, therefore, the United States had no reserved rights in the National Forest lands for these secondary uses.[50]

The case was appealed to the United States Supreme Court and in *United States v. New Mexico*[51], the Supreme Court affirmed the position of the New Mexico court in holding that the establishment of the Gila National Forest by Congress did not reserve the use of the waters of the Rio Mimbres for purposes of recreation, aesthetics, wildlife preservation or stockwatering. The Court recognized that there where secondary uses of Forest Service lands were involved, water rights associated with those uses must be decided under State law. Specifically, with respect to the issue of who holds title to the water right for stockwatering on Forest Service land, the Court stated the following:

> The [New Mexico] District Court concluded that the United States had not established a reserved right to a minimum instream flow for any of the purposes for which the Gila National Forest was established and that water rights arising from cattle grazing by permittees on the forest should be adjudicated to the permittee under the law of prior appropriation and not to the United States.... The United States also argued that it was entitled to reserved right for stockwatering purposes. The State Supreme Court again disagreed, holding that stockwatering was not a purpose for which the National Forests were created.[52]

With respect to this issue, the Court concluded:

> What we have said also answers the Government's contention that Congress intended to reserve water from the Rio Mimbres for stockwatering purposes. The United States issues permits to private cattle owners to graze their stock on the Gila National Forest and provides for stockwatering at various locations along the Rio Mimbres. The United States contends that, since

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[49] 426 U.S. 138, 96 S.Ct. 2062, 48 L.Ed.2d 523 (1976).

[50] 564 P.2d at 617.

[51] 438 U.S. 696, 98 S.Ct. 3012, 57 L.Ed.2d 1052 (1978).

[52] 438 U.S. at pp. 704-705.

> Congress clearly foresaw stockwatering on National Forests, reserved rights must be recognized for this purpose. The New Mexico courts disagreed and held that any stockwatering rights must be allocated under state law to individual stockwaters. We agree. (Emphasis added).[53]

In 1993, a Colorado court relied on this decision to deny the claims of the United States to reserved water rights for maintaining instream flows on National Forest lands.[54]

Based on these cases, it is clear that there are no inherent reserved rights for stockwatering purposes for the United States on Forest Service lands. Unless the claimed water right is based on one of the primary purposes of the original reservation, the United States must appropriate surface water rights on Forest Service lands pursuant to state law and such rights will have a priority and be quantified subject to the requirements of state law. Nevertheless, the DWR Policy would have granted such rights to the United States even though prior private rights had been claimed and, in many cases, established under existing state law.

These same principles have been recognized by Congress as recently as 1986 when it adopted an amendment to the Federal Land Policy and Management Act of 1976 ("FLPMA").[55] The original FLPMA contained a section authorizing the Secretary of Agriculture, with respect to National Forest Service lands, and the Secretary of Interior, with respect to other public lands, to grant certain rights-of-way:

> ...over, upon, under or through such lands for - (1) reservoirs, canals, ditches, flumes, laterals, pipes, pipelines, tunnels, and other facilities and systems for the impoundment, storage, transportation, or distribution of water....[56]

In 1986, Congress amended this provision by adding subsection (c) which deals with "Permanent Easement for Water Systems; Issuance, Preconditions, etc." These provisions clearly recognize existing private water rights on National Forest Service lands. This section authorizes a private applicant to request a permanent easement from the Secretary of

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[53] 438 U.S. at 715.

[54] *In the Matter of . . . Application . . . for Reserved Water Rights in the Platte River . .*, No. W. 8439-76 (Feb. 12, 1993).

[55] 43 U.S.C. § 1701, *et. seq.*

[56] 43 U.S.C. § 1761.

Agriculture for a water system described under 43 U.S.C. §1761(a), as described above, across National Forest lands if such system was "in operation and placed into operation prior to October 21st, 1976" provided the following conditions are met:

> (A) The traversed National Forest lands are in a State where the appropriation doctrine governs the ownership of water rights;
>
> (B) At the time of the application the water system is used solely for agricultural irrigation or livestock watering purposes;
>
> (C) The use served by the water system is not located solely on Federal lands;
>
> (D) The originally constructed facilities comprising such system have been in substantially continuous operation without abandonment;
>
> (E) The applicant has a valid existing right, established under applicable State law, for water to be conveyed by the water system;
>
> (F) A recordable survey and other information concerning the location and characteristics of the system as necessary for proper management of the National Forest lands as provided to the Secretary of Agriculture by the applicant for the easement; and
>
> (G) The applicant submits such application on or before December 31st, 1996.[57] (Emphasis added).

This statute clearly recognizes the existence of private water rights on National Forest Service lands and sets forth the means by which those rights can be exercised by the private water right holder both on and off the federal lands on a permanent basis. With respect to that part of the right for utilization on federal lands, it is arguable that the DWR Policy would never have allowed a permittee to utilize this federal law because he could never make the showing required under subparagraph (c)(1)(E) that he had a "valid existing right" for use and/or diversion of water on such lands.

Also included in 1986 FLPMA amendment was a provision making it very clear that Congress did not intend to assert any new rights on behalf of the United States to surface waters on public lands by this legislation. Subparagraph (3)(B) sets forth the following:

> Nothing in this subsection shall be deemed to be an assertion by the United States of any right or claim with regard to the

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[57] 43 U.S.C. § 1761(c)(1).

> reservation, acquisition, or use of water. Nothing in this subsection shall be deemed to confer on the Secretary of Agriculture any power or authority to regulate or control in any manner the appropriation, diversion, or use of water for any purpose (nor to diminish any such power or authority of such Secretary under applicable law) or to require the conveyance or transfer to the United States of any right or claim to the appropriation, diversion or use of water.[58]

What Congress clearly did not intend to do by this legislation, DWR was doing under the Policy. DWR was unilaterally attempting to grant certain rights to the United States for surface waters on federal lands which the United States, in many cases, did not even claim.

B. BLM Lands

Generally, BLM lands do not possess reserved water rights because they are not reserved lands. One exception involves a 1926 Executive Order entitled "Public Water Reserved No. 107"[59] which withdrew certain public springs and water holes to preserve water for domestic and stockwatering uses and to prevent monopolization of water sources in arid regions. If certain BLM lands are determined to come within PWR 107 reservation, the 1926 priority date of that reservation will be significant.

1. Public Water Reserve No. 107

One of the best discussions of PWR 107 is found in a series of Department of Interior opinions written by several different Solicitors between the years 1979 to 1983. The first and most detailed of these opinions is dated June 25, 1979.[60] The 1979 Solicitor's Opinion discusses in great detail the intent and effect of PWR 107 which it states is the most important reservation of BLM lands. Specifically, the reservation stated the following:

> Every smallest legal subdivision of the public land surveys which is vacant, unappropriated, unreserved public land and contains a spring or water hole and all lands within one quarter of a mile of every spring or water hole, located on unsurveyed public land, be, and the same is hereby withdrawn from settlement, location,

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[58] 43 U.S. § 1761(c)(3)(B).

[59] 30 C.F.R. § 758.

[60] M-36914, 86 I.D. 553.

> sale or entry, and reserved for public use in accordance with the provisions of Section 10 of the Act of December 20, 1916 (39 Stat. 862), and in aid of pending litigation.

The 1979 Solicitor Opinion points out that the purpose of the 1926 reservation was to prevent private monopolization on the public domain but that it had no impact on prior vested rights.[61] Additionally, this Opinion makes it clear that all such prior vested private rights on the public lands which came under the 1926 reservation were transferrable to other private owners:

> Of course a person holding a valid, vested private right to use water of a spring or water hole on vacant, unappropriated, unreserved public lands may transfer that right in accordance with the applicable state law, but no private right can be perfected after abandonment or forfeiture of a right, i.e., the withdrawal attaches immediately upon forfeiture or abandonment.[62]

The Solicitor Opinion dated February 16, 1983,[63] narrowed the interpretation of PWR 107 in the 1979 opinion by citing the holding of the Colorado Supreme Court in the case of *United States v. City and County of Denver*[64] for the following proposition:

> The purpose of the [PWR 107] reservation was to prevent monopolization of water needed for domestic and stockwater purposes...reserved water from public springs and water holes is available for the purposes of human and animal consumption in the amount necessary to prevent monopolization of the water resources...[there as, however,] no intent to reserve the entire yield of public springs and water holes. *Denver v. U.S., supra.* slip opinion at 57.[65]

Consequently, with respect to a PWR 107 reservation, the amount of such reservation is to be strictly limited to the necessary human and animal consumption uses. Additionally, the reservation is only effective for determining rights between the years of 1926 to 1976 when the

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[61] 86 *Id.* at 581.

[62] 86 *Id.* at 587 and 588.

[63] M-36914 (Supp. II), 90 I.D. 81.

[64] 656 P.2d 1 (Co. 1983).

[65] 90 I.D. at 83.

legislation under which the PWR 107 Executive Order was issued was repealed by the Federal Land Policy Management Act.[66]

2. Taylor Grazing Act

The Solicitors' opinions also discuss the impact of the Taylor Grazing act of 1934[67] with respect to private water rights on BLM lands. The 1979 Opinion held that laws such as the Taylor Grazing Act did not create any reserved water rights and essentially reinforced the long standing federal policy of recognizing privately held water rights on public lands. The 1979 Opinion stated:

> What matters is that Congress, with few exceptions, has not authorized Interior agencies to transform any 'federal' ownership of unappropriated waters into a federal water management system for private water rights competing with state systems, but rather has directed private parties to seek water under state law [citations omitted]. However, I agree with and reaffirm Solicitor White's conclusions that by Congressional directives to administer federal lands for particular management objectives, Interior agencies have the right to appropriate and make beneficial use of unappropriated water on the various federal lands for Congressionally authorized management programs.[68]

Therefore, while the Taylor Grazing Act did not create any federal stockwatering rights and, in fact, confirmed such rights of private parties on BLM lands, it also recognized that the United States could seek similar rights under state law. (Notwithstanding assertions to the contrary, under present Arizona law, the BLM is free to seek new stockwatering rights. See A.R.S. §45-151(E).)

3. Federal Land Policy Management Act of 1976

The Federal Land Policy Management Act of 1976 ("FLPMA")[69] also retained the status quo with respect to private rights on BLM and other public lands. Additionally, as stated earlier, FLPMA repealed the earlier acts which were the basis of the PWR 107 reservation. The net result of FLPMA with respect to water rights on public lands

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[66] 86 I.D. 588.

[67] 43 U.S.C. § 315.

[68] 86 I.D. at 613.

[69] 43 U.S.C. § 1701 *et. seq.*

has been to maintain the status quo according to the 1979 Solicitor's Opinion which described the status quo as follows:

> The status quo is a recognition of existing laws and practices and this allows for (a) the continued appropriation of unappropriated non-navigable waters on the public domain by private persons pursuant to state law, as authorized by the Desert Land Act, (b) the right of the United States to use unappropriated water for Congressionally recognized and mandated purposes set forth in legislation providing for the management of the public domain, and (c) application by the United States to secure water rights pursuant to state law for these purposes.[70] (Emphasis added).

The September 11, 1981, Supplemental Solicitor Opinion[71] confirmed the view that neither FLPMA nor the Taylor Grazing Act gave the BLM an independent statutory basis for water uses which is inconsistent with the substantive and procedural requirements of state law. The Opinion states that one of the reasons for its issuance was to remove:

> ...a new and unnecessary cloud of ambiguity over private water rights dependent upon water sources that are on, under, over or appurtenant to federal lands.[72]

The Opinion also recognized that Congress has reaffirmed in at least 37 statutes the original principles set forth in the homestead laws with respect to private rights on public lands:

> These three statutes, the Desert Land Act, as well as the 1866 and 1870 acts, had the effect of severing water from land on the public domain, requiring state laws to be followed in making all non-navigable waters a part of the 'public juris' and subject to the 'plenary control' of the Western States. These statutes, which are still in effect, demonstrate the early congressional deference to state water law.[73]

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[70] 86 *Id.* at 614 and 615.

[71] 88 *Id.* at 1055.

[72] 88 *Id.* at 1056 and 1057.

[73] 86 *Id.* at 1059 and 1060.

4. Cases Involving BLM Lands

An important case involving BLM lands is the recent case of *Fallini v. Hodel*[74] in Nevada. In this case, the plaintiffs grazed cattle on 2,700 private acres and 160 acres of BLM lands. The sources of water for this ranching operation were on the BLM land and the plaintiffs held the water right under Nevada law for the stockwatering on the BLM lands. The BLM grazing permit authorized the plaintiffs to make improvements at the various water sources and, in so doing, the plaintiffs put guardrails to prevent wild horses from depleting these stockponds. The BLM notified the plaintiffs that these were unauthorized improvements and, if not removed, their grazing permit would be canceled. The plaintiffs refused to remove the guardrails and their permit was canceled. The plaintiffs filed the required complaint with the BLM and an administrative law judge ruled in the plaintiffs' favor but this ruling was ultimately reversed by the Interior Board of Appeals.

On appeal from the Interior decision, the United States District Court for Nevada determined that the plaintiffs' water right predated legislation from Congress protecting wild horses on federal lands and, consequently, the wild horses and other "wildlife" could not be given a preference over cattle for utilization of this particular water source. The court rejected the BLM position that the federal law overrides state granted water rights and stated the following:

> Federal law may override state law in the administration of the state permitted water rights asserted in this case if: 1) the federal government has impliedly reserved those water rights by statute; or 2) the state laws as applied are in conflict with 'needful regulations' respecting federal public lands.[75]

The Court observed that the Acts of 1866, 1870 and 1877 set forth "Congressional authorization for private individuals to acquire rights to use waters appurtenant to the public domain" and that any subsequent "reservations" of federal lands could not invalidate prior private water rights on those lands.[76] The Court concluded that water for wild horses was a secondary use of the BLM land and that under *United States v. New Mexico*[77] it could not take priority over previously vested private water rights under the Constitution.

The Nevada District Court determined that the primary purpose for which the BLM

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[74] 725 F.Supp. 1113 (Nev. D.C. 1989).

[75] 725 F.Supp. at 1119.

[76] 725 F.Supp. at 1120.

[77] 438 U.S. 696, *supra.*

lands were withdrawn under the Taylor Grazing Act of 1934 took precedence over the secondary purpose of protection of wild horses under a subsequent Congressional act:

> Defendants, therefore, have no right based on the Property Clause to jeopardize Plaintiffs' certified water right or interfere with this State's authority to regulate water.[78]

The Court also acknowledged a Fifth Amendment right held by the plaintiff-ranchers to their water rights on federal lands. The Court explained this right as follows:

> Owners of water rights possess vested property rights protected from unconstitutional takings although they may withdraw the water only by license from the United States and regardless of whether these water rights derive from ownership of the appurtenant soil or from specific grants by the State....The Fallini's water right, therefore, is protected from unconstitutional takings....There remains practically no economically viable use to the water right for the Fallini's if its use is, in effect, limited to wild horse use.
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> ***
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> The consent of the United States in allowing the costly building of Deep Well for stockwatering subject to certain requirements for wildlife use 'led to the fruition' of the expectancy that such requirement would not lead to the almost complete deprivation of water access for stockwatering purposes.[79] (Emphasis added).

The importance of this case is not only that it recognizes private water rights on BLM lands but that it also takes the additional step of confirming that such rights are protected by the Fifth Amendment of the United States Constitution.

Another case involving BLM lands under the Taylor Grazing Act is the Oregon case of *Wilber v. Wheeler*[80]. This case involved an original certificate of water right for irrigation purposes on 17 acres of BLM land (not owned by the original applicant) included in a larger body of land that was owned by the applicant. A subsequent owner of the land contended that

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[78] 725 F.Supp. at 1121.

[79] 725 F.Supp. at 1123.

[80] 543 P.2d 1052 (Ore. 1975).

there must have been a mistake on the part of the state agency which issued the certificate of water right to have included the 17 acres of BLM lands in the original appropriator's certificate. The Oregon Supreme Court disagreed with this position and stated the following:

> There is nothing in O.R.S. Chapter 597 which would prevent someone from applying for water rights to lands which they do not own but do intend to irrigate. As this court stated [before]: 'It was the plan of the Water Law of 1891 and runs through all of the cases, that an appropriation may be made by one person for future use of another; and for future use upon lands which the appropriator does not then own, or which he does not contemplate owning, in which he never does own....' [citations omitted].
>
> Under our statute, it is clear that water rights are appurtenant to the land, and not to the ownership of the land which changes hands frequently. *See* O.R.S. § 540.510.[81]

This case draws the important distinction between a water right being appurtenant to the land, as opposed to being appurtenant to the ownership of the land. This may really be the line of reasoning in *Tattersfield* and the other Arizona irrigation cases relied upon by DWR. This is particularly true since Oregon case law is recognized as being instructive for interpreting Arizona surface water laws.[82]

C. Other Federal Lands and Pertinent Issues

1. Cases

One of the key federal cases involves national monument lands. In *Hunter v. United States*,[83] the United States sought an injunction against a rancher for grazing within the Death Valley National Monument. The rancher responded that he and his family had diverted certain spring water for livestock watering in the area since 1880 and he had a vested water right which the United States must honor under the Act of 1866, as well as implied easement across the land for grazing. The District Court ruled in favor of the United States and granted the injunction on the theory that Hunter had no water right or easement

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[81] 143 P.2d at 1055 and 1056.

[82] *Stewart v. Verde River Irrigation & Power District*, 49 Ariz. 531, 68 P.2d 329 (1937).

[83] 388 F.2d 148 (9th Cir. 1967).

right within the National Monument property.

The 9th Circuit reversed a portion of the District Court's ruling by holding that Hunter had a legal basis for the acquisition of an appropriation of water, although this did not automatically convey him an easement for grazing. However, he was entitled to a right-of-way across federal lands to divert his water from those lands to other property even though he could no longer graze his cattle on the federal lands. The court recognized that a prior law appropriation is sufficient to give priority over subsequent claims based on current laws and that Hunter had sufficiently shown this prior appropriation by watering livestock "directly from the water source". The court stated:

> We believe that a legal basis for acquisition of an appropriation to water by virtue of local decisions has been established. On the basis of the facts found by the district court, we conclude that Hunter's predecessors must be deemed to have appropriated these waters; that the right is the equivalent of a grant of the use of waters from the federal government; and that it is entitled to protection.[84]

The Court then goes on to enunciate the well recognized rule and tradition of private water rights on federal lands as follows:

> The rule is well settled that a squatter on the public domain may acquire by appropriation the right to the use of water that is used by him to irrigate such lands and that if he is evicted he may nevertheless divert the water elsewhere if he is able. [Citations omitted].[85]

V. STATE TRUST LANDS

A. Introduction/Arizona Law

Both the Arizona Constitution and the Enabling Act contain key provisions impacting water rights on state trust lands. At the time of statehood, the Arizona Constitution recognized that all existing water rights 'for all useful or beneficial purposes are hereby recognized and confirmed.'.[86] Article X, Section 10 of the Arizona Constitution, also protects

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[84] 388 F.2d at 153.

[85] 388 F.2d at 155 (Footnote 4).

[86] Article XVII, Section 2.

a lessee's water rights as improvements on state trust lands and this provision is based on Section 28 of the Enabling Act which provides in part:

> ...nothing herein contained shall prevent...the Legislature of the State of Arizona from providing by proper laws for the protection of lessees of said lands, whereby such lessees shall be protected in their rights to their improvements (including water rights) and in such manner in case of lease or sale of said lands to other parties the former lessee shall be paid by the succeeding lessee or purchaser the value of such improvement and rights placed thereon by such lessee. (Emphasis added).

The Arizona statute recognizing a lessee's rights to reimbursement for privately owned improvements, including water rights, on state trust lands is found at A.R.S. § 37-322(A). These provisions suggest that, at a minimum, surface water rights perfected by state land lessees during the course of the lease are permanent improvements the value of which is subject to reimbursement by a new lessee when the lease is transferred or assigned or when the state trust land is sold.

This interpretation is supported by the old Arizona case of *Burns v. State Land Department of Arizona*.[87] This case involved the sale of irrigated state trust lands whose water rights were attributable to the state including the lands in the Roosevelt Agricultural Improvement District No. 1 by direct contact between the state and that district. When the land was to be sold by the state, the existing lessees claimed reimbursement for all irrigation district assessments and charges paid by the lessee plus the value of the water right under the statutory predecessor of A.R.S. § 37-322(A). The actual language of the statute at the time stated the following:

> Section 3429. Lessee of State lands to be credited with assessment by him. In the event of the sale of any such state lands, a lessee in possession thereof at the time of such sale, shall, in addition to having his improvements placed thereon appraised in the manner provided by law, be accredited with the water right acquired through the payment of district taxes, assessments and charges paid by him, which water right shall be considered and appraised as an improvement made upon said lands.

Obviously, under the language of this statute, the lessee was only entitled to reimbursement for district taxes, assessments and charges paid by him and the Arizona

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[87] 43 Ariz. 194, 29 P.2d 726 (1934).

Supreme Court ruled accordingly. The court essentially based its ruling on the fact that it was the state which had actually contracted for and developed the water right rather than the lessee. In so holding, the court stated the following:

> The justice of allowing a lessee reimbursement to the value of a water right he had acquired for state land is apparent, but is difficult to believe that the Legislature even intended that a lessee of state lands should be paid on the cancellation or surrender of his lease the value of a water right he did nothing either in the way of labor or money to acquire.[88]

This case would clearly seem to support the concept that an actual water right (not just the physical improvement which allows that right to be put to beneficial use) developed and perfected on state lands by a lessee of such lands is a reimbursable improvement under the above-referenced Enabling Act, constitutional and statutory provisions. However, if the subject water right was perfected by the state, it seems reasonable that a lessee may only be reimbursed for the actual cost of the improvement as was the ruling of the court in this case.

VI. CONCLUSION

As noted in the preamble, in May 1994, an interim state legislative committee began studying the state's adjudication process with the goal of simplifying, expediting, and reducing the cost of adjudication proceedings. As a result of their study, House Bills 2276 and 2193 were passed. These amendments included codification of the prior law discussed in this paper regarding water rights on federal and state lands. (See A.R.S. §45-151(E) and (F) and §37-321.01).

Oral argument regarding the constitutionality of HB 2276 and 2193 is scheduled before the Arizona Supreme Court on March 19, 1998. After a decision is rendered by the Supreme Court, presumably the adjudication will move back to a case-by-case approach. Only then, will the principles set forth herein be subjected to further scrutiny. Hopefully, this will mark the return to an era of cooperation between the public land agencies and the ranchers and rangeland water development will be maintained and enhanced.

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[88] 29 P.2d at 727.

Should Livestock Water Developments Be Allowed On Public Lands In Those States That Prohibit BLM From Obtaining New Water Rights for Livestock.

Tim M. Bozorth

Recent State legislation in Arizona and Nevada that prohibits the Bureau of Land Management from obtaining new livestock water rights on the public lands it manages raises the question; is it in the greater national public interest, in the future, to permit livestock water developments to be constructed on public lands in these states?

BLM should consider the cost to the public, potential impacts to upland, riparian vegetation and wildlife, the risk of not having water available for other public land management purposes, the workload associated with seeing that the water right transfers with the change in grazing authorizations, and the risk of water being removed from the public land.

Bureau of Land Management (BLM) regulations require that new permanent water improvements on public lands such as spring developments, wells, reservoirs, stock tanks, and pipelines are authorized through cooperative agreements. These regulations call for the BLM to retain title to all new grazing-related improvements constructed on public lands. Exceptions are made for temporary improvements such a portable storage tanks for hauled water. The Bureau is currently enjoined from enforcing this regulation and until such time as it is revered on appeal title to structural range improvements will be shared by the United States and cooperators in proportion to the actual amount of their respective contributions.

The BLM Grazing Regulations state, "Any (water) right acquired on or after August 21, 1995 to use water on public lands for the purpose of livestock watering on public land shall be acquired, perfected, maintained and administered under the substantive and procedural laws of the State within which such land is located. To the extent allowed by the law of the State within which the land is located, any such water right shall be acquired, perfected, maintained and administered in the name of the United States. In all cases involving the development and registration, pursuant to State law, of new water rights on public land for livestock watering, cooperative agreements will be used and maintained in conjunction with the grazing permit or leases and do not give rise to a claim for compensation in the event the permit or lease to which it is attached is canceled in whole or in part to devote the lands to another public purpose." The regulation are silent regarding what happens if States do not allow BLM to obtain water rights for livestock watering on the public lands under it's management.

If the BLM cannot solely or jointly hold water rights for livestock watering on public lands it administers is it in the greater public interest to invest public funds in the development of livestock watering facilities in these states in the future?

The expenditure of public funds is not limited to equipment, materials or labor for the construction of livestock watering facilities. The authorization of any livestock watering facilities on

public lands requires expenditure of public funds in staff time for cultural clearances, Endangered Species Act consultation, Section 404 Clean Water Act Permits and other state permits, design approval, National Environmental Policy Act compliance, etc, as well. These costs should be, but are not usually, considered when calculating percent ownership in range improvements.
It would remove a valuable tool for the improved distribution of livestock if it was considered inappropriate for public funds to be expended for the construction or authorization of new livestock water developments in states where the BLM was not allowed by state law to obtain new water rights for livestock watering.

Water developments can serve as a tool to better distribute livestock out of riparian areas and more evenly across upland range. Water development can be a key tool for the BLM and livestock permittee/lessee to utilize in attaining the recently developed Standards for Rangeland Health. Without this vehicle to improve livestock distribution the likelihood of livestock reductions to achieve the standards for rangeland health increases.
It may be more appropriate to use range improvement funds on more justifiable uses such as fish and wildlife habitat improvement projects if BLM is prohibited from obtaining water rights for new livestock water developments.

The Taylor Grazing Act was enacted by Congress in 1934 to stop the continuing deterioration of the public rangelands and to stabilize the livestock industry pending the disposal of the lands. Public rangelands within Taylor Grazing Act grazing districts were withdrawn by Congress from entry and acquisition of private title (except mining patents), unless and until specific lands were reclassified by the Secretary of Interior as more appropriate for non-grazing use.

Past Department of Interior legal opinions and the recently revised Bureau grazing regulations have held that water on public land within grazing districts may be appropriated by private individuals under state law. Congress has also frequently deferred to state law in order to not disrupt state water rights.

However, "the Supreme Court has held that federal statutes authorizing appropriation of water under state law apply only to lands that are available for entry and disposal under the public land laws. There is evidence in the structure, language, and legislative history of the Taylor Grazing Act to support the view that Congress intended that water not be alienated from grazing district lands unless and until the lands were reclassified as available for acquisition of private title." (Baldwin, 1994) This interpretation could prohibit or invalidate states granting water rights to private individuals on public lands within Taylor Grazing Act Districts. Grazing Districts encompass about 60 percent of Bureau of Land Management Public Lands in the contiguous United States.

Section three of the Taylor Grazing Act states that "the creation of a grazing district or the issuance of a permit ... shall not create any, right, title, interest, or estate in or to the lands. 43 U.S.C. section 315b and FLMPA Section 402(h), 43 U.S.C. Section 1752(h) ("Nothing in this Act shall be construed as modifying in any way law existing on October 21, 1976, with respect to the creation of right, title, interest or estate in or to public lands...") This could be interpreted to mean congressional intent was not to create **any** vested interest or title to public lands including water.

In light of the recent State legislation in Arizona and Nevada that prohibits the Bureau of Land Management from obtaining new livestock water rights on the public lands it manages, and because of the significance of water both to the states concerned and to the management of the federal rangelands, Congress may wish to reexamine the issues.

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THE EXCLUSIVITY REQUIREMENT IN THE LAW OF PRIOR APPROPRIATION.

By

Fritz Holleman, Trial Attorney, United States Department of Justice.[1]

ABSTRACT

Which Rancher Owns the Stockwater Right? The "Exclusivity" Requirement in the Law of Prior Appropriation and its Ramifications

Assuming that it is legally permissible for private ranchers to own water rights for stockwater purposes on the federal public land, any individual rancher must still satisfy the requirements of state prior appropriation law before any such right may be decreed. A seldom discussed aspect of the law of prior appropriation is the requirement that an individual claiming a water right must demonstrate exclusive use of the water at least as of the claimed priority date. Where a rancher has used stockwater tanks and other range developments in common with other ranchers, application of the "exclusivity" requirement to a claim for stockwater may result in a very junior priority date, or, in some cases, no water right at all.

Introduction

There has been controversy in the Western States regarding whether the stockwater sources on public grazing lands should be owned and controlled by private ranchers or by the land management agencies of the federal and state governments. While there are many strong feelings on the issue, those feelings have led to surprisingly few contested court cases, and therefore very

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[1]The views expressed in this paper are those of the author. They cannot be attributed to the Department of Justice or any agency in the United States Government.

little case law to guide resolution of this controversy.[2]

The purpose of this paper is to look past the question of whether stockwater rights should be owned by individual ranchers or by the public land management agencies, and instead, assuming for the sake of argument that it is legally possible for individual ranchers to own stockwater rights on the federal public land, examine the state law prior appropriation doctrine hurdles any such private claims to ownership must overcome.

One rarely discussed element in the law of prior appropriation is the requirement that a water rights claimant demonstrate exclusive use of the water claimed. Though directly discussed in only a few court cases, the "exclusivity" requirement is a logical extension of the traditional "diversion" requirement in the prior appropriation system. It is also analogous to requirements in other areas of property law, such as the law of capture, where an individual can create a private property interest by possession and use of public resources.

A similar requirement exists in the law of adverse possession, where property belonging to another may be acquired by a would be adverse possessor by, among other requirements, a

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[2]A couple of the leading cases regarding contested ownership of stockwater rights on public land are State v. Morros, 766 P.2d 263 (Nevada 1988), and Department of State Lands v. Pettibone, 702 P.2d 948 (1985). In Morros, the Nevada Supreme Court ruled that the United States was the beneficial user of the stockwater rights on the federal public land and overturned a Nevada State Engineers decision that such rights should be held by private ranchers. With respect to state owned school lands, the Supreme Court of Montana in the Pettibone decision held that the state and not private ranchers should own the stockwater rights.

showing of exclusive use of the property claimed. With water, as with claims based on the rule of capture and adverse possession laws, the exclusivity requirement means that a private property interest is only created where the claimant has used the water at issue to the exclusion of and adversely to other would be users of that same property.

The exclusivity requirement is appropriately applied in the context of private claims to stockwater on the federal public land because many, if not most of the developed stock water sources on the federal public land have been used by cattle owned by more than one rancher. As demonstrated in the next section of this paper, no rancher has the legal authority to exclude other ranchers from using the public domain for the same grazing purposes.

II. Background: A Quick Glance at the Law with Respect to Grazing on the Public Domain.

Prior to 1934, Congress had a simple, explicit policy with respect to grazing on the public domain--it authorized, even promoted grazing, but directed that the public domain be kept as a commons, available to all who desired to graze on it. The Supreme Court described this "federal grazing commons" in the following way:

> We are of opinion that there is an implied license, growing out of the custom of nearly a hundred years, that the public lands of the United States, especially those in which the native grasses are adapted to the growth and fattening of domestic animals, shall be free

> to the people who seek to use them . . . Everybody [has] used the open uninclosed country which produced nutritious grasses as a public common on which their horses, cattle, hogs and sheep could run and graze.

Buford v. Houtz, 133 U.S. 320, 326, 10 S.Ct. 305, 307 (1890); See also Omaechevarria v. Idaho, 246 U.S. 343, 352, 38 S.Ct. 323 (1918); McGinnis v. Friedman, 2 Idaho 393, 17 P. 635 (1888).

Congress enacted legislation to prevent exclusionary acts on the grazing commons with passage of the Unlawful Inclosures Act in 1885. Act of February 25, 1885, ch. 149, 23 Stat. 321, codified at 43 U.S.C. § 1061. The act prohibited all fencing or other exclusionary acts on public land where the person constructing the inclosure did not do so under claim or color of title and with the intent to enter the public lands and establish a permanent settlement.

Case law construing the Unlawful Inclosures Act explains it was intended to preserve access to the public domain. See e.g. Omaechevarria v. Idaho, 246 U.S. 343, 352, 38 S.Ct. 323, 327 (1918); McGinnis v. Friedman, 2 Idaho 393, 396, 17 P. 635, 636 (1888); Bircher v. U.S., 169 F. 589, 591 (Mont. 1909)("The obvious intention of the statute was to make unlawful any exclusive use and occupancy of any of the public lands without claim or color of title.")

Congress also sought to ensure the public's access to stockwater sources on the federal public land when it passed the Stockwater Reservoir Act of 1897. Act of January 13, 1897, ch. 11, 29 Stat. 484, codified at 43 U.S.C. § 952. The act allowed a

right of way for private parties to construct stockwater reservoirs on unoccupied public lands. Use of such reservoirs, however, was subject to regulation by the Secretary of the Interior. Congress explicitly stated that these sources must remain available to the public for stock watering:

> [A]ny person . . . engaged in breeding, grazing, . . . livestock may construct reservoirs upon unoccupied public lands . . . for the purpose of furnishing water to such livestock . . . provided, that such reservoir shall not be fenced and shall be open to the free use of any person desiring to water animals of any kind . . . . under such rules, regulations, and conditions as [the Secretary of the Interior] may prescribe . . . to protect livestock, to conserve water, and to preserve its quality and conditions: Provided, that such reservoir shall be open to the free use of any person desiring to water animals of any kind . . . . ."

43 U.S.C. § 952 (emphasis added). The language, and the policy it reflects, could not be more clear: stockwatering reservoirs on the public rangelands were not to be under the exclusive control of any individual stock owner or company, but were to remain open so that all stockraisers could water their animals.

It is important to note that Congress applied this rule of common access even though the act clearly contemplated that the stockwater reservoirs would be privately financed and privately constructed. Significantly, Congress deleted a proposed provision which would have given the person constructing the reservoir "exclusive possession and control" of the reservoir.[3] 28 Cong. Rec. 3347-3348.

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[3] The House report on the bill proposing the Act is worth noting. It states in relevant part:

> [The Act] is not intended to give title to the land upon

Congressional intent to preserve public, non-exclusive use of stockwater sources on the federal rangeland is further illustrated by the Stock Raising Homestead Act of 1916. Act of Dec. 29, 1916, ch. 9, 39 stat. 862, codified at 43 U.S.C. §§ 291-298 (repealed 1976). This Act attempted to promote homesteading of semi-arid regions that were not susceptible to crop farming but were able to support grazing. Congress directed the Secretary to designate these "stock-raising" lands and make them available for homesteading. 43 U.S.C. § 292 (repealed 1976).

At the same time, however, Congress specifically directed the Secretary not to designate "[l]ands containing waterholes or other bodies of water needed or used by the public for watering purposes . . . ." 43 U.S.C. § 300 (repealed 1976). Congress also authorized the Secretary to reserve the lands surrounding these water holes so that these water holes would "be kept and held open to public use . . . ."[4] Id.

The House report explained the obvious intent and effect of these provisions, stating that they were designed to prevent the private appropriation of stock watering sources:

> which the reservoirs are located, and the companies can only have control of such reservoirs under such rules and regulations as may be prescribed by the Secretary of the Interior, and only for such time as such reservoirs are maintained and water kept therein. The act also provides that the land shall not be fenced and shall be open to the free use of any person desiring to water animals of any kind.

H.R. Rep. No. 1527, 54th Cong., 1st Sess. (1896).

[4] The Secretary subsequently used this authority to reserve every spring or waterhole on unappropriated unreserved public land. Public Water Reserve No. 107, Executive Order of April 17, 1926.

> This is a new section, and authorizes the Secretary of the Interior to withdraw from entry and hold open for the general use of the public, important water holes, springs, and other bodies of water that are necessary for large surrounding tracts of country; so that a person can not monopolize or control a large territory by locating as a homestead the only available water supply for stock in that vicinity.

H.R. Rep. No. 35, 64th Cong., 1st Sess. 18 (1916)(emphasis added).

With passage of the Taylor Grazing Act in 1934, Congress sought to better utilize and conserve the Nation's lands through more formal regulation of the public grazing program. Ranchers holding grazing permits issued under the Taylor Grazing Act do not, however, acquire an interest in the land, but simply a license to graze their cattle on that land. United States v. Fuller, 409 U.S. 488 (1973); Swim v. Bergland, 696 F.2d 712 (9th Cir 1983). The Act specifically provides that "[T]he creation of a grazing district or the issuance of a permit pursuant to the provisions of this subchapter shall not create any right, title, interest, or estate in or to the lands." 43 U.S.C. §315b.

In contrast to a lease which gives a lessee rights against the owner of the land and all others who might attempt to use the land which is the subject of the lease, a rancher holding a BLM grazing permit issued under the Taylor Grazing Act cannot exclude others holding similar permits from using that same land. A license "is defined as a personal, revocable, and unassignable privilege, conferred either by writing or parol, to do one or more acts on land without possessing any interest therein." 25

Am. Jur. 2d Easements & Licenses § 123 (1966).

> The distinction between a license and a lease:
>
> is whether the contract gives exclusive possession of the premises against all the world, including the owner, in which case it is a lease, or whether it merely confers a privilege to occupy under the owner, in which case it is a license.

Kaiser Co. v. Reid, 184 P.2d 879, 884 (Cal. 1947) emphasis added (quoting Goerlitz v. Turner, 150 P.2d 278, 280 (Cal. Ct. App. 1944); See also Branson v. Miracle, 111 Idaho 933, 936, 729 P.2d 408, 411 (Idaho 1986)("While acting pursuant to permission the claimant's rights are in the form of a license. Unless the licensor is estopped, a license is revocable at will . . . . No interest in property vests in the licensee.").

When a grazing permit expires or when a rancher does not comply with its terms, the United States, as the proprietor of the public domain lands, may allow other grazers to use the forage and the stockwater sources on the federal property. Many BLM grazing allotments are permitted for use by more than one rancher at the same time. Permits change hands and BLM allotments change boundaries. Many allotments are permitted to different ranchers at different times of the year. Many ranchers sublease portions of their BLM grazing permits to other ranchers for their use. In short, any individual stock tank is likely to have been a source of water for cattle owned by many different ranchers. In light of these many users, the question is whether any one rancher is entitled to a water right under state law; and, if so, additional questions remain regarding the quantity

and priority date to which he or she is entitled.

This paper concludes that if it is legally possible for a private rancher to own a stockwater right on the federal public land, such a claim must be limited to a priority date no earlier than the date that he or she had exclusive use of the quantity of water claimed.

I. The Exclusivity Requirement

A. Case Law.

The best discussion of the exclusivity requirement in the context of private claims to stockwater rights on the public land appears in Robinson v. Schoenfeld, 218 P. 1041 (Utah 1923). The dispute in Robinson was over the right to use two springs located in the head of a box canyon on the unsurveyed public domain in Kane County, Utah. The waters from the springs were used by the plaintiff, Robinson, and his predecessors in interest for watering stock running at large on the public range. Robinson's predecessor in interest had constructed a trough and some other collection works intended to make the water available for irrigation, but the only beneficial use to which the water had ever been put was stockwatering. Id. at 1041 and 1042.

The key undisputed fact in the Robinson decision was that "the range cattle of other stockraisers frequented [the] springs and drank therefrom." Id. at 1042.

Robinson brought the lawsuit requesting that he be declared the owner of the waters from the spring and that the defendant,

Shoenfeld, be enjoined from using the spring. The trial court decreed Robinson to be the owner of the springs, and enjoined Schonfeld from interfering with Robinson's use of the spring water.

The Utah Supreme Court reversed and remanded the decision primarily because:

> The proof fail[ed] to show any use or appropriation of the waters of the springs by plaintiffs or their predecessors in interest to the exclusion of others having stock running at large upon the public domain in their vicinity.

Id. at 1042-43. The Utah Supreme Court elaborated on the significance of exclusivity to a claim for water rights:

> Plaintiff's testimony, without dissent, shows that other stock owners having cattle on this range had enjoyed the same rights and privileges with respect to the waters of the springs here in question as did plaintiffs. In other words, the ownership and use proven by the plaintiffs were in no sense exclusive or subject to the complete dominion and control of plaintiffs. We are therefore of the opinion, and so hold, that the plaintiffs testimony did not show such appropriation or use of the waters of the springs as would authorize the trial court to decree to plaintiff's the use of the waters against defendant.

Id. at 1043.

The Montana Supreme Court reached a similar conclusion in Jones v. Hanson, 320 P.2d 1007 (Mont. 1958). In Jones, the plaintiff had boxed some springs to collect water for domestic and stockwatering purposes. As in Robinson, it was undisputed that water from the springs had been used by other ranchers and their cattle for the same purposes for which the plaintiff was

seeking a decreed water right.

Relying extensively on the Utah Supreme Court's decision in Robinson, the Montana Supreme Court held that while the exclusivity requirement had not been squarely addressed in Montana, "it is based on a common-sense interpretation of our [Montana's] laws relating to the appropriation of water." Jones, 320 P.2d at 1013. The Court held:

> There is no showing by plaintiff that his use of the water was to the exclusion of others and since the springs were not subject to the complete domain and control of the plaintiff, it necessarily follows that the boxing of the springs did not constitute a valid appropriation of water for any purpose.

at 1012 (emphasis added).

The Robinson and Jones decisions are the leading, and maybe the only, cases on the exclusivity requirement in the context of grazing. The rarity of cases addressing the exclusivity requirement may be explained in part by the fact that it is an issue only where the claimant of the water right has no exclusive right to use the land on which the water is located and used. This is an unusual situation. Water rights are usually sought for use on private land. Where the claimant of the water right is also the owner of the land on which the water is used, exclusive use of the water is generally not an issue because there is no question that the water rights claimant may exclude others from the land where the water right is used.

Where water rights are sought for use on land not owned by the water rights claimant, that claimant usually at least has a

sufficient interest in the land which is the place of use of the water right to prevent others from making the exact same use of the land as that for which the claimant is seeking the water right. This is true in the homesteading and mining contexts, other uses of water rights on public land, where the law gives someone using public land for these specific purposes the right to exclude others from using the land for those same purposes.

Grazing permittees, by way of contrast, may not exclude other stock growers from using BLM land for grazing purposes. A similar situation arises in the context of hunting and fishing on the public land. No individual making use of public domain lands for such purposes has the right to prevent others from making the same uses. Where individuals have sought water rights for these purposes on public domain lands, courts have invoked the exclusivity doctrine to deny any appropriative water rights.

In Brasher v. Gibson 406 P.2d 441 (Az. App. 1965) for example, the evidence showed that the water at issue had been used by the general public for the same fishing and recreation purposes for which a private right was asserted. Because use of the water had not been exclusive, the court stated there could be no valid appropriation. Brasher at 449. Similarly, it was the lack of a possessory right in the land, or the ability to exclude other members of the public from making the exact same hunting uses of the public domain, that so troubled the Court in Lake Shore Duck Club v. Lake View Duck Club, 166 P. 309 (Utah 1917). In that decision, the Court found the plaintiff did not have a

protectable property interest in the waters claimed:

> It is manifest in this case that the plaintiff has no possessory right whatever to the lands upon which the water is to be applied. It is therefore impossible for it to acquire the exclusive enjoyment of the use to which the water is applied.

Id. at 311. The Utah Supreme Court elaborated:

> We are decidedly of the opinion that the beneficial use contemplated in making the appropriation must be one that inures to the exclusive benefit of the appropriator and subject to his complete dominion and control.

In each of the cited cases, the court was clearly troubled that one individual was attempting to acquire a private property right for water that had been used by others at the same place of use for the same purpose of use. The use of the land and the water at issue in each case was a use which the water rights claimant had no greater right to make than any other user of the public domain.

B. Prior Appropriation Elements.

The law of prior appropriation grew up out of the law of capture. See Brasher, 406 P.2d 448. As explained by the Supreme Court of Utah in Lake Shore Duck Club v. Lake View Duck Club, 166 P. 309 (Utah 1917), "the very purpose and meaning of an appropriation is to take that which was before public property and reduce it to private ownership." Id. at 310-311. While it is dangerous to generalize, it is widely acknowledged that there are three basic requirements for finding that a valid appropriation has been made. A water right must be (1) *diverted*,

with an (2) *intent* to apply that water to a (3) ***beneficial use.*** See generally Getches, "Water Law in a Nutshell," p. 88 (2nd Ed. 1990).

The exclusivity requirement is closely related or identical to the traditional "diversion" requirement.[5] The heart of the diversion requirement is that the amount of water claimed must have been reduced to actual, exclusive possession before a property interest could be established. See e.g. Hidden Springs Trout Ranch, Inc. v. Hagerman Water Users, Inc., 101 Idaho 677, 619 P.2d 1130 (1980)(and cases cited therein regarding the diversion requirement). Until actually removed from the stream and reduced to possession, water remained "unappropriated," and under the state constitutions in most Western States, subject to appropriation by others.

C. Analogies in Other Areas of Law.

Exclusivity, of course, is the defining characteristic of any type of private property interest. One need look no further than the definition of "property" in Black's law dictionary:

> That which is peculiar or proper to any person; that which belongs exclusively to one . . . More specifically, ownership; the right to dispose of a thing in every legal way, to possess it, to use it, and to exclude every one else from interfering with it.

Black's Law Dictionary 1095 (5th ed. 1979).

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[5]Exceptions to the diversion requirement have been carved out by various statutes throughout the Western States, and for good reason. The diversion requirement remains, however, an analytical cornerstone of the prior appropriation doctrine.

The same "exclusivity" requirement is present in other situations where, as in the creation of water rights, the law allows a party to create a property interest merely by possession. The most obvious example is the law of adverse possession, where it is a black letter principle that use of the property at issue must have been to the exclusion of both the true owner and other would be users of the property at issue. See e.g. Farrell v. Brown, 111 Idaho 1027, 1034, 729 P.2d 1090, 1097 (1986).

The rule of capture provides an equally strong example of the exclusivity requirement. Although subject to modification over the years, the traditional rule was always that oil and gas become personal property only when lifted from the ground and reduced to actual possession. See e.g. Frost v. Ponca City, Okl., 541 P.2d 1321, 1323 (1975); Replogle v. Indian Territory Illuminating Oil Co., 143 P.2d 1002, 1007 (1943). The same rule applies with respect to acquisition of a property interest in wild game: "[A]ll the animals which can be taken upon the earth, in the sea, or in the air, that is to say, wild animals, belong to those who take them." Geer v. Connecticut, 161 U.S. 519, 523, 16 S.Ct. 600, 602 (1896) (quoting the Digest of Justinian); 2 W. Blackstone, Commentaries 411 (1766) ("Every man ... has an equal right of pursuing and taking to his own use all such creatures as are ferae naturae"). Thus, it is clear that property law

generally is suffused with the requirement that those seeking to reduce public resources to private property must demonstrate exclusive use and possession of the property they claim. The rule is the same with water rights, and it must be applied to claims for stockwater rights.

III. Practical Implications.

In water rights adjudications throughout the West, many private ranchers have filed claims for stock water rights with priority dates based on the date their base ranch was patented from the United States Government. In litigation of such claims, it is common to learn that the water development at issue has been relied on by many ranchers in the vicinity of the development. Claims to early priority dates in such situations fail when tested against the exclusivity requirement.

A different ruling would in effect establish a regime where the first to file on a stock tank that had been used in common with other stock growers would get the water right. Ownership would simply be established by a race to the courthouse. The water rights would go to the sophisticated rancher, and while this would not be an unusual result in the world of water rights, it seems inequitable and is the result that clearly troubled the Utah and Montana Supreme Courts in the Robinson and Jones decisions.

Assuming for the sake of argument that it is legally possible for private ranchers to own stockwater rights on the

federal public land, strict application of the exclusivity doctrine requires that the decreed quantity of any such rights be directly tied to the amount used by the claimant's cattle. Strict application also means that the priority date must be no earlier than the date when the claimant's cattle had exclusive use of the amount of water claimed. In short, the claimant cannot acquire a property interest based on use of the particular stockwater source by cattle owned by other ranchers.

Should Grazing Permits Be Saleable to Environmental Groups?

Robert H. Nelson

Most of the papers at the conference have taken the existing parameters of the public land system as a given. In my paper, I want to shift somewhat from the micro to the macro and address a potential paradigm shift for public lands. Should the future uses of public rangelands be determined much more by market forces, instead of administrative decisions made through the existing land use planning system? This could be accomplished by allowing environmental and other non-livestock groups to purchase existing grazing permits for the purpose of changing the use of rangeland forage.

As a way of addressing that question, I will be telling a personal story. I worked for 18 years in the Department of the Interior as a career economist in the Office of Policy Analysis. This is the principal policy office serving the Secretary of the Interior. When I showed up for work there in 1975, my first job was to develop a benefit-cost system for rangeland improvements for the Bureau of Land Management (BLM). The BLM was under pressure from OMB and the Congress to justify plans for funding of fencing, water development projects, and other rangeland improvements.

For my first year on the job, I spent about half of my time on this project. I worked closely with BLM staff and received an excellent introduction to the policy issues of federal rangeland management. Somewhat to the surprise of some of my colleagues in the Office of the Secretary -- BLM was not always friendly towards outsiders meddling in their affairs -- the BLM did adopt the system of doing benefit-cost analyses that I had designed.

I have been away from the subject now for many years. Thus, it has been fascinating at this conference to hear discussion of the current BLM benefit-cost system, which can be traced back in part to those efforts of mine in the mid 1970s. It is also interesting to hear how the discussion and the problems with respect to use of benefit-cost analysis have changed so little over the years.

At the time, I wrote a primer that was sent out to all the BLM field people as official guidance in doing benefit-cost analyses. This primer had the full blessing of the BLM hierarchy; the office of the director of BLM issued a memorandum requiring everyone to do benefit-cost analyses. However, as followup we would do periodic checks on how the field was performing. The results usually showed half hearted compliance.

Indeed, after two or three years it was apparent that the benefit-cost analysis of rangeland investments was not going very well. Many people were not using the new system at all, or if they were using it, they were using it to rationalize things they already wanted to do for noneconomic reasons. Basically, it was the same story that has been presented 20 years later in some of the papers and comments for this conference.

There seems to be a permanent cycle in the BLM application of benefit-cost analysis. The field does not want to do it and resists. BLM field personnel basically do not want their administrative descretion limited, as economic analysis has the potential to do. They want the full freedom to work out deals with the local power structure, or other political groups, as the imperatives of BLM institutional requirements may require.

However, outside pressures from OMB, the Interior Office of the Secretary, Congress or others are periodically exerted to justify BLM spending. Then, there might be a renewed BLM interest and the Washington office might try to pressure the BLM field to do more economic justifications for proposed rangeland investments. During my 18 years at Interior, this was one-of my regular Office of the Secretary roles -- trying to push BLM to take more careful account of economic considerations in its decision making.

Basically, not to mince works, I (and others like me) failed. Following complaints from higher ups, there might be a flutter of activity in BLM, some memos sent to the field reminding people that benefit-cost analysis of water development projects and other rangeland improvements was a required activity, but in the end nothing much would happen.

Although all this did not do much to improve public land management, it was a good education for me. It was an education about how difficult it is to change anything in government and in how the federal bureaucracy works. It was also about how much money could be wasted in government. Part of the money was wasted on BLM fencing and water projects that had high costs and few returns.

I had expected that. The bigger surprise for me was the wastefulness of the decision making process itself. Personally, the benefit-cost analysis itself, given that BLM never really used it, was a waste of money. BLM wanted to create the public image of a rational decision making process, even if it had little intent to make it a reality. Doing benefit-cost analysis for BLM was like the advertising budget for a private firm, part of the image making activity of the organization.

But it was all at significant taxpayer expense. I spent half of my first year -- and the government was paying me a good salary -- and involved lots of high level BLM people in Washington in the effort. Then, there were all kinds of meetings in the field to explain the new benefit-cost system to BLM staff, telling them the technical procedures and so forth. It all involved many hundreds of thousands if not millions of dollars. Yet, as I said, all the efforts to install a new benefit-cost system basically did not have much impact.

So I started thinking over the years, how does the broader public rangeland management system work? I started writing about this subject for audiences inside and outside the government. I could not have expected such a result but that is a main reason that I ended up today as a professor in the public policy school at the University of Maryland.

In any case, the BLM rangeland benefit-cost experience was just one small case of a story which I would see repeated many times over. In fact, it has become magnified over time. Today, public rangeland management has processes following processes, procedures after procedures. Yet, they don't seem to get anywhere. I was amazed to discover just a few months ago, in a GAO study, that the U. S. Forest Service is now spending $250 million per year on environmental studies. The total budget of the Bureau of Land Management is about $600 million or $650 million. The operating budget of the Forest Service may be $1.5 to $2 billion. To be spending $250 million per year on environmental studies is grossly excessive in light of the scale and money value of the decisions being made.

Moreover, I have a feeling that a lot of the environmental analysis is basically tying the Forest Service up in knots, more than it is actually improving environmental decision making. I suspect that the people who push the ideas for doing environmental studies, if they went through my experiences, and went to check and see how much improvement was actually being realized in public decisions, would find that it was pretty limited. Environmental planning yields a lot of activity, but there is not much result in comparison to the costs.

All the wasted spending in BLM for both the process of decision making and on-the-ground investments caused me to start thinking more broadly about the economics of public land grazing. One of the things about the federal rangelands is that the economic returns to grazing on these lands are very small. Essentially, much of the rangeland was worthless for any other economic activity. Without anything else to do with the land, the early settlers put cows on it -- and very few per acre by midwestern and eastern standards.

So, when you have the escalation of procedural requirements at high cost, but serving a very low economic value activity, it doesn't take long before the procedures alone cost more than the economic output is worth. In fact, this is a point that the BLM passed quite some time ago in the case of its livestock grazing program.

In the 1970s, I looked into the costs, for example, for the grazing environmental impact statement (EIS) in Challis, Idaho. This EIS was the first of many required under a court settlement of NRDC v. Morton. As a result, the BLM spent a lot of money on it, by my estimate around $7 million. However, the capital value of all the BLM grazing permits in the Challis area was less than $7 million. We spent more on the grazing environmental impact statement than the total economic value of the grazing resource being studied.

This is not an isolated problem. Consider the BLM as a whole. What do we spend on grazing in total? It is not easy to determine. In fact, I spent about two months in the early 80's on the subject. The biggest problem is what to do with all the overhead. If you ask the BLM what it spends on an activity, the number generated will be small. Most of the BLM costs are actually burried in overhead and not attributed to grazing, water development, timber, recreation or any other specific activity.

So I decided to ask a question new to BLM. Assume as a requirement that the costs of grazing management plus timber management plus oil and gas management plus rights of way management plus coal management -- and any other specific outputs -- would have to add up to 100 percent of BLM costs. In other words, every cost would have to be assigned to some specific area of output activity.

Using this approach, in the early 1980s I estimated that the full costs of grazing management amounted to around $125 million a year. Adjusting for inflation, the costs for 1997 are probably around $200 million. This is actually a conservative estimate. If one considers what would happen to the BLM as an organization if there were no livestock grazing on the federal rangelands, the answer might be that the BLM would have surprisingly little to do.

The management of elk, deer and other wildlife is really a state government responsibility. The management of recreation on BLM lands does not really involve large responsibilities, at least as BLM has historically practiced recreation management. On close inspection, much of the nongrazing activity for BLM really involves dealing with problems and impacts that are themselves created by use conflicts with livestock grazing. The truth of the matter is that the BLM in some ways amounts to a large mitigation agency for livestock grazing. From this perspective, my estimate of $200 million a year for BLM livestock grazing management is a significant underestimate.

What does the government receive in revenue from BLM livestock grazing? In 1997 the grazing fee will bring in something like $13 million. The grazing fee is $1.35 an animal unit month (AUM) and there are about 10 million AUMs on BLM land.

A good economist, of course, will also ask what is the actual market value of the BLM rangeland forage. This provides the best estimate of the value to society of the forage. Howevever, even if you use a pretty high number for the market value of the forage, this BLM forage is still worth only $75 million to $100 million per year.

That figure then has to be compared with the $200 million plus the government is spending for BLM grazing management. Obviously, the BLM grazing program altogether fails by this simple benefit-cost test. If the BLM grazing program were run like a private business operation, there would be an easy answer. The grazing program would be abolished as a cost cutting and profit enhancing device.

I should point out, however, that much of the government expenditures do not amount to a subsidy to the rancher. Above the market value of the BLM rangeland forage, the additional cost of BLM grazing management is simply a deadweight loss to the American economy. It goes to pay the costs of BLM management, mostly the costs of personnel. If anyone is being subsidized, BLM staff are the greatest beneficiaries, the recipients of good paying federal jobs in attractive rural locations where such jobs are scarce.

Another way of looking at this is to ask what is the capital value of all of the grazing forage obtained on the BLM rangelands. Using $50 to $100 per AUM for the market value of a grazing permit, and given about 10 million AUMs of BLM grazing per year, the total capital value of all BLM grazing permits amounts to around $500 million to $1 billion. This is the long run capitalized value of the forage asset.

Compare that amount with the $200 million a year the government is spending just to administer the BLM grazing program. If the government applied the $200 million a year to buy up grazing permits at market value (and assuming ranchers were willing to sell), it would take only two and one-half years to five years to buy out all the grazing permits on BLM rangeland.

It should be obvious by now that the BLM grazing program can not be justified by any ordinary economic standard. Of course, one solution might be to reduce the government costs sharply. Much of the land use planning, environmental analysis and other high decision making costs offer little real benefit to anyone. Whatever the answer, from an economic perspective at least, something drastic needs to be done.

Of course, government is more about politics than about economics. That was one clear lesson of the 18 years I spent in the Office of the Secretary of the Interior. Politics, not economics, explains the existence of the BLM grazing program in its current state. And politics will ultimately determine any attempted solutions to the current major problems of the program.

To get back to the evolution of my own thinking, after a few years I started wondering if there might be a better basic approach to managing BLM livestock grazing. Would there be some other way to deal with this key activity on BLM lands, a better way to resolve some of the fierce controversies it generated.

As long ago as 1963, a leading western agricultural economist by the name of Del Gardner (now a professor emeritus at Brigham Young University) suggested that the basic workings of the BLM grazing program should be fundamentally altered. The best way to allocate access to BLM rangeland forage, he argued, would be to simply to allow the marketing of the forage rights. BLM grazing forage should be treated like most other resources in the American market system. This resource should be used by the party willing to pay the most to use it.

Other economists would subsequently propose similar approaches to other types of environmental problems. In the case of air pollution problems in Los Angeles, the starting point was that there were too many polluters and someone would have to stop emitting. What to to? One approach would be to fix the total amount of allowable pollutants, and then let people compete in a market for the access to pollution rights.

Of course, it would be difficult for environmentalists to buy air pollution rights in Los Angeles in order to cut down on emissions, because these rights might be worth many millions of

dollars. However, in the case of BLM livestock grazing this was much less of a problem. As mentioned earlier, the value of BLM grazing is very low, in some cases close to worthless. It is possible to buy out BLM grazing rights in many places for about $4.00 an acre.

To illustrate, it would cost perhaps $100 million to $150 million to buy out all the grazing rights (Forest Service as well as BLM) in the entire U.S. wilderness system. That is not really all that much money. Ted Turner alone recently announced he would give $1 billion to the United Nations. He could have given 10 percent of that and purchased all the grazing permits for their private market value in all wilderness areas across the United States (again assuming ranchers were willing to sell). It is not unrealistic to think that someone like him might even be willing to put up the money for that exact purpose.

There is no doubt that many environmentalists would like to remove livestock grazing from wilderness areas. However, rather than paying for the grazing permits, they presently want the Forest Service and BLM (or the federal courts) to order the ranchers out without compensation. I would have to ask: How long is it going to take using this approach to resolve the issue of livestock grazing in wilderness areas? How much money will be spent in litigation and other fighting about the proper role of livestock grazing in wilderness areas under current procedures?

In considering such questions, the need for a new approach to resolving BLM rangeland use disputes seemed obvious to me. It would be better for environmentalists to offer to buy out grazing permits in wilderness areas, rathen than seek to have these permits cancelled by administrative fiat. Allowing sales of permits would also be better for ranchers. In short, allowing open sales of grazing permits to anyone would be the best way of addressing the question of the proper use of the grazing forage on the BLM rangelands.

I came to this conclusion by the early 1980s. I was not alone, as the idea was bandied around by other Interior Department economists at that time as well. However, sale of grazing permits to nonranchers was not going anywhere then in terms of actually being implemented. I did raise the proposal at academic conferences like this, and it would get shot down by both environmental and ranching sympathizers.

However, times change. Environmentalists have now seen that the development of a market in western water rights can effectively serve to increase in-stream flows and other environmental purposes. If the goal is to increase the flow of water in a river, it may be that the fastest and cheapest (in the long run) way to get the water is simply to buy the water rights from existing farmer holders of these rights.

Basically, in terms of the structure of the problem, the situation is almost identical in the case of the use of BLM grazing forage. You have an existing resource, you want to change the use of it. Much as environmentalists have turned to buying up water rights, they are now starting to look favorably at buying up federal rangeland grazing rights, in order to convert the use of

BLM forage to some other more environmentally acceptable purpose.

The current way of resolving BLM rangeland conflicts, environmentalists are increasingly recognizing, is basically a work program for lawyers. If the goal is to get something accomplished, a more promising approach is to do it directly by buying the control over the access to the resource.

To give another example relating to groundwater use, some urban areas in the West desperately need new sources of water supply. The approach in growing use today is to buy the rights to groundwater from farmers. Here in Arizona, when Tucson needed more water, the city did not try to take their water from them, perhaps by regulating nearby farmers out of business. Instead, the City of Tucson went out and bought groundwater rights to meet its needs. If the farmers went out of business, it was their choice. In fact, some of them might have continued to farm but applied new ways of farming that used much less water. In any case, it was a willing seller and willing buyer transaction.

The same approach could be adopted in the area of BLM (and Forest Service) rangeland grazing. If some party wants to remove livestock grazing from a BLM riparian area, for example, then this party can buy the grazing permit and thus the rights to the forage use there.

Some environmentalists may say, why should we pay to remove livestock grazing when the rancher has no business being there in the first place? There are two responses to this, one practical and the other more theoretical.

First, as a practical matter, environmental groups are likely to achieve their objectives much more quickly by simply offering to pay. They may well also achieve their objectives at less total cost in the long run. The current process of litigation, review of land use plans, public particulation, and other steps in the cumbersome process of public land decision making absorbs large financial resources on all sides. If the funds now being directed into attempts to influence government rangeland decisions were instead redirected to purchases of grazing rights, the result might offer a substantial net gain for the environment.

The second consideration is more conceptual. Environmentalists are sure that by an objective standard their use preferences for the BLM rangelands are correct. But ranchers are equally so convinced. It may be that in an important sense both are wrong. There may not be any one objective standard of public land decision making. It may be simply a matter of personal tastes and values. The ethos of public rangeland management has been that uses should be scientifically determined. However, if there is no scientific answer, if the use chosen must always rest heavily on value judgments, the government will have no objective way of resolving the use claims of one group versus another.

In that case, environmental efforts to remove livestock grazing are simply an attempt to use government power to assert their own values over the values of the ranching community. Of

course, it is also true the other way around. There is no objective reason why grazing use should be preferred over other uses more attractive to environmentalists.

If there is no one objectively best use of the land, how is government to decide. If any final use decision for BLM rangelands contains an unavoidable arbitrary element, why not let the contending parties resolve the matter among themselves? The government need not get in the middle of what is in essence a dispute among conflicting value claims for the use of the BLM rangeland forage resource.

There might even be some broader benefit to the federal treasury -- and the federal taxpayer -- through reductions in BLM administrative costs. For people like me who were working in federal policy offices in the 1980s, that was one of our goals in raising the idea of allowing environmental buyouts of grazing permits.

As I mentioned, there was not much enthusiasm back then. The newest development, however, is that some members of the environmental community have started to explore this idea in an active way.

In fact, there is a negotiation process for this purpose that I have been involved in it for about two years, also involving Karl Hess. Frank Gregg, who is a former director of the BLM in the Carter administration, and is now an Arizonan, has also been participating. Others who are involved represent some of the the top leaders of the western livestock industry and of the environmental community concerned with BLM lands.

The negotiating process started with a meeting in Reno in February of 1995. A lot of issues have been under discussion. If the livestock industry and the environmentalists are eventually able to reach an agreement, the quid pro quo would be something along the lines that I have been describing.

First, environmentalists would be given the legal right to buy out the grazing permit on particular areas of BLM lands and to make use of the rangeland forage for whatever use they deem appropriate. This would essentially overturn the Taylor Grazing Act, which effectively says that livestock grazing will be the dominant use for most of the BLM lands. Instead, there would be no one use preferred over another. The actual use would be determined by market negotiations among willing sellers and willing buyers.

That is why I said above that we are talking about a basic paradigm shift for BLM management of its rangelands. The proposed new system would start off with existing ranchers holding the grazing permit but then anyone else could buy it from them, assuming they can find a mutually acceptable price. Some environmental purchasers would probably want the forage left unused altogether; others would use it for elk forage or some other brand new use. At present, if someone acquires a BLM grazing permit, and does not use it for livestock grazing, that party is subject to losing the permit. The current system is a grazing "use-it-or-lose-it" system.

Another idea under discussion in the rancher-environmental negotiations is to abolish the base property requirement. That would make it much easier for a nonrancher to purchase access to the BLM rangeland forage. Another proposal, although there is some disagreement about this, would be to allow essentially unrestricted sub-leasing of access rights to BLM forage.

Part of the thinking here is that open subleasing would work to the benefit both of potential ranching and environmental purchasers of BLM grazing permits. Consider the following scenario. The Nature Conservancy would come in and buy the existing grazing permit from the current BLM rangeland permittee. The Nature Conservancy would then turn around and sub-lease grazing access back to the same rancher. However, instead of the BLM being principally responsible for setting the terms of grazing to protect the environment, the Nature Conservancy would now assume this role. Moreover, these terms would also be enforced now as a matter of private contract, likely to achieve a more effective enforcement than current often feeble government efforts.

What is the advantage for ranchers? For one thing, if they resist any changes in the public land system, they may in the end simply be overwhelmed by pressures for new recreational and other uses. If change is eventually to occur, it would be better for ranchers to receive some compensation, rather than a later government takeover of the grazing permit without any payment. As long as contending uses have no other way of expressing their demands for new uses of the BLM rangeland, they will be forced to turn to the mechanisms -- however cumbersome -- of the existing command-and-control administrative system.

Another practical advantage for ranchers is that they would have an additional market for grazing permits. Some of them have been looking for buyers for their permits, partly because of the depressed state of the livestock industry.

However, a workable agreement probably also has to involve a recognition of a greater security of tenure for the rancher, if he or she decides to stay in the ranching business. In fact, a longer and more secure tenure would also be a major benefit for any environmental purchasers of grazing permits. If an environmental group obtains a grazing permit, it will not want this permit to expire in a couple of years. After paying good money, it will want to have control over the future use of the forage resource for ten, twenty, maybe thirty years.

An environmental group purchasing a grazing permit would be entering into the land management business. Such groups would also need positive incentives to make rangeland forage investments and to take other actions with long run payoffs. The idea thus would be to lengthen the tenure for forage use permits to maybe twenty, possibly thirty years and then to set more precise conditions for what it takes to retain the permit.

An additional area for discussion is a shift from the current micro management by the federal government of all the details of rangeland forage use. At present the government says to the rancher, start grazing on BLM rangeland on April 15, and get off by June 20. In the new

approaches now under discussion, there would be more of a performance standard. Certain riparian habitat, wildlife forage access and other environmental standards would be set as a condition of continued access to the forage resource in a particular BLM allotment.

If the local elk hunting club bought the grazing permit, it would be subject to the same tough allotment performance standards as the rancher. You would have one performance standard that anybody who owned a forage permit on BLM lands would have to comply with. If they did not, and refused to come into compliance, they would lose the permit.

Another part of the package under discussion would be to spend a lot more money on monitoring and enforcement activities in general. A further subject of concern has been the possible contents of the performance standards and how they would be effectively enforced. How would the BLM set the performance standards for its rangelands so that they would be workable and enforceable and less subject to the political manipulation so common in in the past?

I should mention one last development. Many of you know that Andy Kerr was a prominent environmental architect of the spotted owl campaign in Oregon against timber harvesting. He has recently announced that in the case of livestock grazing he has had at least somewhat of a change of heart with respect to determining the use of federal rangelands. He has recently issued a new position paper on the subject. As Kerr now writes,

> It has been two decades since the passage of the Federal Land Policy and Management Act. The effort to reform livestock grazing on the public lands has stalled. The time has come to propose a solution outside the box we (environmentalists, ranchers, bureaucrats and politicians) are stuck in. The environmental movement is becoming increasingly polarized on the public land grazing issue. While abolitionists are ascendent, the reformers -- for the moment -- hold much of the power on the issue within our movement.
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> While immediate abolition is the most ecologically rational, it is the least politically feasible. While "reform" (however it has been defined) may be more politically feasible than abolition, it is clearly the least rational, fiscally and ecologically. Nonetheless, the last several political attempts at reforming livestock grazing policies have not been successful. Reform measures that focus on range fee, range management standards, public involvement processes, etc., have not and will not gain a critical mass of support within the environmental community.
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> Expanding the AUM market to all comers, however, can be supported by all factions of the environmental movement, save its most idealist link. To idealists, it is morally wrong to pay permittees for something they don't own, are being subsidized to do, and which causes environmental harm.

This last point is obviously a major obstacle for some environmentalists. It brings to mind a similar discussion relating to the creation of a market in rights to pollute. Many environmentalists initially objected that society should not legitimize pollution by explicitly and legally recognizing the sale of rights to pollute. Refraining from pollution was an obligation that had to be accepted as a matter of morally upright behavior; it should not be sold in the market.

However, attitudes changed and eventually the Clean Air Act Amendments in 1990 included the creation of a new market in rights to emit sulfur dioxide. Of course, rather than be explicit and call it the sale of a right to pollute, the legislation describes such rights as "allowances" to emit so much pollution.

It may take some similarly innovative legislative draftmanship, but I optimistic that in the next few years we will see the emergence of freely saleable forage rights (or whatever they may be called) to use the forage resource of the BLM rangelands. Not only ranchers but environmentalists, hunting clubs, birding enthusiasts, or any other parties would be able to hold these rights and control the use of that part of the federal rangeland forage now devoted to livestock grazing.

Nicholas Targ*

Recent Development in the Wild and Scenic River Act: Taming the Planning Process.

I. Introduction

The Bureau of Land Management[1] is responsible for managing over 4,000 miles of river and associated lands[2] under the Wild and Scenic Rivers Act.[3] While the WSRA requires that "primary emphasis... be given to protecting [the rivers'] esthetic, scenic, historical, archaeologic, and scientific features," the act also provides that river management plans "may establish varying degrees of intensity for its [sic] protection and development...."[4] Given that the WSRA contemplates multiple uses, albeit with a "preservationist bias",[5] it is not surprising that the BLM is frequently confronted with tough planning decisions involving the compatibility of potentially conflicting uses.

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* Mr. Targ is an attorney adviser with the United States Department of the Interior. The views expressed are solely those of the author and do not necessary reflect those of the Department of the Interior or any other agency of the United States.

1 Hereinafter "BLM."

2 Wild and Scenic Rivers Reference Guide, Interagency Wild and Scenic Rivers Coordinating Council (May 1997).

3 Wild and Scenic Rivers Act, 16 U.S.C.A. §§1271-1287, Pub. L. No. 90-542, 82 Stat. 906, hereinafter "WSRA."

4 16 U.S.C.A. §1281.

5 Wilderness Society v. Tyrrel, 701 F.Supp. 1473, 1482 n.8 (E.D. Cal. 1988)(discussing congressional intent of Wild and Scenic River Act), rev'd 918 F.2d 813 (1990).

Three recent legal determinations suggest that increased collaborative public participation in the planning and management of Wild and Scenic rivers can help reconcile competing river uses. These determinations also indicate that, while the WSRA has a substantial preservationist focus, because the standard of protection required under the act is somewhat open-ended, courts may review agency determinations based in part on river resource users' needs and expectations, as well as the river's fact-specific ecological condition.

The first of these determinations is Oregon Natural Desert Association v. Green.[6] This case provides the only judicial ruling on the legal standard under which Wild and Scenic River Plans are reviewed. The second determination, a Department of the Interior "M-Opinion,"[7] describes the critical legal importance of public participation in protecting rivers eligible for designation, but which have not yet been included within the National Wild and Scenic Rivers (NWSR) System. Finally, the process by which BLM and the State of Montana negotiated a reserved water right compact for the Upper Missouri Wild river,[8] under the WSRA, demonstrates that consensus based decisionmaking can, at least under certain circumstances,

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[6] Oregon Natural Desert Ass'n v. Green, 953 F.Supp. 1133(D.OR. 1997)(hereinafter "Donner und Blitzen," so named for the river at issue, the Donner und Blitzen).

[7] Memorandum of November 12, 1997, To: Director, Bureau of Land Management, From: Solicitor, Department of the Interior, "Managing Areas Eligible for Protection under the Wild & Scenic Rivers Act."

[8] Compact between the United States and the State of Montana Concerning Water Rights for the Upper Missouri National Wild and Scenic River and Bear Trap Canyon Public Recreation Site, September 10, 1997.

reconcile competing resource uses under the WSRA. Together the determinations can be read as encouraging broad based public participation in the planning process under the Wild and Scenic River Act. These determinations also suggest some of the preconditions that make Wild and Scenic river resource planning issues good candidates for consensus building efforts.

II. Lessons from Three Recent Determinations under the Wild and Scenic Rivers Act

A. The Donner und Blitzen Decision

The Donner und Blitzen case addressed the adequacy of the BLM's River Plan for the Donner und Blitzen, a river in Oregon included within the NWSR System. Challenging the protective adequacy of the River Plan, environmentalist-plaintiffs alleged that the plan, which permitted livestock grazing within riparian zones, failed to protect the river's outstandingly remarkable features. The plaintiffs argued that because "current grazing [permitted under the plan] and the legacy of past grazing has had and continues to have an inordinate adverse impact on native plant and plant communities in the river area,"[9] the plan did not sufficiently protect the river resource. Based on the administrative record prepared for the River Plan and the associated NEPA analysis, which included findings that grazing had substantially impaired the ecological

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[9] Plaintiffs' Memorandum in Support of Summary Judgement and Injunctive Relief at 9, Donner und Blitzen, 953 F.Supp. 1133.

integrity of portions of the river system,[10] the plaintiffs urged the court to find: 1) BLM did not fulfill its duty to "protect and enhance" the river, as required under the planning provisions of the WSRA; and 2) the NEPA analysis prepared for the plan failed to consider adequately all reasonable management alternatives.

The Federal District Court for the Oregon District agreed with the plaintiffs' claims and ordered BLM to prepare a new River Plan, making numerous conclusions of law. The court's most significant holdings relating to the plan and associated environmental compliance include as follows: 1) the BLM has authority under the WSRA to exclude cattle grazing from an area designated as "Wild" under the WSRA;[11] 2) the River Plan for the Donner und Blitzen river impermissibly allowed WSRA values to be degraded by continued grazing in the river area;[12] 3) an Environmental Impact Statement is required, as a matter of law, if substantial questions are raised as to whether an action may cause degradation to values for which a river is included within the NWSR System;[13] and 4) the status quo baseline from which to compare alternatives under the National Environmental Policy Act[14] for a river that has been included within the NWSR System is the river and its immediate environment without grazing activity,

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10 Id. at 6-9.

11 953 F.Supp. at 1145.

12 Id. at 1144-1146.

13 Id. at 1147.

14 National Environmental Policy Act, 42 U.S.C.A. §§4321-4347; Pub. L. No. 91-190 (1970); 83 Stat. 852, hereinafter "NEPA."

even if BLM permits grazing activity at the time of the environmental review.[15] Important, too, the court did not conclude that the WSRA prohibits grazing in a Wild river corridor.[16] To the contrary, the court held that grazing may continue along a Wild river, "but only in accordance within [sic] the strictures of the WSRA to protect and enhance."[17]

The court appears to have considered the evidence as a whole and made two basic conclusions. First, the court concluded that the values for which Congress included the Donner und Blitzen within the NWSR System would be degraded under the River Plan.[18] Second, the court found, under the facts of the case, BLM's NEPA analysis was flawed.[19] Regarding the first issue, the protective adequacy of the River Plan under §10 of the WSRA,[20] the environmental-plaintiffs directed the court's attention to the first clause of §10. This provision simply states that the river management agency must "protect and enhance" river values.

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15 Id. at 1147.

16 Id. at 1144.

17 Id.

18 Id. at 1146.

19 Id. 1146-49.

20 Section 10 of the WSRA provides, in part:

> Each component of the national wild and scenic rivers system shall be administered in such manner as to protect and enhance the values which caused it to be included in said system without, insofar as is consistent therewith, limiting other uses that do not substantially interfere with public use and enjoyment of these values.

The Bureau agreed with the standard presented by the plaintiffs. However, BLM argued that it had satisfied the §10 requirement by proscribing activities that "substantially interfere with the public's use and enjoyment [of the river values]," the requirement under §10's second clause. The Bureau argued, as well, that the meaning and the measure of the phrase "protect and enhance," and the determination of what activities "substantially interfere with the public's use and enjoyment" of a Wild and Scenic river, are determinations to which great deference is owed the agency.[21]

Without specifically adopting either standard as controlling, the court engaged in a scrutinizing exploration of the administrative record upon which the River Plan was based. On the basis of this evaluation, the court balanced the resource uses permitted under the plan and their impacts to the river's WSRA values, and found the River Plan failed to meet the protective standard set by §10. In the fact specific context of the Donner und Blitzen River Plan, the court found that the River Plan did not "strike[] the appropriate balance between continued grazing and protecting and enhancing the river values."[22]

Also important in reaching this conclusion, the Donner und Blitzen court found that the River Plan neglected to modify existing land use plans that had historically impacted WSRA values.[23]

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[21] Federal Defendant's Memorandum in Opposition to Plaintiffs' Motion for Summary Judgement and for Injunctive Relief at 27, Donner und Blitzen, 953 F.Supp. 1133.

[22] Donner und Blitzen, 953 F.Supp. at 1146.

[23] Donner und Blitzen, 953 F.Supp at 1146.

Thus, the court found, under the facts of the case, that BLM should have developed a more comprehensive and protective River Plan, including modifications to the existing land use plans.

The Donner und Blitzen cases leave unclear whether a formal balancing test exists under §10 of WSRA. While the court explicitly balanced uses and impacts, it established no specific balancing criteria to determine whether a given set of uses meets the protective standard of §10. Indeed, the Donner und Blitzen court engaged in a fact intensive review of the record, and concluded, contrary to BLM, that the level of protection under the plan did not protect the river values.[24] The court's analysis suggests that BLM may expect, at least in the District of Oregon, a court (in its determination of whether a River Plan is sufficiently comprehensive and protective) to engage in a generalized review of the facts involved, resource experts' opinions, and the history of the river's past management.

The scope of the River Plan for the Donner und Blitzen river is also central to the second aspect of the court's ruling, the legal adequacy of the River Plan' associated environmental compliance. On this point, the court ruled that BLM should have conducted a full Environmental Impact Statement ("EIS"), rather than an Environmental Assessment ("EA"). It is somewhat surprising that the court reached this issue. Once the court ruled that the plan both did not sufficiently protect the values for which the river was designated and had to be

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[24] Donner und Blitzen, 953 F.Supp. at 1145.

more comprehensive in scope, not only was the previous NEPA compliance underlying the agency's decision moot, but the EA's analysis was necessarily incomplete.

BLM oriented the River Plan's NEPA analysis toward a plan that was meant to "have ameliorative rather than detrimental effects on the environment."[25] Given the intended scope of the plan, to "improve and enhance" river values, BLM reasoned that the plan did not "rise to a level of significance [so as to require a full EIS]."[26] By contrast, the plaintiffs characterized §10 as obliging BLM in the River Plan to undertake a comprehensive revision of the river area's land use management plans.[27] Because of the historical adverse impact of grazing on the river area, the required reconsideration of plans, the plaintiffs argued, would require a detailed NEPA analysis. In its response to the plaintiffs' motion for summary judgement, BLM brought into sharp relief the competing views of §10's scope, stating that "[t]he plaintiffs have forgotten that the proposal examined by this EA is for BLM to take certain measures to protect the 'outstandingly remarkable values' that have been found in the Donner und Blitzen River Plan,"[28] not to comprehensively revisit the grazing plans that impact the river area.

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25 Federal Defendants' Memorandum in Opposition to Plaintiffs' Motion for Summary Judgement and for Injunctive Relief at 12, Donner und Blitzen, 953 F.Supp 1133.

26 Id.

27 Plaintiffs' Memorandum in Support of Summary Judgement and Injunctive Relief at 17-19, Donner und Blitzen, 953 F.Supp. 1133.

28 Federal Defendants' Memorandum in Opposition to Plaintiffs' Motion for Summary Judgement and For Injunctive Relief at 19, Donner und Blitzen, 953 F.Supp. 1133.

Thus, after the court concluded, as argued by the plaintiffs, that the Donner und Blitzen River Plan violated §10 because it did not take sufficient steps to protect and enhance the river values, nor struck the appropriate balance of resource uses, the court could not have found that the EA prepared for the plan: took the "requisite 'hard look';"[29] adequately resolved "whether a project... may cause significant degradation of some human environmental standard;"[30] or used the appropriate baseline (after having determined the existing plans permitted degradation of WSRA values).[31] The analysis of an EA is simply not as comprehensive as that required for the EIS. Once the court concluded that the scope of the River Plan was too limited, the EA could not have passed muster.

The court's review of the River Plan and NEPA analysis in Donner und Blitzen suggest that fuller public participation in WSRA planning process may help the Bureau build a stronger administrative record and a more defensible River Plan. By searching the administrative record, the court demonstrated its willingness to give only limited deference to BLM and to rely on facts and concerns raised by others. While the Donner und Blitzen court stated that the Bureau was entitled to deference,[32] upon concluding that the Bureau had in the past (under

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29 Id. at 1146.

30 Id. at 1147, quoting La Famme v. FERC, 852 F.2d 389, 397 (9th Cir. 1988).

31 Id. at 1148.

32 953 F.Supp. at 1144.

plans prepared before the river's designation) permitted activities that degraded the river,[33] and that some controversy existed over the level of protection that the River Plan would provide,[34] the court did not defer to any great degree to the agency's findings. Recognizing the court's willingness to engage in such analysis, the Bureau may improve the defensibility of its River Plans by developing more robust administrative records and by documenting and engaging the public's participation more fully in decisionmaking processes.

Aside from reasons of legal defensibility, full and open public participation in the develop of River Plans has non-legal policy advantages, as well. The determinations of what "may cause significant degradation," and what set of resource values "strikes the appropriate balance," are only, in part, fact-based, and they do not lend themselves to purely fact-based, objective analysis. Rather, these questions, in large part, pertain to the use-demands, priorities and interests placed on rivers by passive and active resource users at both the local and national levels.

These resource allocation issues involve economic, recreational, and aesthetic interests, among others, and are political and value laden, as well as ecologically based. Members of the public have, by their use of the river, an understanding of their dependence, interests, and alternatives. Because they are uniquely well qualified to express their subjective concerns on these issues, their active participation in the planning process can contribute substantially to the

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33 Id. at 1144-1146.

34 Id.

Bureau's ability to create a responsive River Plan. The Bureau's use of a participatory, broadly inclusive planning process can help translate open-ended standards into concrete efficient plans, especially if long standing controversy exists. Such a process provides opportunities for the public to communicate its interests and priorities, and thereby helps the agency make any resulting decision respond to, if not reconcile, potentially competing resource uses.

B. Solicitor's M-Opinion on Managing Areas Eligible for Protection under the WSRA

This recent M-Opinion addresses the process for, and timing of, the protection of rivers that are eligible for inclusion, but that have not been incorporated, into the NWSR System.[35] The M-Opinion concludes that the BLM has the authority to prevent degradation of Wild and Scenic river values for rivers that BLM has identified as eligible for inclusion in the NWSR System, although this authority does not derive from the WSRA.

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[35] A river area is "eligible" for inclusion within the NWSR System if the stream is free-flowing and "the related adjacent land area possesses outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values." 16 U.S.C.A. § 1273(b)(incorporating 16 U.S.C.A. § 1271 by reference). An agency's identification of an eligible river segment reflects the agency's determination that the segment has the potential to be included in the NWSR System. Inclusion in the NWSR System, however, requires either congressional, or in some circumstances, Secretarial action. See 16 U.S.C.A. § 1273.

The essential reasoning of the M-Opinion is that the protective mandate of the WSRA[36] is only afforded to designated river areas.[37] To protect a river that has not been designated would short-circuit the public participation process and the planning criteria required under the Federal Land Policy Management Act ("FLPMA").[38] In addition, pre-designation protection would eliminate State and national[39] elected representatives' influence over the shaping of the

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[36] See, e.g., Section 10, supra note 20, See also, 16 U.S.C.A. § 1278 (restricting water resource projects on river segments designated by Federal statute as components of, and potential additions to , the NWSR System); § 1279(a)withdrawing public land within components of the NWSR System designated by Federal statute); § 1279(b) (withdrawing public lands that constitute the bed or bank, or within 1/4 mile of the bank of a river segment designated by Federal statute for potential addition to the NWSR System).

[37] This contrasts with the protection afforded under the Wilderness Act. 16 U.S.C.A. § 1131, et seq.; See Parker v. United States, 448 F.2d 793 (10th Cir. 1971), cert. denied, 405 U.S. 989 (1972) (interpreting Wilderness Act to prevent Forest Service from taking action that would under cut the President's authority to recommend that Congress designate an area as Wilderness). While § 5 of the WSRA, 16 U.S.C.A. § 1275(d)(1) only provides general authority for the Secretaries of the Interior and Agriculture to evaluate potential additions, § 3 of the Wilderness Act, 16 U.S.C.A. § 1132, requires evaluation and submittal to the President of land suitable for inclusion within the Wilderness System.

[38] 43 U.S.C.A. § 1712

[39] Congressional debate over whether to include a river within the NWSR System, with rare exceptions, involves deliberation on the degree of restriction that will be placed on intensive resource uses. Constituents or interest groups, as well as the condition of the river, may influence legislators' classification as Wild, Scenic, or Recreational. 16 § 1273(b)(1)-(3). Generally, if a river has a high classification, BLM must place more restrictions on its use. Similarly, Congress may respond to resource demands on rivers eligible for inclusion within the NWSR System by identifying values which are to be protected, id., explicitly providing for the continuation of specific uses, or by mandating use of a specific river management or planning processes. See, e.g., 16 U.S.C.A. § 1274(18)(providing that "Riprapping related to natural channels with natural rock along the shorelines of the Skagit segment to preserve and protect agricultural land shall not be considered inconsistent with values for which such segment is designated); See, also, 16 U.S.C.A. § 1274(22)(providing that planning decisions shall be made in "coordination with, and pursuant to the advice of a Recreation Adviser Group,"
which may include political subdivisions, political officials, Federal agencies, and private

terms of the river's designation.[40] Without following the legislatively established procedures for including a river within the NWSR System, other congressional action, or adherence to the FLPMA, the M-Opinion concludes that public land cannot be withdrawn from the public domain.

The M-Opinion, however, also describes various routes by which BLM may consider and protect an eligible river's WSRA values as part of the Bureau's ordinary planning process. The M-Opinion explains that precisely because public review is mandated in most land use planning decisions,[41] an action that would adversely impact the values of an eligible river would also trigger public review and comment. For example, when BLM considers issuing a lease or permit, or taking some other action that could degrade an eligible river, the Bureau may choose not to take the action, or to include appropriate conditions to protect the river segment's integrity, through the NEPA compliance and other decisionmaking processes. Indeed, the M-Opinion notes, "although BLM must structure NEPA compliance to accommodate individual circumstances, where BLM is considering a proposed action that could

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groups.)

[40] A river must meet two tests before it enters the NWSR System. First, the river must possess the basic factual criteria for entry: free flowing character, and have at least one outstandingly remarkable feature. Second, elected representatives must agree that as a matter of policy the river should be included and explicitly state which values are to be protected.

[41] See, e.g., NEPA, 42 U.S.C.A. § 4321, et seq.

impact an identified river segment, NEPA would typically require BLM to consider an alternative that preserved or enhanced the river segment."[42]

The M-Opinion states that BLM is required to take a hard look at the proposed action's impact to WSRA values during the NEPA planning process. By doing so, on a case-by-case basis, the agency can protect the impacted river consistent with its obligations under NEPA and FLPMA. This process promotes transparency in the decisionmaking process and establishes parity between the decisionmaking procedures for actions that protect or cause degradation to rivers eligible for inclusion within the NWSR System, allowing decisionmaking informed by the public in both instances. Finally, by following the M-Opinion BLM will reserve to elected officials' the right to make critical policy decisions.

C. Quantification of Federal Reserved Water Rights on the Upper Missouri Wild River: Opening the Planning Process

The first-ever quantification of a federal reserved water right under the WSRA was ratified by Federal and Montana State representatives on September 10, 1997. The action is important for several reasons. As a matter of law, it helps resolve the thorny issue of whether reserved water rights are created by the designation of a river under the WSRA.[43] From a natural

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[42] Opinion at 5

[43] The existence of Federal reserved water rights under the WSRA has been a hotly contested issue. Three separate Department of the Interior Determinations have established, repudiated, and, most recently, revived the legal basis upon which the Department may claim

resource point of view, the reservation makes available sufficient flows to preserve important riparian and instream habitat and recreational opportunities,[44] while at the same time accommodating domestic, agricultural, and hydroelectric demands on a valuable water resource.[45] From a process perspective, the reservation is important because the terms of the reservation were negotiated rather than litigated.

The substance of the action-- the establishment of the reserved right-- is tied in important ways to the negotiated process by which the parties developed the Compact's terms and conditions. Had BLM and the State of Montana adjudicated the issue in court, it is unlikely that a judge, working as an outside party, could have developed such an adaptive, scientifically acceptable and satisfying water rights regime.[46] The adversarial, adjudicative court process probes law and fact, but does not address how the parties value, or subjectively rank, demands placed on river resources. Without an opportunity to explore the parties' prioritization of interests, trade-offs and practical solutions (such as seasonally based water rights) are difficult to achieve. Likewise, because the quantification of a water right through an adjudicative process

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Federal reserved water rights under the WSRA. See Federal Reserved Water Rights in Wilderness Areas, M-33914 (Supp. III), July 26, 1988(overruling a portion of Solicitor Opinion M-36914, June 25, 1979), withdrawn by way of Federal Register notice. 59 Fed. Reg. 19692-01, April 25, 1994.

[44] BLM Technical Summary, Upper Missouri Wild & Scenic River and Bear Trap Canyon Recreation area Water Rights Compact, 1996.

[45] Id.

[46] Nicholas Targ, Water on Public Lands: Facing a Fork in the River, 12 Nat. Resource and Env't 14, 18 (Summer 1997).

is a legal and not an engineering or political matter, opportunities to minimize the impacts of a reservation, or to recognize a reservation's national significance, are not relevant to a court's findings and conclusions.

Under the best circumstances, the federal reserved rights doctrine can result in substantial controversy. Controversy surrounding the quantification of reserved water rights is most frequently expressed through litigation over the reservation's purpose or the "minimum amount of water necessary to achieve the reservation's purpose." These issues are complicated and difficult to resolve. Typically, they involve mixed questions of law, fact, and scientific methodology.[47] Moreover, because the scope of each individual reservation's associated water right is intimately connected to the specific terms of its withdrawal, these factual and legal determinations must be made on a case-by-case basis. Nonetheless, regardless of how the parties frame their questions, in Federal reserved water rights litigation, the judge must always reach the basic issues of how much water the United States should receive from existing water users.

The issues confronting BLM in its application for a reserved water right on the Upper Missouri share a principal common aspect with other Wild and Scenic river resource planning decisions, namely the allocation among competing resource users of a limited and valuable natural resource. In addition, as with other complex planning issues, the parties faced

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[47] Id. at 16.

complicating factors such as, novel issues of law (i.e. the existence of reserved water rights under the WSRA); competing BLM, State, Native American and private resource demands; and overlapping management responsibilities of other resources. Contrasting with other resource decisions that the Bureau confronts, however, BLM typically follows State procedures in its application for the reserved water rights.[48] Thus, instead of allocating the river's water under the agency's planning procedures, BLM filed its water rights claim with the State Water Court as part of the State's ongoing water rights adjudication, and was bound by the State's rules and process.

To pursue BLM's claim, as permitted under Montana State law, BLM served notice to the Montana Reserved Water Rights Compact Commission that it wished to negotiate, rather than litigate, the reserved water right.[49] The Commission primarily negotiates Federal reserved water rights benefiting Native American Tribes. The parties, however, adapted the Compact Commission's informal, but structured, negotiation process to allow the multiple State, Federal, Tribal and private parties to work together toward a pragmatic solution that would achieve common goals and satisfy needs. The alternative-- litigation-- would have required a judge, who likely would have had limited natural resource management training, to decide which among the multiple and competing scientific methodology would be used to determine

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[48] See McCarran Amendment, 43 U.S.C.A. §666; See also, United States v. Eagle County, 401 U.S. 520, 524 (1971)(holding that for reasons of efficiency and expertise, state courts are preferable to federal courts for determining federal reserved water rights).

[49] MCA 85-2-703 and 85-2-228(3).

minimum flows, and how much water was needed to "protect" river values. Instead, based on a history of productive negotiations, shared integrated resource management responsibilities, and recognition of common goals, the parties negotiated a compact that recognizes and preserves an environmental resource of national significance, while meeting the needs of downstream appropriators, the Upper Missouri Wild river, and the State of Montana.

The collaborative decisionmaking process used in the reservation of water for the Upper Missouri Wild river presents a possible method of managing potential conflicts among ranchers, river administering agencies, river enthusiasts, and others who demand resources connected to the rivers included within the NWSR System. Some of the elements that recommended against litigation in the context of the Upper Missouri River included: complexity of issues, establishment of adverse precedent, multiple parties with both overlapping and conflicting interests, a desire for long term stability of water rights, and maintenance of working relationships. In short, the parties had multiple common, but differently prioritized, interests, making efficient trade-offs possible.

Given the opportunity to communicate candidly and to develop a common base of information, BLM, the State of Montana, and the other stakeholders were able to recognize and creatively satisfy each other's most pressing needs and interests, including protection of the Upper Missouri River. By contrast, litigation would have required a judge, whose expertise is law, and not necessarily natural resource management, to make complex factual determinations and assign water rights on the basis of law, rather than on shared interests, priority of needs, and

other practical considerations. While litigation is an indispensable and valuable tool in many instances, the experience from the Upper Missouri negotiation suggests that consensus based planning may provide a supplement to traditional planning processes and an alternative to litigation, if the parties have shared, but differently valued interests, and a common understanding of each other's relative power in the planning process.

III. Conclusions

Each of the three determinations discussed above required consideration of how BLM, within the context of the WSRA, can, or is required to, manage the competing demands placed on resources by users of significant rivers. The determinations also cast light on how BLM can respond effectively and appropriately to resource users' allocation-demands. The first, Donner und Blitzen, helps level and establish expectations, the court providing that BLM must create a protective balance among resource uses and that a reviewing court may explore in-depth the River Plan, administrative record, and NEPA analysis. The second, the M-Opinion, describes the legal importance of involving resource consumers in decisionmaking processes that impact eligible, but not yet designated, rivers. Third, the Montana reserved water rights negotiation presents a model, and implicitly suggests some of the conditions that may favor negotiation as a decisionmaking process, for the resolution of Wild and Scenic river resource conflicts and planning decisions. The factors, which favored a negotiated resolution in the Montana water rights case, include: scientific uncertainty; desire to avoid litigation; multiple, shared, but differently prioritized interest and values; need for stability; flexible standards; desire to

maintain a good working relationship; and an established opportunity for the parties to resolve their resource needs through structured but informal negotiations.

Contrasting with the Montana reserved water right negotiation, the absence of at least one these factors, a mutual agreement of the law's meaning, helps explain why the BLM and the environmental plaintiffs appropriately litigated the Donner und Blitzen case. The factors also point to some policy consideration, apart from legal requirements, why agencies seek public involvement in the multiple use/multiple-demand decisionmaking process: transparency, deliberative decisionmaking, stewardship, efficiency, and responsive government. Moreover, while an agency should not shy away from making important decisions that will likely lead to litigation, BLM's continued and increased use of broad-based, participatory decisionmaking in the WSRA context can minimize litigation even as natural resource demands increase.

Legal Constraints on Public Land Livestock Water Developments: NEPA, FLPMA, MUSYA, and the Wilderness Act

Joseph M. Feller[1]

Abstract – The construction of new livestock water developments is a common feature of many range management plans developed by the U.S. Forest Service and the Bureau of Land Management. In a typical scenario, water developments are used to facilitate a shift in grazing use from heavily grazed riparian areas to upland areas that have previously received less grazing use. While such a shift in grazing use may benefit the riparian areas, it may have negative impacts on the upland areas to which grazing pressure is shifted. Further, the construction of new water developments may be more costly than other alternatives for protecting riparian areas.

The National Environmental Policy Act (NEPA), and the principle of "multiple use" as defined in the Federal Land Policy and Management Act (FLPMA) and the Multiple Use-Sustained Yield Act (MUSYA), place procedural and substantive constraints on the construction of new livestock water developments. NEPA requires the land managing agency to consider alternatives, including the alternative of reducing livestock numbers or closing an allotment or a portion of an allotment to grazing. NEPA and the multiple use principle may also require that the decision to authorize grazing in an area be reconsidered in light of the costs and environmental impacts of the water developments and other facilities necessary to manage such grazing. An appeal currently pending before the Interior Board of Land Appeals (IBLA) concerning grazing on the BLM's Santa Maria Ranch Allotment in the Arrastra Mountain Wilderness in western Arizona demonstrates the importance of, and may help to clarify, these legal requirements.

In wilderness areas, the Wilderness Act and its associated congressional grazing guidelines place additional constraints on construction of livestock water developments. According to a recent decision of the Chief of the Forest Service concerning grazing on the Diamond Bar Allotment in the Gila Wilderness and the Aldo Leopold Wilderness in New Mexico, the Wilderness Act does not allow the construction of new water developments for the purpose of increasing livestock use in one part of a wilderness in order to compensate for the elimination of grazing in another part of the wilderness.

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[1] Professor of Law, Arizona State University.

INTRODUCTION

Regulations, policies, and land use plans of the U.S. Forest Service and the Bureau of Land Management (BLM) place a high priority on protection and enhancement of riparian areas. Most BLM and National Forest riparian areas have been degraded by livestock grazing,[2] and restoration of these areas requires seasonal, temporary, or permanent rest from livestock grazing.[3] Therefore, finding ways to relieve riparian areas from grazing has become a major focus of BLM and Forest Service management.

The simplest and fastest, and sometimes the cheapest, way to relieve a riparian area from grazing is to close to grazing the pasture or allotment containing the riparian area. However, the BLM's and the Forest Service's tradition of avoiding actions and decisions that harm the interests of livestock permittees frequently prompts these agencies to seek alternative solutions to riparian grazing problems. A common approach is to propose the construction of new water developments to facilitate a shift in grazing from the riparian area to an upland (non-riparian) portion of the pasture or allotment that has historically received less grazing pressure. Under this approach, the permittee's loss of use of the riparian area is compensated by increased use of upland vegetation that is made possible by the increased availability of upland water.

While the use of water developments to shift grazing pressure from riparian to upland areas may benefit riparian areas, it may have detrimental effects on the upland areas to which grazing is shifted. In a landscape where livestock are nearly ubiquitous, upland sites where grazing is precluded or limited by the unavailability of water are often the only places where relatively undisturbed native vegetation can be found. Historically, the provision of livestock water to such sites has led to the degradation of upland soils, vegetation, wildlife habitat,

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[2] *See, e.g.*, U.S. ENVIRONMENTAL PROTECTION AGENCY, LIVESTOCK GRAZING ON WESTERN RIPARIAN AREAS (1990); Robert D. Ohmart, *Historical and Present Impacts of Livestock Grazing on Fish & Wildlife Resources in Western Riparian Habitats*, *in* RANGELAND WILDLIFE 245 (Paul R. Krausman ed., 1996); Thomas L. Fleischner, *Ecological Costs of Livestock Grazing in Western North America*, 8 CONSERVATION BIOLOGY 629, 635 - 36 (1994).

[3] *See, e.g.*, U.S. ENVIRONMENTAL PROTECTION AGENCY, MANAGING CHANGE: LIVESTOCK GRAZING ON WESTERN RIPARIAN AREAS (1993). For examples of riparian areas rehabilitated by rest from livestock grazing, see U.S. ENVIRONMENTAL PROTECTION AGENCY, *supra* note 2, at 9-31; U.S. GENERAL ACCOUNTING OFFICE, RANGELAND MANAGEMENT: SOME RIPARIAN AREAS RESTORED BUT WIDESPREAD IMPROVEMENT WILL BE SLOW, GAO/RCED-88-105, at 18-30 (1988). *See also* William S. Platts & Fred J. Wagstaff, *Fencing to Control Livestock on Riparian Habitats Along Streams: Is It a Viable Alternative?*, 4 N. AM. JOUR. OF FISHERIES MANAGEMENT 266, 269 (elimination of livestock grazing "highly beneficial" to riparian habitat in thirteen of fifteen areas, and "slightly beneficial" in one of fifteen areas).

scenery, and aesthetic qualities by grazing.[4] Furthermore, in some instances the cost of providing upland water may be greater than the value of the livestock production facilitated by that water.[5]

Since the construction of upland water developments for livestock may have significant environmental consequences, proposals for such developments must be considered in the light of environmental laws. This paper will discuss certain aspects of the application of four such laws: the National Environmental Policy Act (NEPA),[6] the Federal Land Policy and Management Act (FLPMA),[7] the Multiple-Use Sustained-Yield Act (MUSYA),[8] and the Wilderness Act.[9]

NEPA

NEPA requires the BLM and the Forest Service to analyze and consider the environmental impacts of, and alternatives to, any proposed livestock water developments on public lands.[10] For NEPA purposes, however, the decision to authorize construction of a water development should not be considered in isolation. Rather, analysis of the costs and impacts of water developments should be integrated with analysis of the environmental impacts of the livestock grazing with which the developments are associated.

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[4] *See* Joseph R. McAuliffe, *Rangeland Water Developments: Conservation Solution or Illusion?*, and Joan E. Scott, *Do Livestock Waters Help Wildlife?*, in CENTER FOR THE STUDY OF LAW, SCIENCE, AND TECHNOLOGY, ARIZONA STATE UNIVERSITY, ENVIRONMENTAL, ECONOMIC, AND LEGAL ISSUES RELATED TO RANGELAND WATER DEVELOPMENTS: PROCEEDINGS OF A SYMPOSIUM (1998); LYNN JACOBS, WASTE OF THE WEST: PUBLIC LANDS RANCHING 211 - 220 (1991). The U.S. Fish & Wildlife Service has identified the development of livestock waters in previously ungrazed areas as a major factor contributing to the decline of the desert tortoise, which is now listed as a threatened species. *See* 55 Fed. Reg. 12,178, 12,181, 12,185 (1990).

[5] *See, e.g.*, Joseph M. Feller, *What is Wrong with the BLM's Management of Livestock Grazing on the Public Lands*, 30 IDAHO L. REV. 555, 584 & nn. 158 - 159 (1994).

[6] 42 U.S.C. §§ 4321 - 4370d.

[7] 43 U.S.C. §§ 1701 - 1785.

[8] 16 U.S.C. §§ 528 - 531.

[9] 16 U.S.C. §§ 1131 - 1136.

[10] *See* 42 U.S.C. § 4332(2)(C) (requirement for environmental impact statements).

Historical Development of the Application of NEPA to Grazing

In 1974, the court in Natural Resources Defense Council v. Morton[11] required the BLM to prepare environmental impact statements (EISs) that "discuss in detail the environmental effects" of livestock grazing on "specific areas" of BLM land.[12] The court held the EISs must assess "the specific environmental effects of the [grazing] permits issued."[13] The court did not require a separate EIS for each permit; they could be grouped together by district or otherwise. Whatever the format, however, the EISs must assess "the actual environmental effects of particular permits or groups of permits in specific areas."[14]

In the twenty years following the decision in *Morton*, the BLM has prepared approximately 150 grazing EISs that purport to satisfy the requirements of the decision. Each EIS covers an average of over one million acres of BLM land and encompasses on the order of 100 grazing allotments. Some of these are special-purpose grazing EISs prepared specifically for the purpose of complying with *Morton*. After the passage of the Federal Land Policy and Management Act (FLPMA) in 1976, however, many of these EISs were prepared in connection with the land use plans required by FLPMA, and therefore address other land uses in addition to grazing. In 1985, the court in *Natural Resources Defense Council v. Hodel*[15], held that a typical such EIS is adequate to satisfy the requirements of NEPA with respect to the land use plan.

In a 1997 decision known as the "Comb Wash" case,[16] however, the Interior Board of Land Appeals (IBLA) held that a typical EIS such as that considered in *Hodel* is *not* adequate to satisfy the requirements of *Morton* and NEPA with respect to the renewal of a permit for a grazing allotment containing important resources that have been significantly affected by grazing. The Board affirmed the finding of an administrative law judge (ALJ) that the EIS prepared for the land use plan was insufficient to support the grazing permit because it was "simply devoid of any site-specific information or analysis regarding the impacts of grazing on the resource values of the particular allotment in question."[17] The

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[11] 388 F. Supp. 829 (D.D.C. 1974), *aff'd per curiam*, 527 F.2d 1386 (D.C. Cir. 1976), *cert. denied*, 427 U.S. 913 (1976).

[12] *Id.* at 841.

[13] *Id.*

[14] *Id.*

[15] 624 F. Supp. 1045 (D. Nev. 1985), *aff'd*, 819 F.2d 927 (9th Cir. 1987).

[16] National Wildlife Federation v. BLM, 140 IBLA 85 (1997).

[17] *Id.* at 93 - 94. For a more detailed discussion of the ALJ's decision and its implications, see Joseph M. Feller, *The Comb Wash Case: The Rule of Law Comes to the Public Rangelands*, 17 PUB. LAND & RES. L. REV. 25 (1996).

Board also affirmed the ALJ's decision prohibiting grazing on the most sensitive parts of the allotment until an adequate EIS is prepared.

Under the Comb Wash decision, the BLM is required to prepare additional NEPA documentation, in the form of either an environmental assessment (EA)[18] or an EIS, whenever it issues or renews a grazing permit for an allotment that has not been addressed with sufficient specificity in any existing EA or EIS. Given the BLM's widespread dependence on large-area EISs of the type found inadequate in the Comb Wash case, such additional analysis will be required for most allotments on which grazing is having significant environmental effects. Such analysis may also be triggered by the development of allotment management plans or by reviews undertaken pursuant to the BLM's "rangeland reform" regulations issued in 1995.[19]

Because the Comb Wash decision is an administrative decision of the Department of the Interior, it is not directly applicable to National Forest grazing permits. The decision, however, was based on NEPA, which is equally applicable to the Forest Service. Therefore, the legal basis and the reasoning of the decision extend to the Forest Service as well as to the BLM.

Integrated NEPA Analysis of Grazing and Water Developments

Any NEPA analysis of livestock grazing should include an analysis of the costs and environmental impacts of any water developments necessary to support, or mitigate the impacts of, that grazing. Specifically, before authorizing grazing on the assumption that new water developments will help to reduce grazing impacts on riparian areas, the BLM should evaluate the costs and impacts of the developments and compare them with the costs and impacts of alternative strategies for riparian protection, including the "no grazing" alternative.

Integrated analysis of grazing and water developments is required by the NEPA regulations issued by the Council on Environmental Quality (CEQ). The CEQ regulations require "connected actions" to be considered together in a single NEPA document. Connected actions are defined as actions that

> (i) Automatically trigger other actions which may require environmental impact statements.
> (ii) Cannot or will not proceed unless other actions are taken previously or simultaneously.

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[18] An EA is an environmental document prepared for determining whether the impacts of a proposed action are significant enough to require an EIS, and for documenting the impacts of the proposed action and alternatives when no EIS is determined to be necessary. *See* 40 C.F.R. § 1508.9.

[19] *See* 60 Fed. Reg. 9,894 (1995) (amending 43 C.F.R. Parts 4, 1780, and 4100).

(iii) Are interdependent parts of a larger action and depend on the larger action for their justification.[20]

In *Thomas v. Peterson*,[21] the United States Court of Appeals for the Ninth Circuit held that Forest Service timber sales and the construction of a road to facilitate those timber sales were "connected actions" within the meaning of this definition. Similarly, rangeland water developments and livestock grazing authorizations are clearly "connected actions" if the purpose of the water developments is to facilitate, or to mitigate the impacts of, the authorized livestock grazing. Therefore, the NEPA analysis of these actions should be integrated in a single NEPA document, be it an EA or an EIS.

Consideration of Alternatives

A fundamental requirement of NEPA is that any federal agency proposing an action -- including the construction of a rangeland water development or the issuance or renewal of a grazing permit -- must evaluate and consider alternatives to that action.[22] The requirement to evaluate and consider alternatives is broader than the EIS requirement; it applies even to agency actions whose impacts are not considered "significant" enough to require an EIS.[23] In other words, an EA, as well as an EIS, must evaluate alternatives.

Where livestock water developments are proposed for the purpose of relieving grazing pressure on riparian areas, obvious alternatives are to simply reduce or forego grazing on the pasture or allotment containing the riparian area. Such alternatives may be cheaper and/or more effective than the construction of new waters. Failure to carefully evaluate and consider such alternatives may render a decision to construct a water development subject to a challenge under NEPA.

FLPMA, MUSYA, and the Meaning of "Multiple Use"

Both the BLM and the Forest Service are required to manage the lands under their administration in accordance with the principle of "multiple use." While NEPA requires the BLM and the Forest Service to evaluate and consider the costs and impacts of water developments when deciding whether to authorize or re-authorize grazing in particular areas, the statutory definitions of "multiple use" provide substantive guidance for such decisions once the required information on costs and impacts has been assembled. "Multiple use" is defined for the BLM in the Federal Land Policy and Management Act (FLPMA) of 1976 as follows:

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[20] 40 C.F.R. § 1508.25(a)(1).

[21] 753 F.2d 754 (9th Cir. 1985).

[22] 42 U.S.C. §§ 4332(2)(C)(iii), 4332(2)E); 40 C.F.R. §§ 1502.14, 1508.9(b).

[23] Bob Marshall Alliance v. Hodel, 852 F.2d 1223, 1228-29 (9th Cir. 1988), *cert. denied*, 489 U.S. 1066 (1989); Aertsen v. Landrieu, 637 F.2d 12, 20 (1st Cir. 1980)

> The term "multiple use" means the management of the public lands and their various resource values so that they are utilized in the combination that will best meet the present and future needs of the American people; making the most judicious use of the land for some or all of these resources or related services over areas large enough to provide sufficient latitude for periodic adjustments in use to conform to changing needs and conditions; the use of some land for less than all of the resources; a combination of balanced and diverse resource uses that takes into account the long-term needs of future generations for renewable and non-renewable resources, including, but not limited to, recreation, range, timber, minerals, watershed, wildlife and fish, and natural scenic, scientific and historical values; and harmonious and coordinated management of the various resources without permanent impairment of the productivity of the land and the quality of the environment with consideration being given to the relative values of the resources and not necessarily to the combination of uses that will give the greatest economic return or the greatest unit output.[24]

A nearly identical definition of multiple use is applied to the National Forests in the Multiple Use-Sustained Yield Act.[25]

This definition of multiple use was applied to BLM grazing authorizations by the IBLA in the Comb Wash decision. The Board held that, in deciding whether to authorize or re-authorize grazing in a particular area, the BLM must "engage in [a] reasoned [and] informed decisionmaking process" and that that process "must show that the BLM has balanced competing resource values to ensure that the public lands [in question] are managed in the manner that will best meet the present and future needs of the American people."[26] The Board affirmed the decision of an Administrative Law Judge (ALJ) prohibiting grazing in five canyons because the BLM had failed to engage in such a "reasoned and informed decisionmaking process" regarding grazing in those canyons.[27]

Compliance with the Board's requirement for the BLM to "balance competing resource values" and to "best meet the needs of the American people" logically requires some consideration of the relative merits and demerits of rangeland water developments as compared to alternative strategies for achieving rangeland management goals. In particular, where upland water developments are proposed as a tool to relieve grazing pressure on

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[24] 43 U.S.C. § 1702(c). For a discussions of the history and meaning of multiple use, see George C. Coggins, *Of Succotash Syndromes and Vacuous Platitudes: The Meaning of "Multiple Use, Sustained Yield" for Public Land Management*, 53 U. COLO. L. REV. 229 (1982).

[25] *See* 16 U.S.C. 531(a).

[26] 140 IBLA at 101.

[27] *Id.* at 102 - 104.

riparian areas, the costs and impacts of this strategy should be compared with the alternative strategy of simply foregoing grazing on the allotment or pasture in question. If the no-grazing alternative is economically preferable (i.e., if cost of the water developments equals or exceeds the economic loss that would be caused by removing grazing), and if the no-grazing alternative would protect riparian and other resource values as well as or better than the developments would, then no grazing is the "best" alternative under the multiple use principle. Expenditure of public funds for water developments that cannot be economically or environmentally justified would represent a failure to rationally "balance competing resource values."

The Wilderness Act

The Wilderness Act, and Congressional "guidelines" elaborating on the grazing provision of the Act, place significant constraints on the construction of rangeland water developments in designated wilderness areas.

Section 4(d)(4)(2) of the Wilderness Act provides that livestock grazing, "where established prior to September 3, 1964, shall be permitted to continue," subject to "reasonable regulations."[28] The Congressional grazing guidelines provide guidance for the implementation of this statutory command. The guidelines first appeared in a committee report in 1979,[29] and in 1980 Congress declared that the Wilderness Act "shall be interpreted and administered in accordance with" the guidelines.[30] Since that time, the guidelines have also been incorporated by reference in several bills designating wilderness areas in individual states.[31]

According to the guidelines, "[i]t is anticipated that the numbers of livestock permitted to graze in wilderness would remain at the approximate levels existing at the time

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[28] 16 U.S.C. § 1133(d)(4)(2).

[29] H.R. Rep. No. 617, 96th Cong., 1st Sess. 11 - 13 (1979). The full text of the guidelines can also be found in Mitchel P. McClaran, *Livestock in Wilderness: A Review and Forecast* 20 ENVT'L L. 857, 872 - 74, nn. 65 - 66.

[30] Pub. L. 96-560, Title I, § 108, 94 Stat. 3265, 3271 (1980) (codified at 16 U.S.C. § 1133, note).

[31] *See* McClaran, *supra* note 29, at 876 n. 80 (citing bills applying the guidelines to National Forest wilderness areas in Arizona, Utah, Wyoming, and Nebraska). *See also* California Desert Protection Act of 1994, Pub. L. 103-433, § 103(c), 108 Stat. 4471, 4481 (1994) (applying the guidelines to BLM wilderness areas in California); Arizona Desert Wilderness Act of 1990, Pub. L. 101-628, § 101(f), 104 Stat 4469, 4473 (1990) (applying the guidelines to BLM wilderness areas in Arizona).

an area enters the wilderness system."[32] Grazing should not be curtailed "simply because an area is, or has been designated as wilderness."[33] However, reductions in livestock numbers may be made through the "normal grazing and land management planning and policy setting process."[34]

The guidelines allow the construction of new range improvements in wilderness areas, but specify that such new improvements "should be primarily for the purpose of resource protection and the more effective management of these resources rather than to accommodate increased numbers of livestock."[35]

In 1996, the Chief of the Forest Service issued a very significant decision interpreting and applying these provisions of the grazing guidelines. In a "Discretionary Review Decision," the Chief affirmed a decision by the Supervisor of the Gila National Forest to discontinue grazing on approximately 40,000 acres of the Gila and Aldo Leopold Wildernesses in order to protect sensitive riparian areas that could not adequately be protected by fencing or livestock management. The Chief held that closure of a wilderness area to grazing is permissible so long as the closure is justified by resource considerations other than the wilderness designation itself.[36]

The Forest Supervisor had also decided to authorize the construction of numerous new water developments in another part of the Wilderness in order to increase livestock grazing there to compensate for the loss of grazing on the closed part of the Wilderness. This part of the Forest Supervisor's decision was reversed by the Chief. Although the grazing guidelines allow the construction of new range improvements in wilderness under some circumstances, the Chief held that the guidelines disallow the construction of range improvements for the purpose of increasing livestock numbers on a portion of a wilderness, even if that increase is intended to compensate for a decrease elsewhere in the same wilderness.[37]

The chief's decision clarifies the authority of federal land managers to exclude grazing to protect riparian areas, on wilderness as well as on non-wilderness public lands.

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[32] H.R. Rep. No. 617, *supra* note 29, at 11 - 12, *reprinted in* McClaran, *supra* note 29, at 872 - 73 note 65.

[33] H.R. Rep. No. 617, *supra* note 29, at 11, *reprinted in* McClaran, *supra* note 29, at 872 note 65.

[34] *Id.*

[35] H.R. Rep. No. 617, *supra* note 29, at 12, *reprinted in* McClaran, *supra* note 29, at 873 note 65.

[36] Forest Service, U.S. Dep't of Agriculture, Discretionary Review Decision For Appeal #95-03-00-0028-A251 of the Diamond Bar Allotment Management Plan 29 (Feb. 7, 1996).

[37] *Id.* at 28 - 29.

The decision also makes clear that land managers need not -- and on wilderness lands they must not -- authorize new water developments in upland areas for the purpose of compensating livestock operators for the loss of use of riparian areas. Although the decision does not come from a court, it represents a reasoned interpretation of the Wilderness Act and the grazing guidelines by an agency charged with administering them, and as such should be entitled to deference by the courts. Furthermore, since the same provisions of the Wilderness Act and the grazing guidelines apply to the BLM,[38] the decision should provide guidance for BLM as well as Forest Service managers.

Testing the Waters on BLM Land: Sycamore Spring and Peeples Canyon

A case currently pending before the Interior Board of Land Appeals illustrates the importance of the legal issues discussed in this paper. Specifically, it demonstrates how a typical failure to evaluate and consider the costs and impacts of rangeland water developments, to integrate the analysis of rangeland water developments with the analysis of grazing under NEPA, and to consider reasonable alternatives, can lead to litigation, irrational decisionmaking, and unnecessary degradation of resources.

The case concerns the management of a spring at the head of Peeples Canyon in the Arrastra Mountain Wilderness in western Arizona. Peeples Canyon is scenically spectacular and ecologically unique. It has been described in a BLM EIS as an example of "the rarest and most productive wildlife habitat" in the western Arizona desert.[39] Other BLM documents describe Peeples Canyon as "uniquely pristine,"[40] as having "exceptional wilderness values,"[41] and as "a rare and lush riparian habitat in the midst of a rugged desert."[42]

The stream in Peeples Canyon has been classified by the State of Arizona as a

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[38] *See* 43 U.S.C. § 1782(c) (applying the provisions of the Wilderness Act to BLM lands). *See also supra* note 31 (legislation applying the Congressional grazing guidelines to BLM wilderness areas in California and Arizona).

[39] BUREAU OF LAND MANAGEMENT, UPPER SONORAN FINAL WILDERNESS ENVIRONMENTAL IMPACT STATEMENT 177 (1987).

[40] ARIZONA STATE OFFICE, BUREAU OF LAND MANAGEMENT, BLM WILDERNESS AREA MAPS AND INFORMATION, Arrastra Mountain Wilderness.

[41] BUREAU OF LAND MANAGEMENT, UPPER SONORAN DRAFT WILDERNESS ENVIRONMENTAL IMPACT STATEMENT 17 (1982).

[42] BUREAU OF LAND MANAGEMENT, UPPER SONORAN DRAFT WILDERNESS ENVIRONMENTAL IMPACT STATEMENT 42 (1982).

"unique water."[43] "Unique Water" is the term that Arizona uses in its program implementing federal Clean Water Act regulations' requirement for designation of "outstanding National resource" waters.[44] This designation is reserved for "waters of exceptional recreational or ecological significance."[45] Both the Clean Water Act regulations and Arizona law forbid any degradation of such a body of water.[46]

Sycamore Spring, the headwaters of Peeples Canyon, sits in a rocky desert basin at the head of the canyon. The basin is about two square miles in area and, except for the immediate area around the spring, is quite sparsely vegetated. According to the BLM's forage inventory for the allotment, this two-square-mile basin produces only enough forage to support about half a dozen cattle yearlong.

Peeples Canyon and the surrounding BLM land were acquired by the BLM in two land exchanges in the 1980s, and are included in a BLM grazing allotment called the Santa Maria Ranch Allotment. In 1991, after environmental organizations protested a BLM proposal to issue a grazing lease for the allotment, the BLM prepared an environmental assessment (the 1991 grazing EA) for grazing on the allotment.[47]

In the 1991 grazing EA, the BLM recognized that violations of the Clean Water Act, as well as degradation of riparian habitat, could occur if cattle were allowed into Sycamore Spring, which is the headwaters of Peeples Canyon Creek.[48] In order to avoid these adverse impacts, the EA, and the BLM's final decision authorizing grazing on the allotment, committed the BLM to fence Sycamore Spring from cattle and to provide an alternative water source outside the fence.[49] This approach to riparian protection -- relocation of cattle and provision of an alternative water source -- is extremely typical for the BLM and the Forest Service. Indeed, this approach is almost universal within these two agencies.

The 1991 grazing EA was also extremely typical in two other respects. First, it did not consider the alternative of simply excluding cattle from the entire two-square-mile

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[43] Arizona Administrative Code (A.A.C.) § R18-11-112.E.3.

[44] *See* 40 C.F.R. § 131.12(a)(3).

[45] *Id.*; A.A.C. § R18-11-112.D.1.

[46] See 40 C.F.R. § 131.12(a)(3); A.A.C. § R18-11-107.D.

[47] Bureau of Land Management, Environmental Assessment: Livestock Use Authorization, Santa Maria Ranch Lease Allotment No. 5046 (EA No. AZ-026-91-14) (May 31, 1991) (hereinafter cited as 1991 Grazing EA).

[48] 1991 Grazing EA, *supra* note 47, at 15 - 16.

[49] *Id.* at 25; Bureau of Land Management, Phoenix District Office, Notice of Final Decision 4 - 5 (May 31, 1991).

basin in which Sycamore Spring is located instead of providing an alternative water source within the basin. Second, it did not evaluate or consider the cost and environmental impacts of providing the alternative water source. Such an evaluation was left to a future EA to be prepared specifically for the water source.

In 1994, the BLM issued a draft environmental assessment (EA) concerning the development of the alternative water source to Sycamore Spring. The EA proposed a complex and expensive system to import water from another spring, McGregor Spring, into the wilderness in the vicinity of Sycamore Spring. Numerous commenters on the 1994 draft EA argued that the proposed system was too expensive and too intrusive on wilderness values, and that it could not be justified as a means to facilitate use of the very small amount of livestock forage in the basin around Sycamore Spring.

In a July, 1996, final EA and decision[50] the BLM responded to these criticisms by abandoning the idea of constructing an alternative water source. In the final EA, however, the BLM still did not consider the alternative of abandoning grazing in the two-square-mile basin around Sycamore Spring. Instead, the BLM's final decision authorized the use of Sycamore Spring itself -- the "unique water" that the BLM originally intended to protect -- as a livestock holding and watering area. This decision is currently under appeal to the Interior Board of Land Appeals, and has been stayed by the Board pending resolution of the appeal.[51]

The BLM's final decision is both tragic and unnecessary. It is tragic both because it has resulted in large commitments of time and personnel to litigation and because, if implemented, it will degrade or destroy unique and valuable riparian and water resources in order to harvest a minuscule amount of livestock forage. It is unnecessary because it could have been avoided had the BLM complied with NEPA and FLPMA at either of the two steps in its decisionmaking process.

When the BLM decided in 1991 to authorize livestock grazing on the Santa Maria Ranch Allotment, it should have evaluated and considered the alternative of foregoing grazing in the sparsely vegetated, two-square-mile basin surrounding Sycamore Spring. It also should have considered at the time the cost and the environmental impacts of building a water source in that basin. Similarly, in 1996, before deciding to authorize the use of Sycamore Spring as a livestock sacrifice area, the BLM should again have evaluated and considered the alternative of foregoing grazing in the basin.

At either step in the process, a *bona fide* consideration of alternatives would likely have led to the conclusion that foregoing grazing in such a small and unproductive area would better serve the public's needs -- and thus better comport with the multiple use

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[50] Bureau of Land Management, McGregor Spring Water System Environmental Assessment (No. AZ-026-92-25) (July, 1996).

[51] Order dated October 11, 1996, National Wildlife Federation, No. IBLA 96-535.

mandate of FLPMA -- than would either the construction of an intrusive and expensive water system in a Wilderness or the use of a Unique Water as a cattle watering trough.

Conclusion

While Sycamore Spring and Peeples Canyon are unique resources, the BLM's pattern of decisionmaking regarding them was entirely typical, both of the BLM and of the Forest Service. Where livestock grazing is degrading or threatening to degrade water quality and riparian habitat, the managing agency generally has three choices: (1) allow the degradation to occur or to continue occurring, (2) provide an alternative source of water in order to shift grazing pressure away from the riparian area, or (3) forego grazing in the pasture or allotment that contains the riparian area. The BLM and the Forest Service generally consider only the first two options and ignore the third. This failure to consider all reasonable alternatives not only violates NEPA and FLPMA, but can also lead to wasteful investments, destruction of resources, and/or costly litigation.

PLANNING, DECISIONMAKING, AND MONITORING FOR RANGELAND WATER DEVELOPMENTS

Rangeland Monitoring Risk and Ecosystem Sustainability

Ward Brady, Professor*

Abstract -- Rangeland ecosystems face risks from numerous stressors. The purpose of monitoring is to provide accurate information on the impacts of these stressors by detecting important ecosystem changes (or the lack thereof). This means that monitoring methods must detect ecosystem changes which are both ecologically meaningful and statistically significant. Monitoring methods, in addition, should be designed to protect against false conclusions of ecosystem change. Good monitoring information provides essential information for risk management and thus provides a powerful tool for making decisions that enhance ecosystem sustainability. While all monitoring activities have risk associated with them, few monitoring activities explicitly address the issue of monitoring error management by considering either the level of desired detectable change or the monitoring errors which are inherent to the statistical design. The concept of risk provides a conceptual tool for accomplishing the design goal of matching statistical significance to the consequences of change in an ecological system. The monitoring risk associated with an ecosystem change may be defined as a function of the consequences of the change and the likelihood of failing to detect that change (or falsely concluding that the change has occurred). A well-designed monitoring system must have explicitly stated goals for describing the magnitudes of change which the monitoring program is designed to detect and the desired probability (i.e. power) of detecting these changes.

*Professor, Environmental Resources Program, School of Planning and Landscape Architecture, Arizona State University, Tempe, Arizona.

Introduction

Rangeland ecosystems face risks from numerous stressors including grazing by livestock and urbanization. The purpose of monitoring is to provide accurate information on the impacts of these stressors by detecting important ecosystem changes (or the lack thereof). This means that monitoring methods must detect ecosystem changes which are both ecologically meaningful and statistically significant. Monitoring methods, in addition, should be designed to protect against false conclusions of ecosystem change. Good monitoring information provides essential information for risk management and thus provides a powerful tool for making decisions that enhance ecosystem sustainability.

Sustainability is an essential goal of ecosystem management. If good monitoring information is available, then managers have a powerful tool for choosing management alternatives that will enhance ecosystem sustainability. Conversely, if monitoring does not produce good information, then unwise decisions may result and sustainability may suffer. Therefore, monitoring systems must be planned so that they are technically feasible, and will provide results which are ecologically meaningful and statistically sound if they are to provide the necessary information for adaptive ecosystem management.

Monitoring Error Management

A rangeland monitoring system is a complex of sampling, statistical, and analytic procedures designed to detect and quantify change in the rangeland ecosystem. In the design of a monitoring system some aspect of ecosystem, such as vegetation biomass, soil bulk density, or water quality is selected as an indicator that will provide an index to important change in ecosystem structure or function. Numerous methodologies are available for collecting this data and range from field sampling methods to using remote sensed data from satellites. Repeated measures are made on this indicator and statistical tests are then used to determine if significant change has occurred.

Yoccoz (1991), however, has cautioned against confusing ecological importance with statistical significance. Monitoring systems need to be designed so that decisions

are first made about what would constitute an important change from a ecological perspective. The system should then be designed so that statistical decisions will directly reflect these ecological criteria. Monitoring designs, in other words, should be ecologically, not statistically, driven.

The interpretation of monitoring results is complicated because the conclusions of statistical analyses are sometimes in error. That is, analysis of monitoring data will sometimes falsely indicate change where none has occurred (a Type-I error, α) or fail to detect change which has occurred (a Type-II error, β). Type-I and Type-II errors are inversely related so that an increase in one error results in a decrease in the other. Monitoring error management demands that monitoring designs consciously consider both sources of error and explicitly link these errors to the consequences of ecological change.

Risk and Monitoring Systems

The concept of risk (Booth 1990, Colinvaux 1991; EPA 1992, 1993) provides a conceptual tool for accomplishing the design goal of matching statistical significance to the consequences of change in an ecological system. The monitoring risk associated with an ecosystem change may be defined as a function of the consequences of the change and the likelihood of failing to detect that change (or falsely concluding that the change has occurred). The importance of change for any given indicator should be defined based on expected effects on structural or functional components of the ecosystem. To minimize monitoring risk, indicator changes with large consequences need to have high probabilities of detection while changes with lesser consequences may have lower desired probabilities of detection. A well-designed monitoring system must have explicitly stated goals for describing the magnitudes of change which the monitoring program is designed to detect and the desired probability (i.e. power) of detecting these changes.

The power of a monitoring design ($1-\beta$, i.e., one minus the probability of a Type-II statistical error) for detecting change is a function of several factors including variability inherent in the data, the level of Type-I statistical error which is acceptable, and sampling

intensity. Evaluation of power for a monitoring design is crucial in that the stated goal of most monitoring is to detect change. Tanke and Bonham (1985) described the use of power curves to evaluate methodology of detecting changes in range condition. Brady *et al.* (1990, 1991, 1993a, 1993b, 1995) described computer simulation procedures to derive power curves for the evaluation of vegetation monitoring procedures.

Monitoring risk can be addressed using the concept of "expected monitoring error" which is the error rate expected when Type-I and Type-II statistical errors are set equal. This approach is useful because Type-I and Type-II statistical errors are inversely related. Therefore, it is not possible to simultaneously minimize both types of error at a fixed sample size (Ott 1993). Expected monitoring error can be interpreted as the expected probability of making either a Type-I error (falsely concluding change when none has occurred) or a Type-II error (failing to detect actual change). Conversely, the probability of detecting true change is approximated by one minus the expected monitoring error. Monitoring error is a function of several factors including the amount of change in the monitored parameter as well as monitoring intensity. Desired detectable change is the concept which links these two factors to insure that ecologically important changes are detected at acceptable error rates.

It is important to note that all monitoring activities have risk associated with them. Only a few monitoring activities, however, explicitly address the issue of monitoring error management by considering either the level of desired detectable change or the monitoring errors which are inherent to the statistical design.

Monitoring Vegetation at Lake Mead National Recreation Area

Design of a system for monitoring ecological change at Lake Mead National Recreation Area required that good indicator variables be chosen for monitoring, that a suitable sampling protocol be developed, that levels of desired detectable change in these indicators be specified, and that the issue of monitoring risk be addressed. A comprehensive discussion of these requirements for the Lake Mead area is not possible in this paper.

Rather we will focus on a representative set of design parameters for one aspect of vegetation change.

One indicator variable chosen for monitoring ecological change at Lake Mead National Recreation Area was the volume of white bursage (*Ambrosia dumosa*) (Bonham and Brady, 1996). White bursage provides a major forage resource for both large and small herbivores (including feral burros) in the Lake Mead area. Volume was chosen as the ecological indicator for monitoring because it is both highly correlated with biomass and nondestructive samples can be collected. Eight stands of white bursage (each approximately 20m x 25m in size) were exhaustively sampled and the location and size of all white bursage plants were located. This data was used to construct spatial databases. Using the actual population data as a base, additional databases were then constructed based on scenarios of increasing or decreasing white bursage volume. Computer models were used to sample these databases using various sampling methodologies.

While identification of general monitoring goals was very straightforward, identification of "desired detectable change" and acceptable rates of monitoring error was difficult. We attributed this difficulty to two factors. First, these questions have seldom been a part of planning monitoring systems and therefore were conceptually new. Second, even if the conceptual hurdle did not exist, the ecological data to support decisions in these areas is lacking. While general relationships are well known, fewer studies in the literature are available to quantitatively relate specific levels of ecosystem change to specific ecological consequences. This poses a major problem for the design of monitoring systems.

However, based on available information and management objectives, the goal of detecting a 20 to 30% change in white bursage volume was selected as a change which would be important to detect. Changes in basal cover of this magnitude would serve as an indicator of ecologically important change that would clearly signal either ecosystem deterioration or improvement and would either initiate necessary changes in management or reinforce the suitability of current management practices. Acceptable error rates should be a function of the ecological consequences of change in the indicator variable.

However, ecological data to support such decisions are frequently lacking. However, in practice actual error rates are often a compromise between the obvious desire for little or no error and those error rates which may occur given available budgets and time for monitoring. In the Lake Mead case, maximum error rates (either failing to detect true change or falsely concluding change) were set at 20% for this level of change in white bursage volume. Both acceptable levels of desired detectable change and acceptable error rates are provisional and subject to modification as ecological information becomes available to support decisions in this area and resources become available to accomplish monitoring goals.

For the purposes of illustrating the design of monitoring methods and the importance of evaluating monitoring risk results from one monitoring site (monitoring plot 2.2), one sampling method (1x5 meter plots) will be used.

Estimates of white bursage volume from monitoring plot 2.2 using 25 1x5 meter plots ranged from less than 4 to 40 m^3/0.1ha with a mean estimate of 19.4 m^3/0.1ha (figure 1). The results of one possible scenario resulting in a loss of 30% of white bursage volume is illustrated in figure 2. As expected the sampling distribution shifts downward reflecting the reduced volume. However, some samples of white bursage volume could represent either sampling distribution. For example, when sample results indicate a volume of 15 m^3/0.1ha which population was the sample drawn from? Monitoring error is minimized when a decision point is chosen such that the probabilities of falsely concluding change and failing to detect change are equal. (This assumes both errors have equal or at least similar ecological consequences. If this is not true then the location of the decision point would be shifted to reflect these differences.) Figure 3 illustrates the decision point minimizing monitoring error for this scenario and sampling method. The area to the left of the decision point line and beneath the full volume curve represents the probability of falsely concluding change. When a sample from the monitoring plot falls below the decision point volume (~16 m^3/0.1ha), the conclusion of change would be drawn and we would expect to be wrong approximately 22% of the time. When a sample falls above the decision point volume, the conclusion of no change would be drawn and

we would again be wrong approximately 22% of the time (the area of the curve to the right of the decision point line and beneath the 30% decrease in volume curve).

Figure 4 illustrates the relationship between white bursage volume change, sampling intensity (the number of 1x5m plots per sample), and estimated monitoring error. As change increases and sampling error increases, monitoring error decreases. Selection of a monitoring method requires that all three components of this relationship be addressed. For instance, if final goals were to detect a 30% change in white bursage with 20% monitoring error rate, then the required sample size would be approximately 40 1x5m plots. On the other hand a 50% change could be detected with less than 10 plots while in excess of 50 plots would be required to detect a 20% change. Likewise acceptable monitoring error could be changed resulting in an entirely new set of monitoring options.

Conclusion

When a system for monitoring ecological change is designed decisions are inescapably made regarding monitoring error and detectable change. These decisions can be implicit and made by default or explicit and made after careful consideration of monitoring goals. The worst case scenario is to choose a sampling method and intensity with no consideration of monitoring goals. Under these circumstances default and unknown values of detectable change and the associated monitoring error result and monitoring may or may not be adequate to support goals of ecosystem sustainability. Monitoring error management (and the attendant minimization of monitoring risk) demands that all aspects of the monitoring system be considered before implementation.

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Figure 1. Sampling distribution for 100,000 estimates of white bursage volume from monitoring plot 2.2 using 25 1x5 meter sample frames.

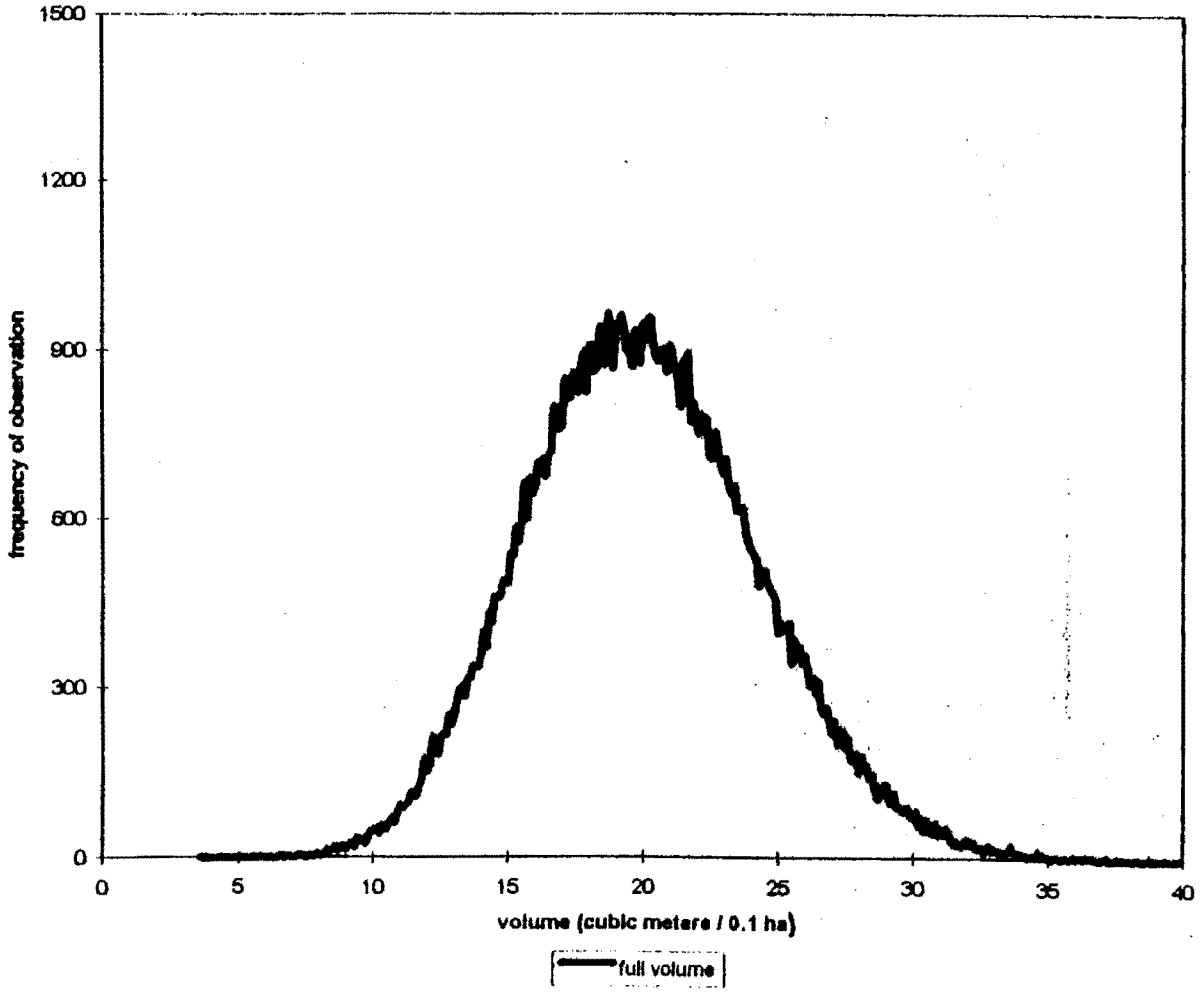


Figure 2. Sampling distributions for 100,000 estimates of white bursage volume from monitoring plot 2.2 using 25 1x5 meter sample frames (measurements were from the actual population and a simulated population with a 30% decrease in volume).

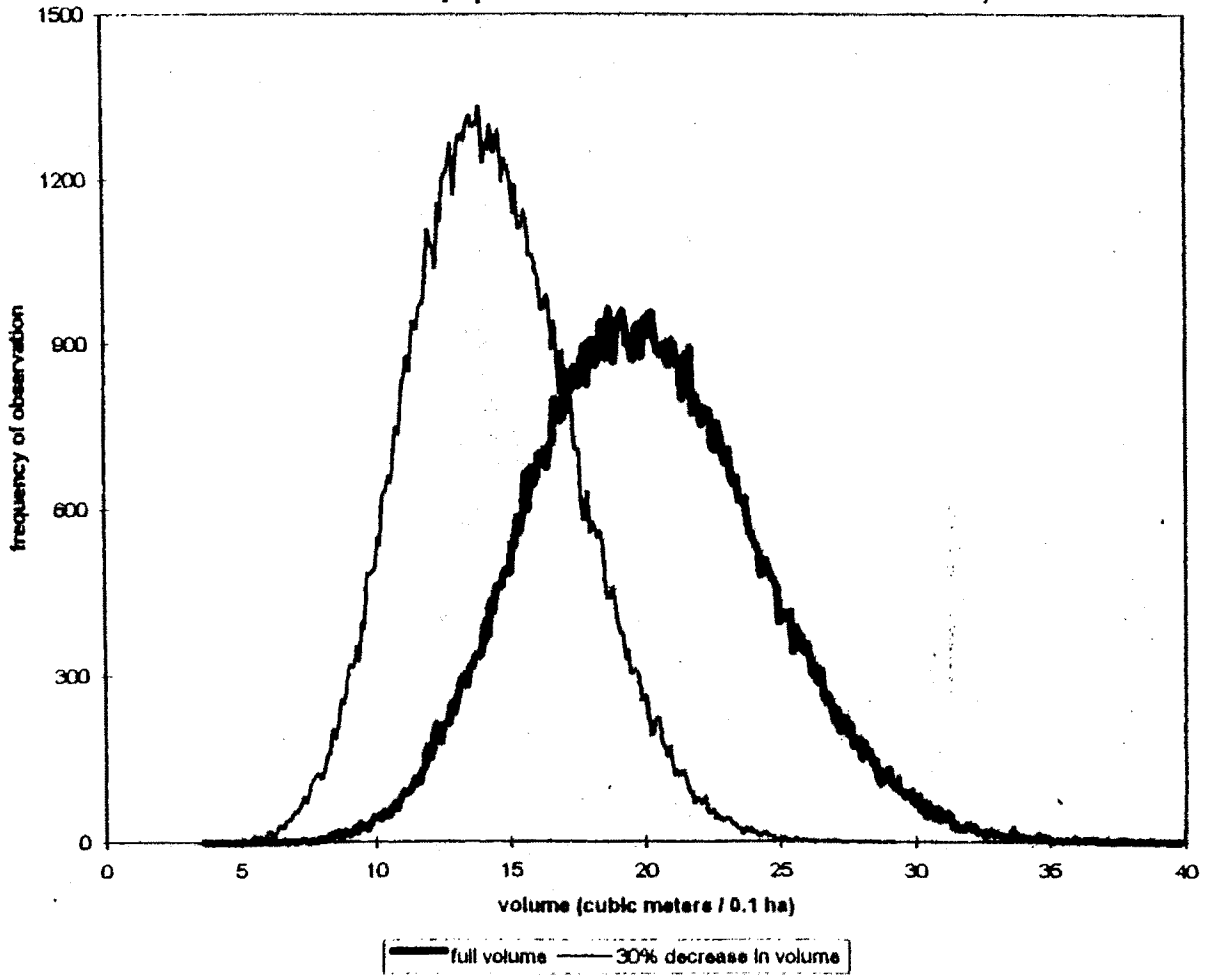


Figure 3. Illustration of the decision point where the probability of falsely concluding change equals the probability of failing to detect change (25% monitoring error for plot 2.2 using 25 1x5 meter sampling frames).

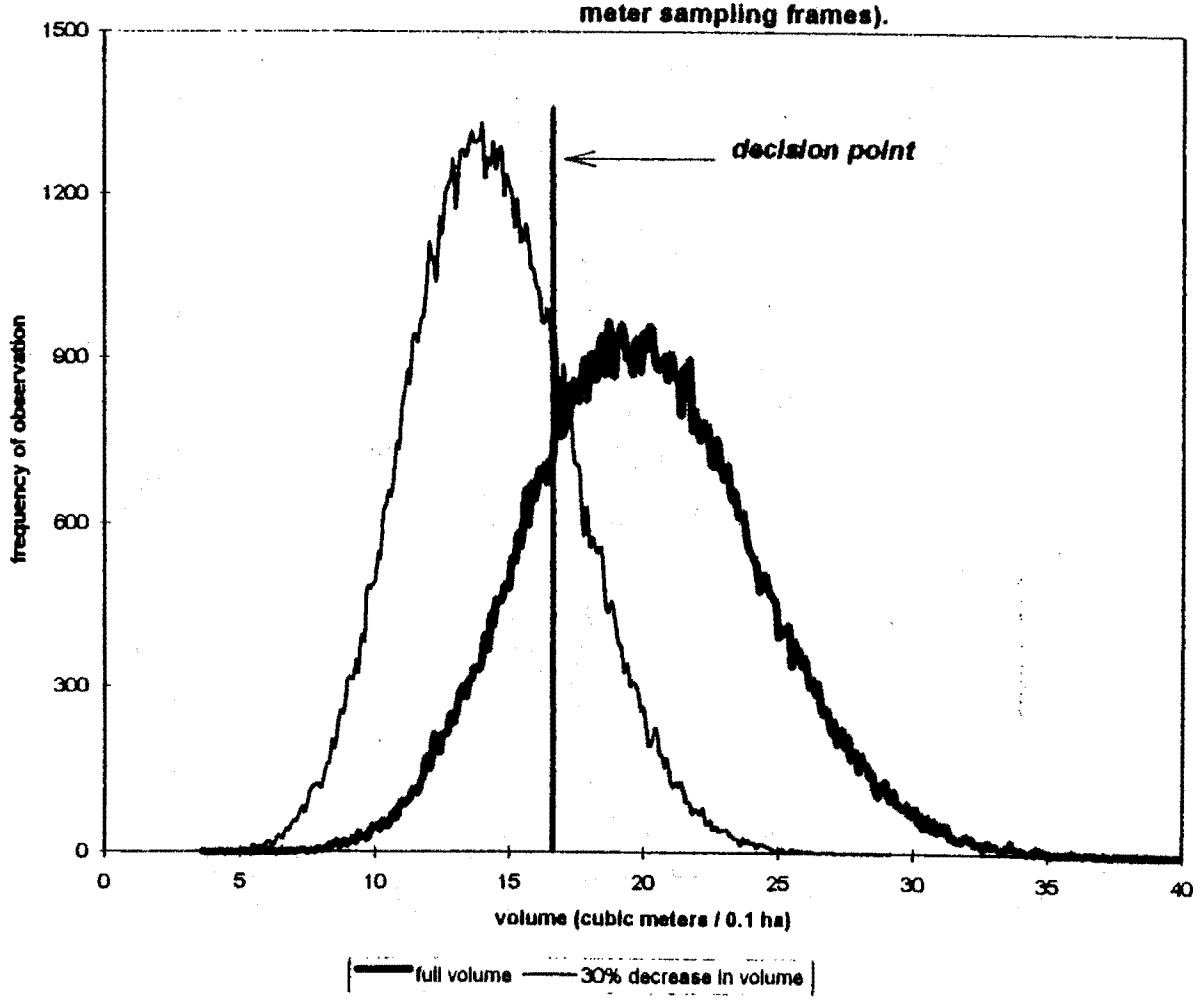
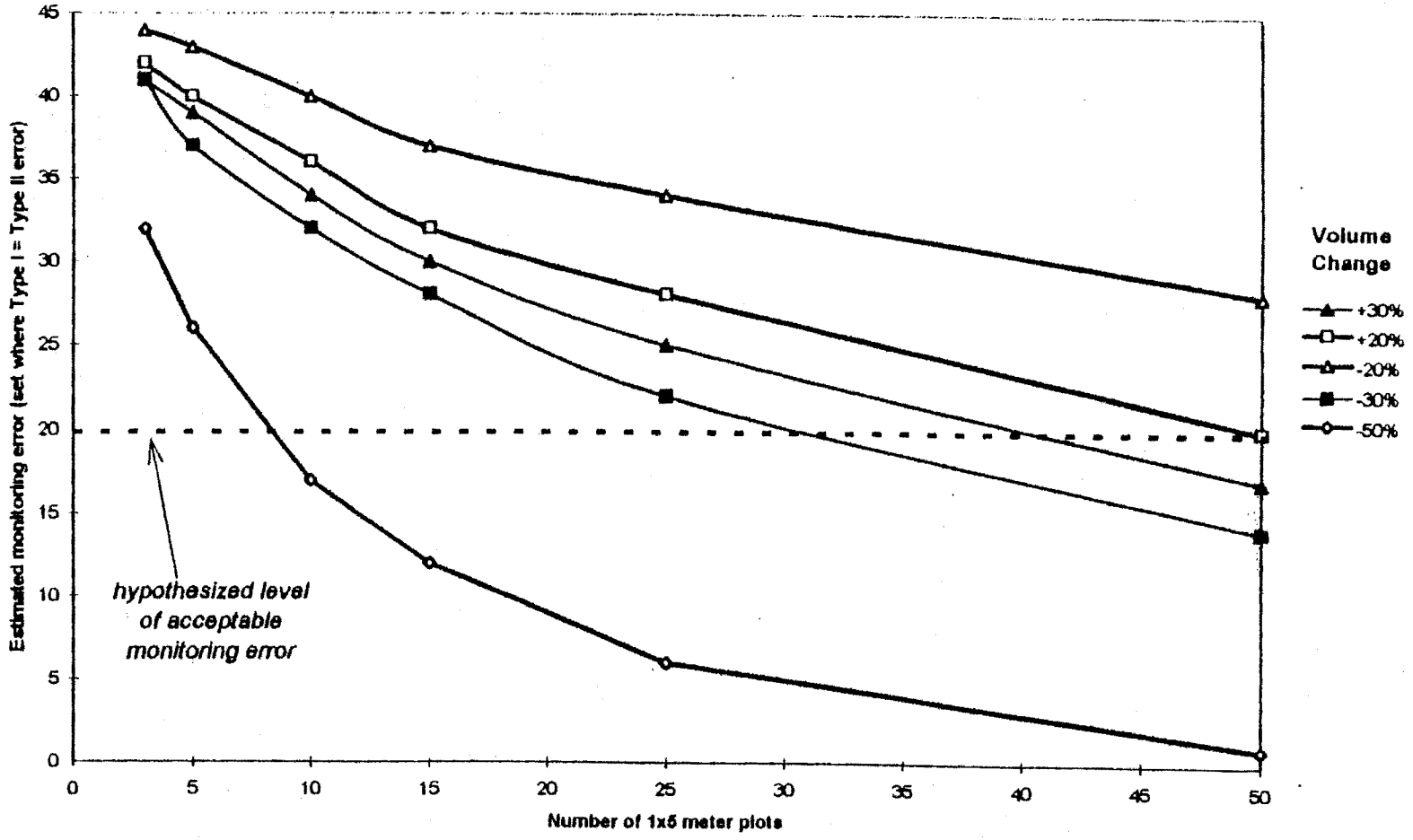


Figure 4. Monitoring change in white bursage volume in plot 2.2 with 1x5 meter plots. Volume changes range form +30% to -50% relative to the actual volume of monitoring plot 2.2.



Decision Making Process: Coordinated Resource Management

John H. Brock, Professor, Environmental Resources, School of Planning and Landscape Architecture, Arizona State University, Tempe, AZ 85287-2005.

History and Legislation

Planning for the use of rangeland resources has been evolving within the last century. The lack of controlled grazing lead agency personnel, land owners and members of conservation groups to begin devising procedures to alleviate livestock impacts to rangelands. As early as 1899, efforts had been made in the US Congress to secure legislation permitting leasing of public domain to stockmen, and to begin control of grazing activities on public land. About this same time period (1913) the concept of livestock rotation (alternate grazing) to maintain and improve rangelands was brought forward as a land management concept. However, the early efforts in managing grazing in a sustainable fashion were sporadic, somewhat isolated and many times of minimal consequence. In 1934 the United States Congress passed the Taylor Grazing Act which laid the foundation for livestock management on public lands, especially lands administered by the US Forest Service. The results included procedures to regulate livestock numbers and agreements on range use by leasees of grazing allotments on public rangelands. These agreements were often commodity oriented and usually between the grazing permit holder and local personnel of the agency on a person to person arrangement. In 1935 the Soil Conservation Service was founded and personnel of this agency provided technical assistance to private range managers who requested their help in planning grazing on their lands.

In 1960 the US Congress passed the passed the Multiple-Use Sustained Yield Act (Westman 1984), for application by the US Forest Service, with the realization that natural resources could be managed for the good of the majority of the people. Fourteen years later (1974), the Forest and Rangeland Renewable Resources Planning Act came into being. This legislation along with the National Forest Management Act (1976) provided a 10 year planning cycle for forested and range lands and provided a further thrust for rangeland planning. Another major boost for rangeland planning occurred in 1969 with the passage of the National Environmental Policy Act (NEPA), and the Federal Land Policy and Management Act (FLPMA) in 1976. While earlier legislation concerning natural resources planning involved public rangelands administered by the US Forest Service, the presence of FLPMA engaged rangelands administered by the Bureau of Land Management into a higher level of planning for land use. Then in 1978 the US Congress passed the Public Rangelands Improvement Act. While having little in the way of funding for direct rangeland improvement, the act did have a major impact on the evolution of the Coordinated Resource Management (CRM) process. While there were many pieces of legislation that have affected planning for rangeland management, perhaps the Endangered Species Act (1973), with changes in 1978 and 1982, pushed public lands planning into the levels of activity observed at present.

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Development of Coordinated Resource Management

The planning process known as CRM developed in parallel to the legislative efforts presented earlier. The first known coordinated plan for rangeland management dates from 1949 for the Eagle Valley Soil and Water Conservation district near Richland, Oregon (Repp 1997). This plan for land use differed from the conventional in that it involved several agencies and land managers rather than the person to person agreements common to that time. In the early 1950's Albert H. Agee and Charles W. Cleary pioneered CRM among land managers and agencies in California, while E. William Anderson simultaneously applied a similar approach in Oregon (Cleary 1997). In the early 1970's a memorandum of understanding (MOU) was developed among the Soil Conservation Service (new name = Natural Resources Conservation Service), the US Forest Service, Bureau of Land Management and the Cooperative Extension Service which is based within land grant universities. This understanding began to bring together agency personnel, land managers, and interested public entities desiring improved land uses.

The 1978 Public Rangelands Improvement Act contained a provision for an experimental stewardship program under section 12 of that legislation. This provision refined the CRM process to get people to work together. In 1987 another MOU among federal/state government agencies was produced that linked the experimental stewardship programs for rangelands with the CRM process. One of the premises under which CRM operates is to yield decisions that are acceptable to all interests. While there was much enthusiasm for the rangeland stewardship program in the early 1980's this was not shared by the whole spectrum persons interested in management of public lands. Sharp (1984) at a CRM symposium in Tucson, AZ stated that the central tendency of the national conservation community was to view coordinated management in general and coordinated management agreements in particular for rangelands (stewardship programs) in a "climate of anxiety, distrust, and opposition". In summarization of his comments Sharp (1984) added that the perspective of the national conservation community on coordinated management was sharply negative, and for coordinated management to be implemented on a significant scale it must be structured in ways that address and accommodate the apprehensions off the conservation community.

CRM Process

Coordinated is defined as: to arrange in proper order, put in proper relation, adjust, harmonize (The World Dictionary). Coordinated Resource Management, is an environmental/social planning process capitalizing on decision making by consensus. In the early phases of CRM development, decision by consensus was viewed with apprehension (Cleary 1984). However, as persons worked through the process all levels of decision were arrived at by consensus and controversy decreased among participants. CRM participation is voluntary and is a collaborative problem solving process for resource management issues. The initial thrust of the CRM approach was to form a tool to encourage better stewardship on grazing allotments (Tidwell 1984), which has been expanded into other land use programs. CRM is a process that benefits from the broad

involvement of its shareholders, requires commitment of its participants in which team players learn to express themselves about land use issues (Cleary 1997). Participants learn to express themselves in terms of needs rather than placing themselves in unyielding positions. People learn other persons interests and how to balance interests. By working on small issues first, teams begin to develop trust. With trust, CRM participants give each other time to talk, try new approaches and buy into the process. The sustainability of resources is often the first point for consensus. The four cardinal features of CRM as outlined by Cleary (1997) include: (1). planning and decision making by consensus, (2). broad involvement of all stakeholders, (3). commitment of all participants, and (4). participants express themselves in terms of needs rather than positions.

The CRM process as initially developed consisted of a fairly large steering committee, a technical committee, and subcommittees. The subcommittees deal with specific issues and bring them back to the steering committee for a larger hearing and consensus. The steering committee contained all interested stakeholders. Because the number of participants on a steering committee can become quite large, an executive committee are often formed which takes care of "business" type activities, while the entire steering committee is the organ which produces consensus on resource management activities.

The technical committee is empowered to "test" land management alternatives and report to the steering committee on what alternatives have been developed for potential land treatments. The technical committee often contains persons with specific scientific training. The CRM process is similar in many ways to environmental planning as described by Steiner (1990). Land planning almost always starts by the development of goals and objectives (Cleary 1984 and Steiner 1990), or by someone asking the question "what needs to be done to improve or protect an area of land". CRM strongly relies on citizen participation and public involvement which satisfies parts of NEPA and is a key element of modern environmental planning.

I believe that CRM is a powerful planning tool and that its application would go a long way to satisfy components of the Administrative Dispute Resolution Act (ADRA) of 1990. The purpose of this act was to authorize and encourage federal agencies to use mediation, conciliation, arbitration, and other techniques for the prompt and informal resolution of dispute, and for other purposes. The ADRA, is an alternative means of dispute resolution used in lieu of adjudication. It promotes facilitation, mediation, and other approaches for cooperative, consensual dispute resolution. It is my belief that the timely use of CRM would abort much of the litigation now present that lengthens the planning process. In some cases, lands stay in a less desirable ecological condition because lower levels of management are kept in place while more intensive land management options that could improve the land are argued over in the courts.

Coordinated resource management can be a powerful process for resolution of land planning problems. With specific mandates from the US Congress, land management

agencies have modified the CRM approach to fit their specific needs. For example, the US Forest Service has developed a similar approach to land use planning called integrated resource management (IRM) to fit its organizational framework. Another planning process that is often cited as being very beneficial for land management is holistic resource management (HRM) as outlined by Savory (1988). While HRM has had wide spread usage in the Southwest in the recent past, as originally designed it does not satisfy NEPA because it does not specifically require public participation to be used as a land planning process.

Conclusion

Coordinated resource management can make large differences in the acceptance of land use plans. However, there is still a lag in the application of sound land management plans. In my opinion this comes about from 3 factors as follows:

1. Lack of adequate staffing in land management agencies.
2. Fear something not expected will happen with the management plans that could put liability on the person(s) implementing the plan.
3. Lack of commitment by some of the persons holding leases on public lands.

Land management agencies have had deep cuts in staff and funding as Congress has moved to curb the nation's budget. This is reflected in too few persons working with land managers to help foster good land stewardship. There is an undercurrent of fear among land managers that if something "happens" on the land that they will be sued. Most persons find being taken to court as being "not where they want to be". The lack of commitment of persons holding leases on public grazing lands also slows ecosystem improvement. With this in mind, in 1990 at the First Conservation Workshop (no others have been scheduled since that time), among other points, Brock (1990) provided a series of questions titled "what if?". Three of these points pertinent to direct livestock management of public lands included: What if, (1). public land leasees had to demonstrate competency before awarded a grazing permit, (2). were required to demonstrate former land management practices included conservation practices before lease renewal, and (3). natural resources management was driven more by providing for ecological stability and diversity rather them by cost-benefits analyses and politics. Backus (1996) included some of these items but several more in an address to the Arizona Section - Society for Range Management. His abbreviated items for public land leasees included: (1). certification for range managers, (2). continuing education in range management, (3). have official management plans filed and present an annual report, (4). assume certain employee type responsibilities (a) report violations of law on public lands (b) perform reasonable cleanup after other public land users (c) plan/install improvements for other land users (wildlife or stream protection), (5). permittees be graded each year, (6). grazing fees be placed on a sliding scale based on the quality of land stewardship, (7). leases be terminated for flagrant violation of grazing agreements, history of poor performance, low grades, (8). persons who have had a lease terminated never permitted another lease of any kind on public lands. Management of public lands continues needed improvement. Not all of ecosystem

improvement will come with the implementation of an CRM process. Environmental education for those living on the land, those who regularly visit public lands, and perons who live in parts of the USA without access to public lands, seems to be the common thread that can lead to improved ecosystem management.

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Do Livestock Waters Help Wildlife?

Joan E. Scott[1]

Abstract – Wildlife benefit is often cited as a justification for development of livestock waters; and now livestock water, with its perceived benefit to wildlife, is being used as justification for domestic livestock grazing in general. However, many livestock waters provide little if any benefit to wildlife. Furthermore, if the development of a livestock water results in greater livestock use of an area, or if it leads to loss of riparian or xeroriparian areas, the net result may be detrimental to wildlife instead of beneficial.

Agency personnel can conduct a better evaluation of the environmental impacts of a livestock water, and do a better job of designing a livestock water, by reviewing the following four questions.

1) Will the livestock water change the distribution and/or the stocking rate of the livestock? If there is a concurrent increase in the stocking rate, or if new cattle use will occur in areas with other resource concerns, the net impact to wildlife may be adverse. Rather than creating a new livestock water, a decrease in livestock numbers may be a better solution to overuse around current water sources.

2) What is the impact of removing water from its natural source? Water that is captured, piped, and stored for livestock may come from a drainage, from a natural spring or seep, or from groundwater reserves. Removal of that water from the source could adversely affect other important components of wildlife habitat, especially riparian values.

3) Is the livestock water available to wildlife? Some water storage and delivery systems deny wildlife species access to free water. Also, many livestock waters do not have wildlife escape ramps, and wild animals drown. Some livestock drinkers are turned off when cattle are moved out of the area; if water is not provided during the dry periods, the value to wildlife is diminished or eliminated.

4) What wildlife species will use the water, and what are their habitat needs? One species may benefit from free water alone, but another species may need associated riparian vegetation that is not available at some livestock waters.

With wildlife-friendly design and management, livestock waters can maximize the number of wildlife species that can use the water, and wildlife values can be provided.

[1] Habitat Program Manager, Arizona Game and Fish Department, Tucson.

INTRODUCTION

"Wildlife populations will be negatively impacted without ranchers to construct and maintain water developments."

Arizona Cattle Grower's Association (1977)

Wildlife benefit is often cited as a justification for development of livestock waters; and now livestock water, with its perceived benefit to wildlife, is being used as justification for domestic livestock grazing in general.

Unfortunately, many livestock waters are constructed and operated in such a manner that little or no wildlife benefit is realized. Furthermore, no livestock water provides benefit for all wildlife species. Resource managers will improve the accuracy and clarity of their statements if they avoid the generic term "wildlife benefit" and instead identify which species are expected to use the water.

To further illustrate how this concept can be taken to the extreme, I'll share with you a recent experience. I was reviewing a public land grazing allotment with a land management agency and the permittee. We were riding through a range that had been significantly degraded by overgrazing. We stopped by an earthen tank that had been so overused that all vegetation was gone from the surrounding area. The rancher turned to me and stated:

> "You wildlife biologists should thank the ranchers, because without livestock waters there would be no wildlife over much of Arizona."

In fact, the degraded condition on this ranch, which was solely caused by this rancher's grazing practices, had caused much more adverse impact to wildlife habitat than could have ever been offset by the addition of livestock waters. Livestock water will never benefit wildlife if it is associated with over-grazing and poor grazing management.

Resource agencies have a responsibility to clearly articulate the justification for public land uses. Grazing of public lands can be and is justified for numerous reasons, including community economic stability and multiple-use mandates. But, if we use wildlife as a justification for development of livestock waters, and even as a justification for grazing, we should analyze more thoroughly and articulate more clearly the benefits that will come to wildlife from the livestock water. Agency personnel can conduct a better evaluation of the environmental impacts of a livestock water, and they can enhance the design of a livestock water, by reviewing the following four questions.

EVALUATION OF LIVESTOCK WATERS

1. Will the livestock water change the distribution and/or the stocking rate of the livestock?

To illustrate this point simply, let us assume a case of an allotment with some number of cattle, but only one reliable water source, such as a natural creek. Most cattle use is near the water source, and little use occurs on other portions of the allotment (Figure 1.A.). A common proposal would be to develop a livestock drinker in another part of the allotment in order to increase cattle distribution. The usual environmental assessment would simply state that the increased water would benefit wildlife.

If the addition of the livestock water results in the same number of livestock distributed more evenly throughout the allotment (Figure 1.B.), the project would likely benefit wildlife as a result of lighter grazing near the old water source.

However, there can be scenarios where the project might not benefit wildlife. If the proposal includes a concurrent increase in livestock numbers (Figure 1.C.), the new water will not lead to decreased livestock use around the old water; rather it will lead to additional livestock use around the new water on land that was relatively ungrazed. The negative impacts from increased livestock use will more than outweigh any benefit from the additional water. Project proponents might justify that the development had no adverse effect on wildlife, if they could show that the proposed stocking rate was at a sustainable level. However, it would be more difficult to claim an actual benefit to wildlife. The livestock water might still be justified for economic or multiple-use reasons, but we should not claim a benefit to wildlife if it cannot be demonstrated.

Also, we need to consider other resources in the area where livestock use will increase. A proposal might bring livestock into habitat that is relatively pristine because of its distance to water. From a commodity point of view, it is an advantage to utilize more of the land. However, from the wildlife point of view, it may not be a benefit. Suppose there was a bighorn sheep population on hills that were previously only lightly used by cattle (Figure 1.D.). Increasing cattle distribution to that area would not likely benefit the bighorn (Figure 1.E.). Or, if this area had steep slopes and erodible soils, increased cattle use would cause adverse land impacts. Under either of these scenarios, the new livestock water could result in negative impacts to wildlife.

If the current grazing level around an old water source is excessive, but greater livestock distribution is undesirable, one could justify an alternative to decrease the stocking rate rather than add a new water (Figure 1.F.). Overgrazing is sometimes the result of a stocking rate that is based on full use of the grazing range, when only a portion of the range is actually used. Consideration of a stocking rate reduction will facilitate an objective analysis of alternatives.

One also should consider whether the habitat around a proposed livestock water is suitable for grazing. For example, if the slope of the land is greater than 60 percent, little livestock use will occur (Holechek, 1988); this land should be deleted from the stocking rate calculations. Similarly on slopes of 31-60 percent, expected livestock allocations should be reduced 60%

(Holechek, 1988). Thus, it is inappropriate to develop a livestock water on a steep slope, because cattle use would be light even if water is provided. The project is unlikely to increase livestock distribution, so expected land improvement would not occur. The expense of creating this livestock water would not be offset by either better cattle management or increased cattle profits.

The environmental review should also evaluate how cattle will be managed around the new water source. High livestock use of forage around a livestock water can adversely impact many species of wildlife. Swank (1958) reported that deer and livestock congregate in the vicinity of permanent water during dry months, depleting forage in these areas; if the food supply falls below demand, a die-off of deer can result. Similarly, Ockenfels et al. (1994) found that pronghorn avoided the first 1320 ft (400 m) surrounding water sources. They attributed the apparent avoidance around water sources to concentrations of livestock which denuded the vegetation surrounding the water source. Stoddart et al. (1975), too, reported that concentrations of livestock at water sources on arid rangelands cause severely denuded areas, which pronghorn avoid.

2. What is the impact of removing water from its natural source?

There is no net gain of water by creation of a livestock water. Water is either diverted from running down a drainage, or tapped from a spring or seep, or pumped from groundwater supplies. The question that begs asking is whether we are causing adverse riparian impact by removing water from its natural source.

Any management action that decreases riparian functions and values generally is considered adverse to wildlife species. More than 60 percent of vertebrates in the arid Southwest are obligate users of riparian areas, while another 10 to 20 percent are facultative users (Ohmart and Anderson, 1986). Even xeroriparian drainages, which have water for only hours after a storm, provide important habitats for wildlife. Johnson and Haight (1985) found that xeroriparian habitats supported five to ten times the bird densities and species diversity of surrounding Sonoran Desert uplands.

Removal of water from the natural source may be significant or insignificant, depending on the quantity of water in the system and the percentage of source water being removed. Of course, wildlife also use water, but cattle use is an increase above the natural wildlife use—an added biomass in the ecosystem requiring free water. How much of our range water resource do we convert to livestock production?

One mature cow requires 8 to 10 gallons of water per day (Vallentine, 1980), and the U.S. Department of Agriculture recommends that water development plans consider 12 to 15 gallons per day for cattle to meet maximum free choice water consumption and allow for evaporation (U.S. Forest Service, 1969; U.S.D.A. Soil Conservation Service, 1982). If we use a figure of 10 gallons of water per day for one cow, 100 cows using a water source for 1 month, or 33.3 cows

using a water source for 3 months, will result in 30,000 gallons of water being removed from the source for livestock use (100 cows x 10 gal. x 30 days = 30,000 gallons, or 33.3 cows x 10 gal. x 90 days = 30,000 gallons). Vallentine (1980) reports that at least one watering facility should be provided for every 50-60 animal units for full growing season use.

(For comparison, daily water consumption for big game herbivores has been estimated at 1.5 gallons for mule deer and desert bighorn sheep, and at 1.0 gallons for white-tailed deer and pronghorn [Clarkson and Sturia, 1990]. The standard rainwater catchment design now used by the Arizona Game and Fish Department has a storage reservoir of 17,000 gallons [Gunn, 1990]. AGFD has found that wildlife water developments of 10,000 gallons or more usually meet wildlife needs if filled annually.)

If the water source is a drainage, we need to assess the function the water previously served in that drainage. Did that water support any riparian or xeroriparian habitat? What portion of the water from that drainage are we giving to livestock? Although one might argue that diversion for a livestock development does not remove the water, rather just delay it or slow it down, I would argue that the portion consumed by livestock is removed. Could this removal of water from drainages be causing loss of riparian functions, above and beyond any grazing impacts from forage consumed and trampling? If water diversion for a livestock development, and associated increases in livestock use, decreases or eliminates riparian or xeroriparian functions and values, the net effect is adverse to wildlife.

Changes in streamflow due to man-made diversions can affect vegetation in the downstream drainage. Diversions of stream water negatively affect riparian vegetation by increasing water stress; by decreasing leaf area; by decreasing cover, abundance, density, and growth rate of riparian trees; by changing the size-class distribution of riparian trees; by increasing tree mortality; by tempering high-flow periods that recharge aquifers and soils; by lowering the water table below the rooting zone of many plant species; and in extreme cases by destroying the riparian ecosystem altogether (Medina, 1990; Smith et al., 1991; Stromberg and Patton, 1991).

Is it possible that without livestock waters there would be more water for wildlife in creeks? Decreases in drainage vegetation can lead to lower summer flows in streams, decreased water intake of soil, and decreased water storage function of the soil (Rauzi and Hanson, 1966; Elmore and Beschta, 1987). Healthy riparian soil acts like a sponge, holding water in the streambanks and slowly releasing it to stream channels; thus groundwater reserves are increased, and the seasonal quantity and quality of water are increased (Chaney et al., 1990; Stromberg, 1993). Early accounts of Coues white-tailed deer in Arizona indicated greater use of riparian areas than we see today (Davis, 1982). With the loss of perennial streams and wetlands in Arizona, Coues white-tailed deer may now be more dependent on human-made water sources (Ockenfels et al., 1991).

If the water source is a natural spring or seep, the environmental assessment should assess whether removal of the water will decrease the riparian and wetland values of the source

site. Springs and seeps are formed when ground water meets tilted rock formations or impervious soil layers which direct the water to the surface, or when ground water is released through fissured rock. An outstanding attribute of these aquatic habitats is that the water they provide is of relatively constant temperature, being warmer in winter and cooler in summer than other waters. Consequently, springs and seeps support a high level of biological activity (Melton et al., 1984).

Water discharge from most springs is insufficient to water many livestock at a time, so the water is usually piped to a storage site for periodic high volume consumption (Kindschy, 1996). A spring that yields only one gallon every six minutes can provide enough water for 25 head of cattle if developed (Vallentine, 1980). Unfortunately, the original riparian/wetland zone associated with the spring is often destroyed by the spring development, which collects all the available water (Kindschy, 1996). Some riparian/wetland values of the natural spring might be preserved if overflow is maintained and the spring is fenced, or if the overflow is diverted to an adjacent area that is fenced (Kindschy, 1996). Nevertheless, if a large portion of the available outflow is converted to livestock water, significant riparian/wetland values will be lost.

If the water source is a well to ground water, the cone of depression around the well may dry up nearby springs which provided other attributes of wildlife habitat. Also, wells may lower the local water table, which could impact vegetation, favoring deeper-rooted shrubs over shallower-rooted grasses.

Ground water in southern Arizona is being depleted at a rate which exceeds the natural recharge rate (Schumann, 1988). Although water use for range livestock is probably less than one percent of the total water use in Arizona (Lee Lambert, Arizona Department of Water Resources, Tucson, personal communication), livestock use may be significant for localized areas. For example, stockponds comprise 10 percent of the total agricultural water use in Cochise County, and most of the supply comes from groundwater (Liverman et al., 1997). In the San Rafael Basin, ranching is the main activity, and most groundwater withdrawal is for watering livestock (Arizona Department of Water Resources, 1997).

3. Is the livestock water available to wildlife?

An evaluation of the impact of a livestock water to wildlife should include a list of the wildlife species in the area, whether or not those species will have access to and exit from the water, and whether or not the water will be available during the period of the year when it would be used by those species.

Deer and pronghorn can access many cattle waters, but Ockenfels et al. (1994) noted that water sources built in drainages with abundant shrubs and trees or with rough topography are avoided by pronghorn because they provide predator hiding cover. Other livestock waters are

fenced so that they function as cattle traps and holding pens; thus wild ungulate entry is restricted or prevented (Ockenfels et al. 1994).

Other forms of wildlife vary in their ability to access and/or use different types of livestock waters. For example, rabbits, javelina, young deer, quail, and reptiles cannot access many trough or metal tank drinkers.

Other species use water habitats for more than just drinking. Leopard frogs need free water for mating and laying eggs. Metal tanks with troughs high off the ground are not accessible to leopard frogs, but earthen stocktanks can provide excellent habitat. Herpetologists have speculated that maintenance of declining leopard frog species in Arizona may be dependent, at least in the short term, on populations in ranch stocktanks (Rosen et al., 1996).

Most bats (except those which feed on nectar) appear to drink water routinely during hot, dry summer months (Cockrum, 1981). Bats usually drink by flying low over a water surface and immersing the mouth (or lower jaw) into the water. Therefore, surface water must be large enough for the bat to successfully drink while in flight. Some bats, such as the Mexican free-tailed bat (*Tadarida brasiliensis*), pocketed free-tailed bat (*Tadarida femorosacca*), and Underwood's mastiff bat (*Eumops underwoodi*), have narrow wings and require large surfaces (15 to 30 feet or more) of free water for long gliding approaches and departures from the water (Cockrum, 1981). Also, barbed wire fences strung across the surface of waters can kill bats (Janet Tyburec, Bat Conservation International, Inc., Austin, Texas, personal communication), so waters designed to benefit bats should be free of obstructions in their flight path.

Some livestock drinkers and storage tanks, especially those with straight sides, allow some wild animal species to access the water, but have no provision for escape from the water, resulting in death of wild animals either from drowning or from struggling to escape the trap (Enderson, 1964; Craig and Powers, 1975). I have found dead rabbits, frogs, skunks, hawks, and quail chicks in steep-walled metal troughs and storage tanks. Although land management agencies encourage the use of escape ramps in livestock waters, I estimate that fewer than 50 percent of livestock waters I have visited have had functional escape ramps. Several designs for wildlife escape ramps have been developed (Wilson and Hannans, 1977; Yoakum et al., 1980; Woltering, 1981; Fredlake et al. 1983; Sherrets, 1989; Sanderson et al., 1990). Lids on large water storage tanks prevent wild animals from being trapped, or a floating platform can function for both access and escape in large storage tanks (Wilson and Hannans, 1977; Yoakum et al. 1980). Maintenance of escape ramps is also essential and too often deficient.

Some livestock waters are operational only seasonally. Cattle are usually rotated through different pastures, and some ranchers shut off water in pastures when cattle are elsewhere. Furthermore, some ranchers use "water-lotting" to move their cattle: waters are turned off at one place to encourage cattle to move to a different portion of the ranch. If a watering site is not available to wildlife during dry summer months, most benefit is lost. Livestock waters can be

designed to meet the need for moving cattle and still provide year-round water for wildlife, if they are fenced in a manner to exclude livestock when necessary, but allow passage of wildlife.

4. What wildlife species will use the water, and what are their habitat needs?

A wildlife biologist stopped by my office after a day in the field during one of our many southwest droughts. He said:

> "Every deer I saw today was in the riparian areas. You can sure tell how dependent the deer are on water during these hot, dry times."

Those deer may have been using water in the riparian areas; but on the other hand they may have been keying in on the shade, hiding cover, and riparian forage. Free water alone may have not have provided those deer with essential survival advantages. We need to ensure that we do not interpret an animal's dependance on riparian areas as a dependance on free water.

Wildlife values of riparian areas include hiding cover; thermal cover and shade; enriched vegetation resources including additional species, succulence, and height diversity unavailable in surrounding uplands; abundant floral resources; enhanced invertebrate resources; microhabitat for prey and increased prey densities; nesting substrate; roosting substrate; hunting perches; night perches; enhanced decomposition and soil with higher organic material; travel corridors and migratory routes; rubbing sites; and wallows. Some stockponds provide riparian vegetation, and a few are even designed to slowly release water to create downstream riparian habitat (Arizona Game and Fish Department, 1996). However the majority of stockponds do not provide any riparian vegetation, and metal stocktanks have no associated riparian functions and values. We need to think more critically about the specific habitat needs of different wild animal species. The provision of water in a metal tank will be of little benefit to a vermillion flycatcher if no riparian habitat is available.

But, habitat needs vary by species. While most wildlife will be adversely affected by declines in riparian condition, a sidewinder is probably unaffected. While most wildlife species will be negatively impacted by overgrazing, horned larks, lark sparrows, and kangaroo rats may actually profit from decreased ground cover resulting from overgrazing. And, while some species may realize no survival advantage from a denuded stocktank, Sonora tiger salamanders and waterfowl may benefit from a dirt tank regardless of a degraded condition. Thus, to evaluate the impact of a livestock water on wildlife, we must know what wildlife species are present and what habitat conditions they require.

Although water is essential to the survival of all animals, the water requirements of animals are met by a variety of means. Some animals do not require free water for drinking. While many animals will drink free water if it is available, there are still questions regarding which

species show population benefits from water developments. (Burkett and Thompson, 1994; Broyles, 1995; Arizona Game and Fish Department, 1997).

CONCLUSION

Without wildlife-friendly design, construction, and maintenance, and without concurrent good range management, little wildlife value will be realized from a livestock water. Many wildlife species cannot use some types of livestock water developments. Furthermore, if the development of a livestock water results in greater livestock use of an area, or if it leads to loss of riparian or xeroriparian habitats, the net result may be detrimental to wildlife instead of beneficial.

We can design livestock waters to insure the provision of water for many wildlife species and to include some wildlife values. If we include the following four questions in our analysis, we will do a better job of planning a livestock water and of evaluating the expected impact to wildlife:

1) Will the livestock water change the distribution and/or the stocking rate of the livestock?

2) What is the impact of removing water from its natural source?

3) Is the livestock water available to wildlife?

4) What wildlife species will use the water, and what are their habitat needs?

I contend that to show a benefit to wildlife from a livestock water, one should demonstrate:

a. That there is no concurrent increase in the livestock stocking rate;

b. That construction of the livestock water will result in more appropriate levels of grazing through a better distribution of the cattle;

c. That the livestock water is being placed in an area 1) appropriate for grazing, 2) identified in the land management plan for grazing, and 3) where no resource concerns conflict with the proposed grazing;

d. That grazing around the new water will be light to moderate, and forage resources will not be depleted around the new water;

e. That the stocking level of the livestock is appropriate for the land, and the livestock management system allows for appropriate rest;

f. That removal of water from the natural source (drainage, spring or seep, ground water) causes no significant loss of riparian or other wildlife values;

g. That drinker design will maximize wildlife access to the water;

h. That adequate escape ramps will be provided in water storage tanks and drinkers, and/or storage tanks will be covered; and

i. That water will be available to wildlife year-round.

Furthermore, to be fiscally responsible, public agencies should evaluate the financial return on creation of a livestock water on public land. Is the public gain as measured by increased livestock production greater than the public cost of the livestock development? Development of a livestock water commonly costs $5,000 to $10,000 of public funds, and matching costs from the permittee are similar. Those cost should be weighed against the additional animal units that will be available for grazing, the net profit to the permittee, and the net public gain from increased livestock production. Also, if game populations are positively or negatively impacted by development of a livestock water, there can be an economic gain or loss from changes in hunting opportunity (Loomis et al., 1991).

To claim a wildlife benefit, a livestock water must be designed and managed to provide wildlife values. Livestock grazing can be compatible with good wildlife management, but it can also be adverse to wildlife without careful planning and management. If livestock grazing persists on public lands, it will be because ranchers and land managers have taken steps to insure that grazing is compatible with other public uses.

ACKNOWLEDGMENTS

This paper benefited considerably from critiques by Bill Broyles, Glenn Frederick, John Gunn, and Jim Heffelfinger. I offer my sincere thanks to these people.

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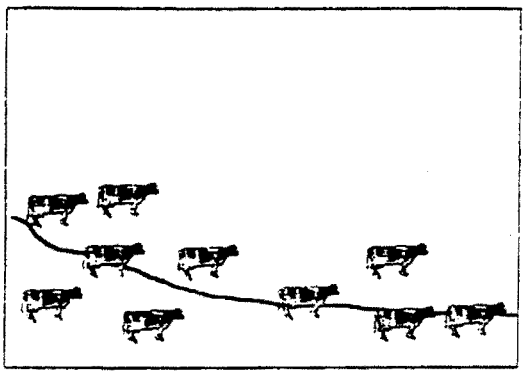
Figure 1. Graphic representation of possible effects of water development on livestock distribution. Line represents a stream. Oval represents a stockpond. See text for explanation of different livestock management scenarios and the potential impact to wildlife.



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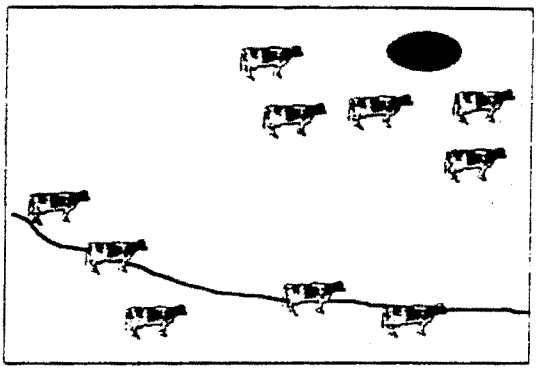

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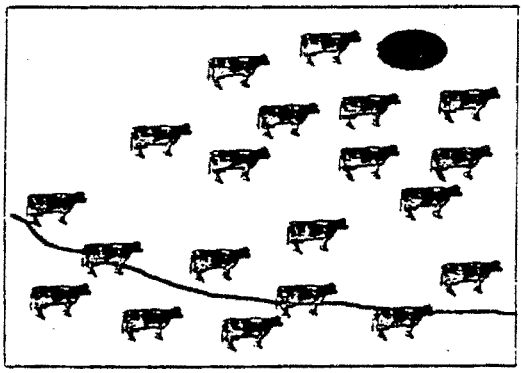

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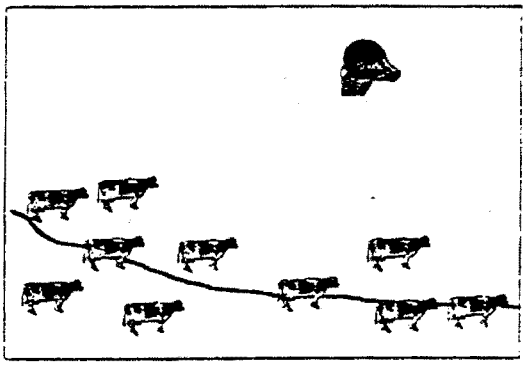

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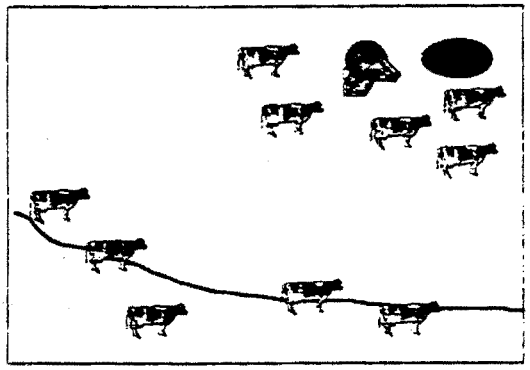

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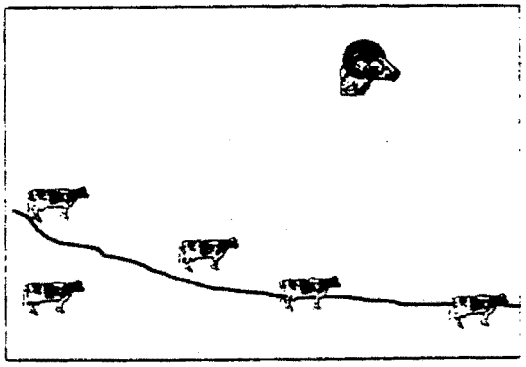

1.F.

The Value of Watersheds in Ecological Planning

Frederick R. Steiner*

Abstract – The watershed is advocated as an appropriate unit for ecological planning. The natural geometries of drainage systems are contrasted with the American grid of Jefferson. Watersheds can be understood through a choreography ordered by ecological understanding. The upper San Pedro River basin of southern Arizona (U.S.A.) and northern Sonora (Mexico) is used as an example. This watershed is currently facing significant growth and development. Rapid urbanization on the U.S. side and cattle ranching, copper mining, and population growth in Mexico have negative consequences for water quality and quantity, pose threats to wildlife habitats, and are degrading the region's scenic resources. A planning process is underway to explore options for more sustainable development in the upper San Pedro River basin. This paper focuses on one element of that process: the identification of environmentally sensitive areas in the watershed.

INTRODUCTION

John Wesley Powell was perhaps the keenest observer of the American West in the late 19th century. He provided a clear practical vision for settling the arid and semi-arid regions of the West. Powell advocated the use of drainage basins. He based his advocacy both on an understanding of natural processes as well as on his observations of native and Hispanic settlements. Drainage basins, which we also call catchment areas and watersheds,[1] are relatively easy to delineate. They are a rather simple *system* to understand: a certain amount of water enters the watershed, a certain amount departs, and, in the process, a certain amount of life can be sustained in between.

* Director and Professor, School of Planning and Landscape Architecture, Arizona State University.

Powell's rational proposal was not heeded. Instead, a different form of rationality was imposed on the American West. The land was divided in the order derived from Jefferson's grid. Jefferson was a child of the Enlightenment, influenced by Rene Descarte and Francis Bacon. Jefferson was also, quite obviously, an idealist who viewed property ownership as the key to democracy. Paul Shepard observed that Jefferson believed that "agriculture produced the only real wealth, that every man had a natural right to land, that cultivation earned the right of ownership, and that labor in the field dignified the farmer and purified him to nature" (1991, p. 139).

This freehold concept is at the root of American democracy. However, there are many contradictory forces in Jeffersonian democracy, slavery being the most hideous, but perhaps his views toward the land have yielded similar oppression. According to Shepard, "Jefferson admired sublime objects" in nature (1991, p. 139). Jefferson acknowledged that not every acre of land could or should be farmed. He said, "Whenever there are in any country uncultivated lands and unemployed poor, it is clear that the laws of property have been so far extended as to violate natural rights." That is, Jefferson recognized that some lands were too environmentally sensitive or, in other words, unsuited for use.

In summation, Jefferson created the myth of the "noble yeoman, the small landholders are the most precious part of the state." The noble yeoman democrat was a creation by a landed gentleman whose slaves did the cultivation, and thus, were, at least theoretically, "purified" by nature. To facilitate the settlement of the nation by these noble yeomen, Jefferson wrote the Northwest Ordinance of 1785. The effect of this ordinance, when combined with the Land Act of 1796 and later the Homestead Act of 1862, was to divide the nation west of the Alleghenies

into a giant checkerboard (Meine 1997). Even Jefferson, who placed private property on the highest pedestal, recognized some lands were unsuited for settlement. In today's terms, settlement can be associated with development.

And so, we have inherited a division of the land, rational in 18th century views, which is incongruent with natural processes and, thus, irrational. Powell presented us with the alternative of using drainage systems to organize settlement.

METHODS

A drainage basin, or watershed, "is the area of land that drains water, sediment, and dissolved materials to a common outlet at some point along a stream channel" (Dunne and Leopold 1978, p. 495). "A *watershed* is defined by the stream that drains it," according to Satterlund and Adams (1992, p. 51). The drainageway, meanwhile, "refers to the principal areas of water accumulation (i.e., channels)" (Briggs 1996, p. 17).

A watershed may be understood through a "choreography," that is, a systematic description and analysis. Ecology can be used to order such a choreography since ecology addresses interrelationships among living things and their environments.

The ecologist Eugene Odum has observed the value of using watersheds in planning. He noted,

> "it is the whole drainage basin, not just the body of water, that must be considered as the minimum ecosystem unit when it comes to man's interests. The ecosystem unit for practical management must then include for every square meter or acre of water at least 20 times an area of terrestrial watershed" (Odum 1971, p. 16).

McHarg (1969, 1997) has identified the principal elements that should be understood in a choreography of a watershed (Table 1). He advocates that these elements be studied chronologically from the oldest to the newest in a "layer cake" arrangement (Figure 1). Such an organization can lead to an understanding of ecological interrelationships of a watershed, which is significant because relationships reveal patterns in the landscape. The layer cake model also can be used to determine the suitability of various uses, including grazing, recreation, and urban development. We can ask: Where the best locations are for such uses? as well as Where are environmentally sensitive areas? The layer cake model provides the theoretical foundation for most geographic information systems. In reality, the world is probably more of a swirl cake or a marble cake than a layer cake. However, McHarg's layer cake is a good starting point to order an understanding of place.

A team from the Arizona State University School of Planning and Landscape Architecture is currently conducting a choreography of the upper San Pedro basin in Arizona and Sonora.[2] Our work is being supported by the U.S. Environmental Protection Agency through the Southwest Center for Environmental Research and Policy (SCERP). SCERP is a multi-university research consortium funded by Congress. One goal of our research is to identify environmentally sensitive areas in the San Pedro watershed.

Table 1. Baseline Natural Resource
Data Necessary for Ecological Planning (McHarg 1997)

The following natural resource factors are likely to be of significance in planning. Clearly the region under study will determine the relevant factors but many are likely to occur in all studies.

CLIMATE. Temperature, humidity, precipitation, wind velocity, direction, duration, first and last frosts, snow, frost, fog, inversions, hurricanes, tornadoes, tsunamis, typhoons, Chinook winds

OEOLOGY. Rocks, ages, formations, plans, sections, properties, seismic activity, earthquakes, rock slides, mud slides, subsistence

SURFICIAL GEOLOGY. Kames, kettles, eskers, moraines, drift and till

GROUNDWATER HYDROLOGY. Geological formations interpreted as aquifer with well locations, well logs, water quantity and quality, water table, flood plains

PHYSIOGRAPHY. Physiographic regions, subregions and features, contours, sections, slopes, aspect, insulation, digital terrain model(s)

SURFICIAL HYDROLOGY. Oceans, lakes, deltas, rivers, streams, creeks, marshes, swamps, wetlands, stream orders, density, discharges, gauges, water quality

SOILS. Soil associations, soils series, properties, depth to seasonal high water table, depth to bedrock, shrink-swell, compressive strength, cation and anion exchange, acidity-alkalinity

VEGETATION. Associations, communities, species, composition, distribution, age and conditions, visual quality, species number, rare and endangered species, fire history, successional history

WILDLIFE. Habitats, animal populations, census data, rare and endangered species, scientific and educational value

HUMAN. Ethnographic history, settlement patterns, existing land use, existing infrastructure, population characteristics

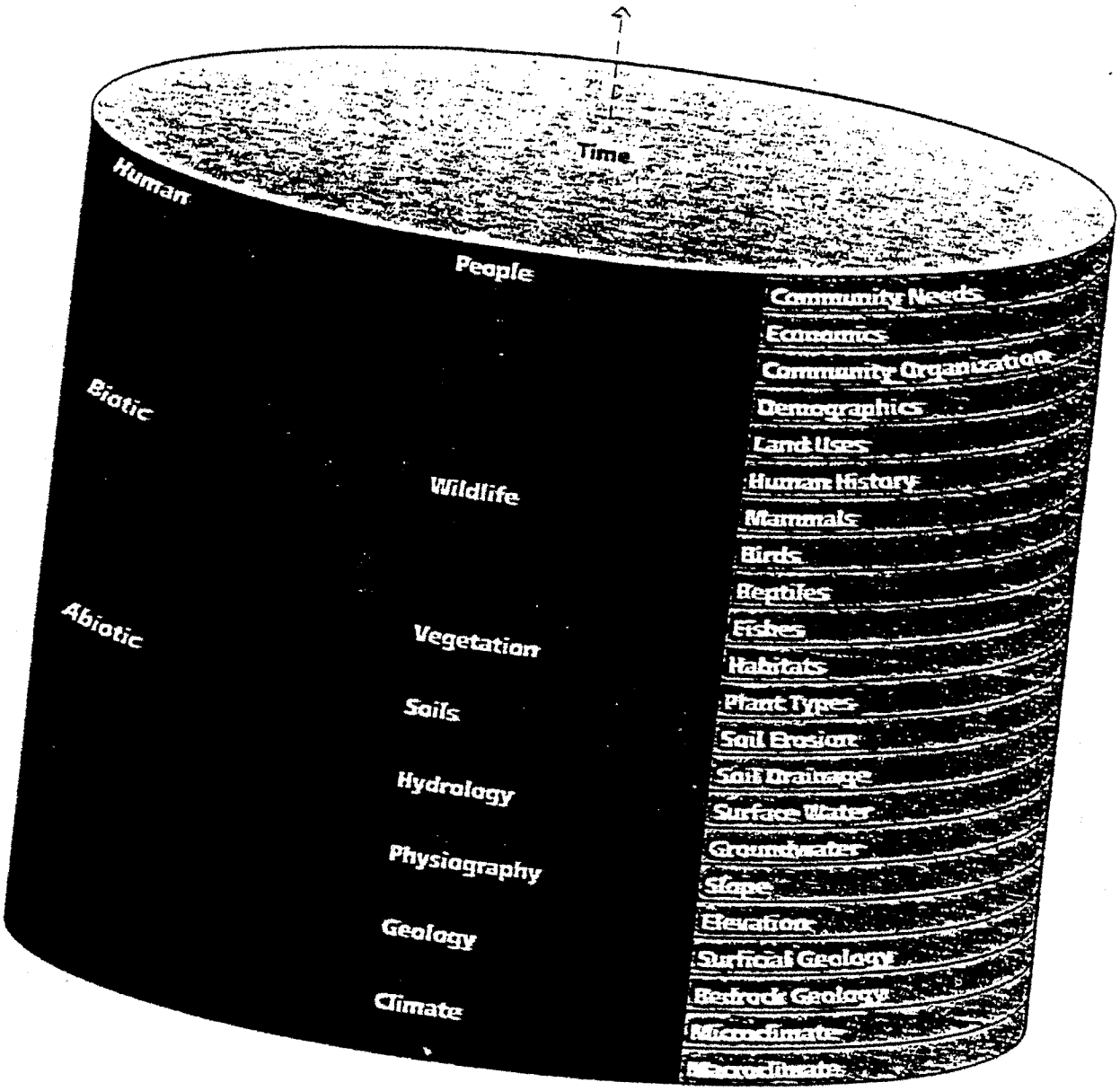

Figure 1

Layer Cake

STUDY SITE

Precipitation varies greatly in the Southwest with dramatic implications for landscapes and land uses. According to Satterlund and Adams,

> "precipitation varies sharply with elevation, ranging mostly between 10 and 100 cm yearly. The seasonal pattern of distribution in Arizona, southern Utah, and western New Mexico is one of prolonged, gentle winter rain or snow (depending on elevation), a very dry spring, intense local summer storms, and moderate drought in the fall. Snow may be very important in the closed forest zones of the upper elevations" (1992, p. 9).

The Navajo, a matriarchal society, have, according to Barbara Kingsolver (1995), names for these precipitation patterns. The loud and sometimes violent summer storms are called the "male rains." The more gentle and valuable winter precipitation is referred to as the "female rains." Climate has helped shape the upper San Pedro watershed. The study area is part of the Basin and Range Province, in which the relatively higher elevation of the valley portions create a more moderate climate than other hotter desert regions of Arizona and Sonora. The north-south trending mountain ranges catch precipitation from Pacific weather patterns, producing a steady water supply.

The San Pedro headwaters begin mostly in the Sierra Elenita and the Sierra El Manzanal around the historic mining town of Cananea, Sonora, and flows north (Figure 2). Some of the drainage also begins in the southern Huachuca Mountains, just at the U.S.-Mexico border, flowing south into Sonora, then back north. The upper San Pedro is approximately 50 km from

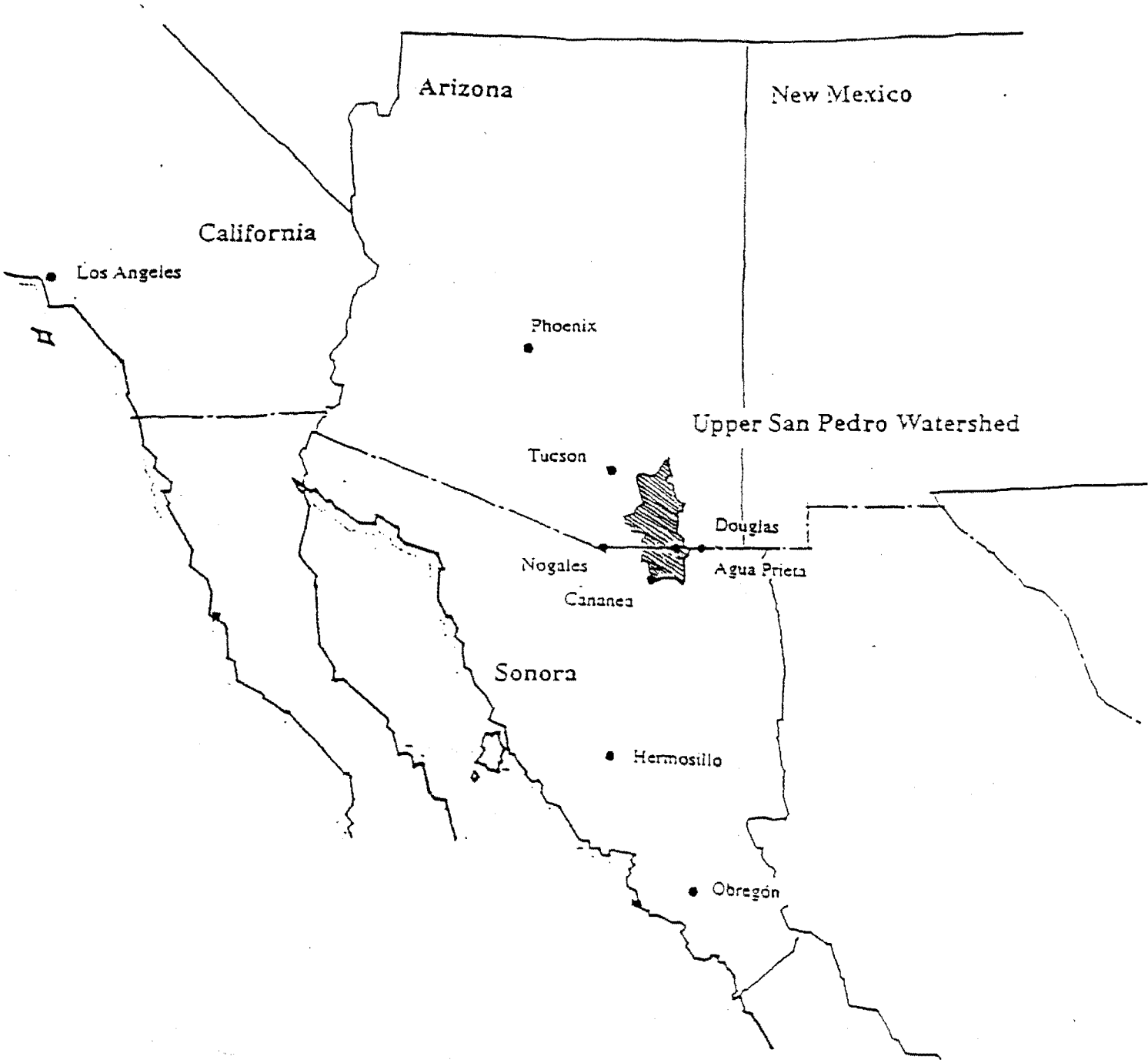

Figure 2

Location of the upper San Pedro basin

east to west and from 150 km north to south. The area drains about 6800 km of which 1800 km^2 lies in Mexico.

The San Pedro flows north between the Huachuca and Mule Mountains. The Spanish explorer Francisco Vázquez de Coronado used these mountains as the northern gateway for his search for the Cities of Gold. Instead, Coronado found a variety of Native Americans living in the valley. These people were well established and, especially the Apache, were strong enough as to prevent significant Spanish and, later, Mexican settlement.

After the Gadsden Purchase in 1853-54, American soldiers, ranchers, and miners entered the valley. In fact, a provision of the Gadsden Purchase Treaty was for the American Army to control the Apache and, thus, protect Mexican settlers.

After the submission of the Apache, the population grew on both sides of the border, especially for mining, ranching, and mining. In the Sonoran portion, *ejidos* were established after the Mexican Revolution. More recently rapid suburbanization and growth has occurred, especially in and around City of Sierra Vista, Arizona. This trend is increasing as tourists and retirees are attracted to the valley because of its beauty and pleasant climate.

The upper San Pedro watershed, internationally recognized for its biodiversity, represents a transition area between the Sonoran and Chihuahuan Deserts. It supports the second highest known number of mammal species in the world and the riparian corridor provides habitat for more than 300 bird species. The Bureau of Land Management's San Pedro National Riparian Conservation Area and portions of the Coronado National Forest lie within the basin. The watershed has many natural values and functions. However, because of the terrain variation and of ecosystem diversity, some portions of the watershed are more sensitive than others.

PRELIMINARY RESULTS

Environmentally Sensitive Areas

A collection of such baseline information can help identify environmental sensitive areas, which can be defined as "places vulnerable to negative environmental impacts, such as unstable soils, steep slopes, flood plains, wetlands, and certain plant and animal habitats" (Steiner 1991, p. 321). Certain states, such as Washington, local jurisdictions, such as Scottsdale, require the protection of environmentally sensitive areas. The State of Washington protects environmentally sensitive areas through its state environmental policy act provisions. In Washington, city and county governments are encouraged to designate areas as environmentally sensitive. Such areas then are subject to more rigorous environmental review requirements for proposed developments or land-use changes. Meanwhile, Scottsdale defines and regulates "land slopes of 15% or more in the mountains, unstable slopes, special features, water courses, geologic conditions, and native slopes" as environmentally sensitive (City of Scottsdale 1991, p. 4).

These places are Jefferson's "uncultivated lands," where "it is clear that the laws of property" have been extended too far and, thus, "violate natural rights." But instead of the "unemployed poor" such lands are increasingly attracting the retired well-to-do. Another way to view such lands is that they pose some level of risk to human health or safety through settlement. A house in the flood plain may be dangerous. Another way is that it possesses constraints that make settlement more expensive, either to the private individual or the government entity. Still another way is to value these places as the homes for other species who share this planet with us.

Environmentally Sensitive Areas in the San Pedro

Much of the upper San Pedro basin can be considered as environmentally sensitive. Elsewhere in the Southwest, dams have interrupted natural flows, resulting in a significant decline of native flora and fauna. The plants and animals of the San Pedro have survived better than other regions. This watershed is a haven for a variety of wildlife, including endangered or threatened species. Significant protected sites include the San Pedro Riparian National Conservation Area and the Nature Conservancy's Ramsey Canyon Preserve. The Centro Ecologico de Sonora, Mexico, prepared a 1994 management plan proposing the creation of a protected area in the upper reaches of the watershed (Beech et al. 1997).

Although much of the watershed is environmentally sensitive, there are varying degrees of sensitivity. Essentially, there are three main landforms in the watershed: mountains, rangelands, and the riparian corridor. In the past, most attention focused on the riparian corridor, rightfully so, because it is probably the most sensitive. However, the corridor is affected by land uses in the uplands and the range areas. In Arizona, rapid development in and around Sierra Vista in the areas between the mountains and the river corridor threaten to cut off water to the river, while continued copper mining in Cananea affects water quality.

The Protection of Environmentally Sensitive Areas in the San Pedro: Fragmented Plans, Fragmented Landscapes

The protection of environmentally sensitive areas has received increasing attention on both sides of the border. We have studied local general plans and federal land management plans in Arizona. Each of the plans examined to date contain discussions, goals, and/or objectives relating specifically to environmental concerns in and around the San Pedro River area. These

concerns are addressed either in specific environmental sections, or in the land-use component of the plans. Several common environmental "themes" emerge from the plans including:

Surface water and groundwater conservation and preservation.

- Preservation of open space.
- Growth management practices to preserve the environment and "quality of life."
- Protection of the San Pedro River area, while permitting recreation and educational uses and opportunities.
- Inter-jurisdictional cooperation towards environmental goals.
- Protection and development limitations in environmentally sensitive areas.
- Active enforcement of laws and regulations designed to protect environmentally-sensitive areas.

A content analysis of five plans in the San Pedro watershed identifies eleven types of environmentally sensitive areas (Figure 3). The types include: drainage ways, flood plains, groundwater basins, hillsides and steep sloops, natural recharge areas, natural washes, riparian area corridors, scenic vistas, sensitive vegetation habitat corridors, sensitive wildlife corridors, and surface water basins. The Coronado National Forest lists the most areas of concern with eleven, while the City of Sierra Vista leads local jurisdictions by listing eight in their general plan (U.S. Department of Agriculture 1996, City of Sierra Vista 1997). The most commonly included sensitive areas are: wildlife habitat corridors, scenic vistas, and groundwater and surface water basins.

Although the plans note both the importance of inter-jurisdictional cooperation towards environmental goals and of active enforcement of laws and regulations, there is a gap between the

sensitive matrix

Figure 3. ENVIRONMENTALLY SENSITIVE CONCERNS IN GENERAL PLANS, Arizona

	SENSITIVE CONCERNS												
	Drainage ways	Flood plains	Groundwater basins	Hillsides, steepslopes	Natural recharge areas	Natural washes	Riparian areas corridors	Scenic vistas	Sensitive geologic areas	Sensitive natural recreation areas	Sensitive vegetation habitat corridors	Sensitive wildlife habitat corridors	Surface water basins
JURISDICTIONS													
City of Benson	X			X		X	X				X	X	
City of Bisbee	X	X	X										X
City of Douglas	X		X	X				X			X		X
City of Sierra Vista	X	X	X			X		X			X	X	X
Cochise County			X		X			X				X	X
Coronado Natl Forest			X	X	X	X	X	X	X	X	X	X	X
U.S. Dept. Interior			X				X	X	X			X	

Sources:
City of Benson, 1993; City of Bisbee, 1996; City of Douglas, 1993; City of Sierra Vista, 1997; Cochise County, 1996; Coronado National Forest, 1996; U.S. Department of Interior, 1989.

recognition of the issue on the one hand, and inter-jurisdictional cooperation and active enforcement on the other. At least in the United States portion of the watershed, fragmented jurisdiction seems to be leading to a fragmented landscape. A watershed approach could help address this dilemma.

CONCLUSIONS

Following Powell's suggestion, watersheds have continually been promoted as a unit for planning. (See White 1995 and Meine 1997, for example.) Gilbert White has identified "watersheds in thought" related to the use of drainage systems in planning, including

- The distinction between soil class and landscape type as a basis for study, teaching, and administration;
- The distinction between upstream and downstream emphasis in managing water and sediment flows;
- The differentiation of quantities of water and sediment flow from non-point sources affecting quality of water; and
- The contrast between emphasis upon serving individual land managers and larger government organizations as primary managers of natural resources (1995, 2).

Increasingly, watershed planning is emphasizing landscape features, downstream consequences, and non-point sources of pollution. Larger government agencies, such as the U.S. Environmental Protection Agency, are exhibiting a greater interest in watershed planning. In Arizona, the Department of Environmental Quality is promoting watershed management (Arizona Department of Environmental Quality [ADEQ] 1997). ADEQ recognizes that watershed management is a challenge because of the interrelated nature of the environment, the

complex interrelationships between the environment and the economy, and the fragmented nature of many environmental laws (ADEQ 1997). Arizona's approach has "three essential components," which are:

- a common geographic focus
- the coordination of activities with an area
- the encouragement of citizen involvement (ADEQ 1997).

Dixon and Easter (1986, after Easter and Hufschmidt 1985) summarize the rationale for a watershed approach to planning (Table 2). They conceived their rationale primarily for rural development concerns, that is, agriculture, forestry, rangelands, and water resources. However, their list is transferable to urbanizing rural areas, especially those with expansive rangelands like the San Pedro.

A lesson from John Dewey and pragmatism is that philosophy works best when eternal questions are connected to everyday practice. An eternal question facing us is how best to live on earth in a sustaining manner.

NOTES

1. Drainage basin "is synonymous with *watershed* in American usage and with *catchment* in most other countries. The boundary of a drainage basin is known as the *drainage divide* in the United States and as the *watershed* in other countries. Thus the term *watershed* can mean an area or a line. The drainage basin can very in size from that of the Amazon River to one of a few square meters draining into the head of a gully. Any number of drainage basins can be defined in a landscape depending on the location of the drainage outlet on some watercourse" (Dunne and Leopold 1978, p. 495).

Table 2. Summary of rationale for a watershed approach to planning

1. The watershed is a *functional region* established by physical relationships.

2. The watershed approach is logical for evaluating the *biophysical linkages* of upland and downstream activities because within the watershed they are linked through the hydrologic cycle.

3. The watershed approach is *holistic*, which enables planners and managers to consider many facets of resource development.

4. Land-use activities and upland disturbances often result in a chain of *envionmental impacts* that can be readily examined within the watershed context.

5. The watershed approach has a *strong economic logic*. Many of the externalities involved with alternative land-management practices on an individual farm are internalized when the watershed is managed as a unit.

6. The watershed provides a framework for analyzing the effects of *human interactions* with the environment. The environmental impacts within the watershed operate as a feedback loop for changes in the social system.

7. The watershed approach can be *integrated with or be part of programs* including forestry, soil conservation, rural and community development, and farming systems.

Source: Easter and Hufschmidt 1985.

2. The principal investigators for the research include Subhro Guhathakurta, Laurel McSherry, Ignacio San Martin, and me. We are being assisted by a team of Master of Environmental Planning graduate students. Matt Holm and Maria Deeb were especially helpful with helping to provide background information for this paper.

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Wildlife Waters at the Urban-Rural Interface: Problems of Maintenance and Enhancement.

Abstract

Urban sprawl and development within Arizona, as throughout the American West, portend profound changes regarding the way in which wildlife experience water availability and reliability on dry ranges. In states such as Arizona urban-rural interface areas grow exponentially as development invades formerly rural areas; often spurred by globalization effects and technology advances that make it possible for more people to live and work from isolated locations. Consequently, the issue of wildlife waters maintenance and enhancement near large human populations can only become more critical to maintaining sound wildlife populations.

Changes related to urbanization are not all negative since human developments, varying from golf courses to housing, sometimes inject wildlife-useable waters into ranges that once had minimal sources. Such artificial waters offer largely unexploited management opportunities for making them, and their surrounding ranges, more friendly to some species. This work involves legal, public policy, and public relations innovation to make enhancement plausible on a broad front at the urban-rural interface.

Overall, however, wildlife species at the urban-rural fringe face negative impacts from increased human encroachment. These threats include water table depletion that affects natural sources, and problems associated with increased human use around once isolated wildlife waters. Under such circumstances, maintaining viable wildlife populations, especially as regards larger species, will require multi-disciplinary approaches of some sophistication.

This paper seeks to address some of these critical issues in a proactive way. Major needs for wildlife water enhancement and development at the rural-urban interface are 1) management of existing waters for an increased diversity of user needs, 2) relocation and rebuilding of seriously degraded waters away from human use corridors, and 3) construction of new waters as part of open-space initiatives which may involve both private and public landowners.

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reply to
Guntram F. A. Werther, Ph.D.
Werther Consulting International
+1 (800) 516-6738

Introduction: The established pattern of urban sprawl and regional development within the dry ranges of the American Southwest is rapidly transforming what was until the 1970's relatively intact rural wildlife habitat into an expanding patchwork of urban-rural interface zones.[1] Long-time residents of states such as Arizona, New Mexico, and Nevada can recall a plentitude of wide open vistas throughout these states, before the advent of what some Western rural residents call "lights marching up the valley"; golf courses, ranchettes, planned housing developments, retirement villages, and the expanding city limits that continue to encroach upon formerly rural lands.

Ranges unoccupied by these newer forms of human use and habitation are becoming an ever rarer event within the American Southwest, and nowhere is this trend more apparent than in the formerly empty spaces of the Sonoran Desert of Arizona. Volumes have been written describing the trend, little has been done to effectively respond to it, and almost nothing

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1 Defining the urban-rural interface is difficult. Certainly it includes "metro" game management units, but it must also include regions of high human activity within a given distance of urban areas. For working purposes, I consider a region to be within the urban-rural interface if it lies within a 30 minute commute of a standard metropolitan statistical area, or of a commuter community associated with such an area.

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to halt it. Given this reality, and the expectation of continued rapid human population migration to the Southwest, along with greater urbanization of the kind with which we have become familiar, the question of what can be done to retain our wildlife heritage within these expanding urban-rural interface areas must be asked, and then effectively answered.

Social Change and the Art of Wildlife Management:

The modern art of wildlife management is increasingly becoming a matter of effectively integrating social science insights into the techniques and goals of managing wildlife species.[2] Whereas in the eastern and southern United States human-wildlife issues often take the form of wildlife recolonizing longtime urban and suburban areas due to better wildlife protection, in the West and Southwest the issue is more likely to be one of human population expansion into formerly remote rural

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2 See the special issue; Warren, Robert J., editor. "Deer Overabundance". Wildlife Society Bulletin: Perspectives in wildlife conservation and sustainable use. (Vol 25, No. 2). Summer 1997, for an array of articles on urban wildlife management issues.

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areas due to high rates of regional growth.[3] Coupled with the arid nature and open aspect of much Southwestern and Western land, this human migration can be expected to affect resident and migratory wildlife populations differently within these arid lands than has been our experience in more well watered climes.

The expanding urban-rural interface phenomenon within the Southwest is the result of a convergence of multiple social trends, some technological, others behavioral, political, legal, and economic. Thus the issue of maintaining viable wildlife populations on dry ranges within the Southwest is not strictly a traditional wildlife management problem nor even a wildlife water management problem, but rather a human lifestyle issue with which wildlife populations and their water resources are intimately involved. Because of this, retaining many of the larger wildlife species within urban-rural interface areas will require a sustained and sensitive multi-disciplinary approach that makes the best of the reality of high rates of future human movement to formerly remote areas.

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3 See, for example, "Rural Counties Booming: Those in the West growing fastest." Arizona Republic (Friday, March 21, 1997, p. A10). Contr.. See "People vs. wily coyotes: Critters' strong comeback forces U.S. into drastic action." Arizona Republic (Sunday, September 14, 1997, p. A26).

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The trends driving this human migration to remote ranges include innovative information and communications technology uses which, when coupled with more effective transportation systems, makes it possible for increasing numbers of professionals to live in and work from isolated locations. This author, for example, manages a global consultancy from a Saguaro-studded valley in Arizona on the theory that a work commute to Asia, Europe, or Latin America might as well begin there as from the less appealing environs of a New York, Washington D.C., or Los Angeles.

Although a somewhat less travelled species, the telecommuter, can nevertheless still choose to work for a Fortune 500 company or operate a small business from home anywhere in the USA that has a telephone line. Technological capacity places rural lifestyle choices increasingly within the range of people once dependent upon cities.

Given the dysfunctional nature of many of America's urban areas, additional millions of citizens are choosing to relocate to the still fresher lands of the West. Thus, the current rate of technology innovation will cause such lifestyle choices to become increasingly popular, with profound consequences for rural wildlife populations, and their rangeland waters, within preferred states and regions.

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Similarly, America's ever more wealthy retired population is increasingly choosing to surrender the joys of locating the family car under a drift of snow in their native climes for the challenges of improving their vocabulary on the golf links of desert Southwest. Whether as seasonal or permanent migrants, the United States' aging cohort of 'baby boomers' virtually guarantees the continuation of this southward and outward migration of humans; with more golf course and retirement community construction as complementary adjuncts of this trend.

Finally, many American's disaffection with urban society continues to fuel a 'back to nature' ethic that makes living closer to wildlands and wildlife a desirable, if increasingly self-defeating, goal for millions of people. This philosophy-driven lifestyle movement of humans into prime wildlife habitat is an increasingly grave wildlife management problem, and a firm demographic reality without apparent end.[4]

Unless we believe that any of these trends in human social and lifestyle choice are going to reverse themselves soon, it follows that

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[4] See for example, Clifford, Hal and David Stalling. "Colorado: Crucible of Elk Country."; and also Hoeker, Steve. "Human Population Growth: Striking at the Root." in Bugle - The Rocky Mountain Elk Foundation (August - October 1997).

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wildlife populations and the water resources they depend upon are going to experience increasing challenges associated with the continued expansion of the urban-rural interface. In part, this means that wildlife populations will face profound changes in the way they experience water availability and reliability on dry ranges, and that wildlife management agencies will increasingly confront an array of social, political, and legal issues that are not typical of their traditional agency orientation.

Before launching into an examination of some of those changes and their possible rangeland water development challenges for wildlife managers, it seems proper to say that what many people may prefer to have happen is barely at issue; these are global trends[5]. My ranching neighbor preferred our valley when there was only he and his cattle, as I was pleased with 'only' a scattered dozen neighbors among the desert deer herds and cattle. We all valued the long view, which is partly why we came. My newer neighbors are satisfied with 'only' a few hundred other neighbors, less scattered now, as those migrants who follow will find

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5 See, for example, Pool, Sola. 1990. Technologies Without Boundaries. Cambridge: Harvard University Press; Naisbitt, John. 1996. Megatrends Asia. New York: Simon and Schuster; Barber, Benjamin. 1995. Jihad vs. McWorld. New York: Random House; or Drucker, Peter. 1989. The New Realities. New York: Simon and Schuster, among many others.

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this valley ever so much better than the 'crowded' place they fled. The current prognosis for my valley is a tenfold population increase by decade's end to perhaps 25,000 people in the surrounding areas. [6]

This process typifies the dynamic of urban sprawl; many millions of individual choices, all aimed at rational lifestyle improvement, take place within our changing system of law, which itself operates within a rapidly changing environment of ethical, moral, and societal preferences.

Accepting the perspective of many rational individuals choosing independently within a rapidly changing global environment is critical to understanding the nature of the problem facing wildlife and land resource managers in the future. From what we can see, in that future governments will have more the illusion of control, rather than actual social control.[7] Thus, managers will need to deal much more frequently with issues of societal flux, structural ambiguity, and ever changing management challenges that are not particularly malleable to traditional solutions. Within such a world, unless one is willing and capable of overturning much

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6 Arizona Republic, August 10, 1997.

7 Werther, Guntram. "Doing Business in the New World Disorder." Competitive Intelligence Review (forthcoming).

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of what American's value in their society, then both the wildlife and water management question rapidly becomes one of adapting to local and global societal change in order to retain the wildlife heritage that we yet have.

As I see it, for the professional natural resource manager the task is one of fruitful adaptation to societal mega-trends, rather than 'slashing at the waves' of an incoming human tide with new regulations, old practices, and the force of government. Within the Southwest, this means, in part, effectively managing water resources at the urban-rural interface for wildlife by gaining the active support and cooperation of new residents whose non-traditional values are changing traditional wildlife habitats and management agendas.[8]

Since we will be managing an ever increasing proportion of our wildlife resources in close proximity to urban, or near-urban communities, attempting to manage wildlife populations within the

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8 Conover, Michael R. "Wildlife management by metropolitan residents in the United States: practices, perceptions, costs, and values." Wildlife Society Bulletin (Vol. 25, No. 2) Summer 1997. pp 298-305; Baker, Susan and Johanna Fritsch. "New Territory for Deer Management: human conflicts on the suburban frontier." Wildlife Society Bulletin. (Vol. 25, No. 2) Summer 1997. pp. 404-407.

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social, legal, and political constraints offered by these rural-urban interface environments becomes the task; a community and management goal is not without negative consequences.

The proximity of wildlife to urban human populations, particularly large species, presents certain discomforts and challenges[9]. For example, in Israel, the preferred food of leopards within urban-rural interface areas is domestic house cats. In this country, an entire industry has developed responding to wildlife-human interaction problems; deer in the gardenias, raccoons in the attic, javelina under the porch, etc.

Changes in Rangeland Water Use at the Urban-Rural Interface:

Western rangeland waters, whether natural or man-made developments, traditionally serviced wildlife, natural resource-based commercial interests such as ranching, and traditional recreational users such as fisherman, hunters, birdwatchers, and hikers. Typical traditional

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9 For a particularly poignant display of frustration at the experience of dealing with urban residents and which has application to other topics, see Kirkpatrick, Jay and John W. Turner, Jr. "Urban deer contraception: the seven stages of grief." Wildlife Society Bulletin. (Vol. 25. No. 2) Summer 1997. pp. 515-519.

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water development projects therefore focussed on livestock and wildlife watering sites, and recreational facilities such as fishing lakes; that is their history. Placement of these waters did not need to take much cognisance of global and societal dynamics since historically relatively few people from well known groups visited the water sites for short periods, and then left.

In rural locations, conflict over the use of such traditional rangeland water resources also usually involved a fairly limited set of policy actors that are well acquainted with each other, and therefore with their respective needs. Indeed, land and wildlife management agencies recruited personnel from within those communities, and thus shared a 'corporate' culture. Among managers and users an ethic of accommodation is commonly practiced which minimizes conflict through at least a degree of mutual respect for the other party's interests.

For example, a land management agency may develop a livestock watering site which all parties understand will have defacto wildlife and recreation benefits. Throughout the year, such a rural livestock water development receives sporadic use by hunters and other recreationists who will generally understand the ethic (and law) of not camping within

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1/4 mile of the water, and of not harassing livestock. They understand and accept the presence of the livestock.

Since traditional recreationists in rural regions often seek "wilderness" or at least remote wildland experiences, they exhibit self-regulated dispersing behavior. Hunters disperse to decrease competition during the chase while many hikers, birdwatchers, and backpackers do so to gain solitude. The cumulative effect of this type of behavior is that many rural wildlife waters have relatively infrequent human presence, and it is this relative isolation and distance from constant human presence that makes them useable to many wildlife species and to livestock.

At the rural-urban fringe, not only do these understandings and forms of mutual accommodations frequently break down, but sometimes because of the new user's ignorance or non-acceptance of traditional values, a clash with traditional user's agendas occurs.[10] Within the arid Southwest, this behavior change when new users appear in rural areas is particularly critical since the volume and type of human use of the small-

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10 See particularly, Messmer, Terry A., Louis Cornicelli, Daniel J. Decker, and David G. Hewitt. "Stakeholder acceptance of urban deer management techniques." Wildlife Society Bulletin. (Vol. 25, No. 2) Summer 1997. pp. 360-366.

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sized waters (tinajas, livestock tanks, seeps, and springs) typical of dry ranges may increase to the point of degrading the resources value for wildlife and livestock. Put bluntly, the people can easily degrade desert waters much more easily than they can affect larger bodies in moister climes, while being just as insensitive to traditional wildlife management techniques and concerns.

This observation immediately points to the major issues for future water development and management at the urban-rural fringe. Here the management focus is primarily for accommodating an increased diversity of needs and preferences on the relatively small and fragile sites typical of desert waters. Second, water placement issues become more important as both societal and technical wildlife management tools. Within arid lands, the strategic placement of water resources is a technique for moving people to wildlife or moving wildlife away from people; as the local situation may demand. Given the conflicts inherent when wildlife and people exist in close proximity, this should be a major focus of future efforts in arid land water development. Finally, water development at the rural-urban fringe must become an integral part of 'open space' initiatives which seek to maintain a modicum of natural space within urbanizing

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environments. Much of the work needed here involves private lands, local communities, and reflects the desires of people for particular lifestyle experiences.

A Case Among Many: Human Use and Wildlife Water at an Urban-Rural Interface within Arizona.

A series of formerly isolated natural wildlife and cattle watering tanks (tinajas) and one developed 'tank' within the Superstition Mountains foothills received perhaps one or two recreation visits per week in 1990. These sites exist on very dry Lower Sonoran desert ranges and are the primary water sources for several herds of desert mule deer, javelina, and associated wildlife. By 1996, residential and commercial growth, with attendant recreation use changes in the area, had increased visitation to between 80-100 people per day on weekends, and 10-20 visits weekdays at the popular upper tinaja site during the peak months of October through May. At the less visited lower tinaja group, recreation visits increased to approximately 30 per week, with visits to a man-made tank still rare. Together, the tanks show a >50 fold increase in use over six years.

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Visitor volume at all sites is expected to increase steadily into the future when a planned hiking/biking trail will transverse the area to connect an existing state park with a popular Forest Service hiking trail system, and as area recreation use increases amid further urbanization. Should this occur, volume along may render the site marginal for area wildlife.

However, the type and duration of user use has also changed dramatically and will continue to do so in the future, and this has a much greater impact on wildlife access to these critical desert waters. In 1990, typical recreationists were very occasional hunters (seasonally), occasional horseback riders, and local resident hikers visiting a particularly fine set of Native American petroglyphs overlooking the upper tinajas. The lower tinajas received mainly sparse hunter and even rarer horseback rider visits. Between 1990-94, I never saw day-long use or camping at either tinaja group.

By 1995-7, the upper tinaja group saw more frequent commercial horseback visits as recreation user demand increased for this service. Hiker use shifted from mainly locals in 1990 to predominantly commercial and non-commercial tour groups, high school outings, plus non-local

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backpackers and day hikers drawn to the petroglyphs by Arizona-wide media reports. Illegal camping within 1/4 mile of, and usually at, the upper tinajas became frequent. By 1996, human use at the upper tinaja series had became virtually day-long, and often nightlong (illegally), during peak season weekends.

A main point is that the behavior of the new user groups is radically different from that of traditional users, showing in general a more casual attitude toward use of the area's water resources, less awareness of its rare and critical nature to area wildlife, and less knowledge of and respect for other area water users.

The nature of the encroaching urbanized housing developments, including the building of backyard swimming pools adjacent to wild lands and other conspicuous displays of water use (artificial waterfalls and fountains, golf courses, etc) clearly show the urban-derived values of many newer residents. As the golf course and country club set replaces rurally-oriented residents, as mini-ranchettes replace ranches, and as urban-favored recreational pursuits displace traditional rural activities, a fundamental values shift in local water use occurs. Water takes on a conspicuous-display value uncommon in rural communities, and a kind of

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water-use narcissism develops. Water's casual use in display and recreation conveys the notion that there is no shortage and that this really isn't a desert; a societal event that transforms desert landscapes.

Coincidentally, these shifting values simultaneously inject new wildlife useable waters into traditionally dry ranges, just when many adjacent historic waters are being degraded by increased human recreation use. In this case, wildlife use actually shifted from high-use recreation sites into select residential areas where there was actually less human activity at most times of the day.

Much of what occurs at interface areas such as this in terms of wildlife management is untested ground. What is unambiguously illustrative in this particular case however is the scope of new demands on a formerly isolated series of natural (tinajas) and developed water sources when they recede into the urban-rural interface zone through the immigration of homeowners and urban-based recreationists. Extrapolating into the future, it seems plausible that some key wildlife populations in this and similar areas would decline or be eliminated as urbanization makes residential sites inhospitable just as traditional sites become unusable.

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Mitigating changes in water location probably need to be made in order to retain wildland populations. The importation of water onto formerly dry areas by development can become this mitigation tool, especially at the intersection of developments and surrounding wildlands.

Some Possible Water Development Responses to the Challenge of Urban-Rural Interface Issues:

Historically, trail and road locations throughout the Southwest specifically were directed toward both natural and developed water sources, in effect connecting the region through a series of water to water transportation systems. There were very functional reasons for this; sparse human populations were concerned with survival and ease of earning a living from the land within the dry ranges of the Southwest. Therefore, transport systems were constructed to maximize ease in getting to water.

New residents at the urban-rural interface have no such orientation to the land. Under the conditions of intense human activity characteristic of urban-rural interface recreational water use within the arid

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Southwest, a transportation system oriented to connecting remote waters becomes dysfunctional for maintaining livestock and wildlife values in the region. This is because the transportation web focusses intense human use precisely on those critically scarce water resources needed by livestock and wildlife, especially during times of stress. Thus one can argue that a principal task of future wildlife/livestock water development in such areas must be to develop remote waters to replace traditional sources unduly challenged by intense human use. Where existing trails and roads cannot be routed away from such primary wildlife/livestock water sources, an excellent case can be made for developing supplementary waters in areas well away from highly travelled roads and trails as a way of mitigating the adverse impact of high intensity human use in the area.

This policy response becomes especially necessary when other, perhaps highly unique, recreation values attract human visitors to a particular water resource in large numbers. It can also serve to mitigate wildlife/human conflicts in problem areas by attracting wildlife to remote locations away from human populations.

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Next, the changed nature of human values in urban-rural interface zones suggest another future water development focus. Where traditional waters face increased use from more urban-oriented individuals, the latter's far more diverse range of interests and uses for scarce desert waters tends to drive out traditional users; the place becomes essentially suburban and then sprawl continues outward. Consequently, to even have a chance of maintaining wildlife and livestock use on these dry ranges over the long-term, existing users had better become integrated into the changing reality of the area. From this perspective, select existing waters might be enhanced as part of an open space initiative that also accommodates the desires of newer users; bird watchers, photographers, land developers, and so forth. The thinking here is that a raw cattle tank, which is typically just a scrape in an arroyo blocked by an earthen damn, has little support from urbanites who might rather live without the presence of livestock on ranges near their homes. But a water development enhanced to better support multiple uses (which can include livestock use) within an open space initiative develops a broader supporting clientele within the local community, changes the character of the community, and can increase property values to surrounding residents. Forming interest

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groups which prefer a mix of rural, suburban, and urban development (ie. retaining significant open space). This is already occurring within the Superstition Mountains, where a local land developer has supported an open space initiative on two sections of State Trust Lands located between the development and the Tonto National Forest. His reasoning is that the open space will increase the value of existing residential developments. The trick now is to include wildlife management considerations into the evolving uses of this land and community.

The alternative to such accommodation and cooperation is the unbridled sprawl with which Westerners have become familiar, and the further degradation of wildlife resources.

Public Policy and Wildlife Water Enhancement:

To accomplish such a transformation of water and land use at the urban fringe, some legal and public policy changes are necessary. Current federal legislative proposals promising to exclude working farms and ranches within 50 miles of urban areas from confiscatory federal estate taxes are a promising start. Giving farm and ranch families a chance to

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keep their business past the current owner's death seems a reasonable public policy target for curtailing urban sprawl, and one onto which wildlife managers need to coat-tail their rangeland water development efforts and wildlife management goals.

Through additional legal and policy initiatives, we might prevail upon private landowners to develop or enhance wildlife-useable waters on their properties. Such a focus is becoming critical throughout the formerly wide open spaces of the West, where wildlife wintering ranges often exist on private lands which are now subject to great development pressures. Within some states, landowners can already declare portions of their lands as private wildlife preserves in exchange for limited tax relief. Such an approach holds great promise for a non-confrontational brand of wildlife waters and wildlife habitat enhancement throughout the West.

Within Arizona, State Trust Land must currently be sold at its highest value to fund education. At the urban-rural interface the highest value for select parcels, if measured more intelligently, might be in maintaining some high quality open space within developing communities. This is particularly true for the largely undevelopable arroyos and their

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neighboring bajadas, which support the bulk of wildlife and livestock grazing within the Southwest and are virtually useless for residential development.

Current land development practice is to channel these arroyos, but a better practice might be to develop multi-use wildlife waters within or near arroyos while retaining them, plus some select adjacent lands as open space and/or recreation lands for surrounding communities. Since several current land use planning initiatives are already tending toward such public policy solutions, the economics and public policy implications of such changes need to be closely examined.

In speaking of these possibilities, I want to make it clear that what will bring about desirable results is more likely a program of cooperative persuasion rather than force. Developers can be persuaded to market wildlife friendly enterprises, and to charge a premium for the privilege of living near intact game populations. Towns and counties can be persuaded of the tourist and lifestyle benefits of wildlife friendly growth. This brings us to the future of wildlife and rangeland water management within the urbanizing West.

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Private Wildlife Water Enhancement as a Management Frontier:

Traditionally, the focus of Western wildlife management and water management policy has centered on the management of public and state trust lands. However, throughout the West some of the finest wildlife habitat remaining is on private lands. For private land owners who choose to do so, enhancement of existing and/or development of new waters to enhance wildlife values remains a largely unexplored topic. Here there exist massive legal and public policy problems.

As just one example, many private landowners within the species-rich Southwest do not improve their lands for wildlife values out of fear of attracting (or keeping) an endangered species, and thus attracting the attention of organizations and groups devoted to the species' preservation. Since the current practical impact of having an endangered species on one's land is to weaken private property rights in development and use, it is no surprise that rational landowners avoid the problem. While the topic is complex, the current policy is clearly dysfunctional when private landowners rationally choose not to enhance land and wildlife values out of fear of future regulatory pain. Perhaps artificially enhanced wildlife

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waters ought to carry a negotiated regulatory exclusion with respect to certain aspects of endangered species issues.

The challenge of private land development of wildlife useable waters at the urban-rural interface provides, in my opinion, the greatest opportunity for maintaining vibrant wildlife populations within the dry ranges of the American Southwest, and it is therefore this focus that thoughtful academics and practitioners ought to pursue with vigor.

The summary result of this brief discussion has been, I hope, to channel thought and inquiry away from traditional rangeland water management issues toward the new frontier of the urbanizing West; the rural-urban interface zones that continue to define the character of the Western landscape and social experience. There is every reason to believe that arid land development is a special case of the urbanization and suburbanization trend sweeping America, and that without a thoughtful approach to retaining critical resources such as useable wildlife water within the urban-rural interface, much wildlife will be irreparably lost.

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TECHNICAL AND DESIGN ISSUES RELATED TO RANGELAND WATER DEVELOPMENTS

Rangeland Restoration Utilizing Mobile Solar Powered Livestock Watering Systems

David Chamberlain and Sidney N. Clouston, Jr.

Abstract - In order to mitigate the impact of riparian livestock grazing on public lands, the federal government proposes to order widespread grazing cutbacks. Such large reductions of livestock will severely impact the profitability of ranching operation and may not achieve the desired riparian improvement. In addition, the construction of riparian corridor fencing has been suggested to provide livestock control and more management flexibility to achieve many riparian zone improvement goals. However fences are expensive to build and maintain and can impede recreational use of these areas. Popular opinion views fencing as being inconsistent with the natural visual appeal of riparian zones. The use of socially acceptable and relatively low cost alternative method of reducing livestock impacts on riparian zones is needed if ranching operations are to remain viable into the future. The Solar powered livestock watering system may add considerably to improve livestock management, grazing and riparian zone conditions.

Historic research and experience has shown that stock water developments do divert livestock use from riparian zones and improves grazing distribution in addition to forage management flexibility. Recently, research indicates that stock water tanks placed near streams will divert up to eighty percent of the cows in streams during the winter feeding period. To demonstrate and evaluate the effectiveness and practicality of an off-stream water source in diverting live-stock from the riparian zone, a mobile solar powered livestock pumping system constructed on a trailer, along with a temporary electric fence was installed in eastern Oregon. The system was installed at strategic locations on creeks in a cooperating rancher's pasture. The watering system and electric fence were moved along with the cattle through each successive pasture sector during May through October of 1994, 1995 and 1996. It was shown that the system does actually divert the cattle use away from the riparian zone. This is especially important where spawning conditions of endangered species of fish such as listed trout and salmon could benefit by this procedure. In conjunction with using strategically located temporary electric fencing, the off-stream water has proven very effective in protecting areas that have historically been heavily used by cattle. At several sites, with the water system and electric fence in place, the rancher's labor costs have been significantly reduced. Details of the system along with estimated costs will be discussed.

*David Chamberlain is the Harney County Agent for the Oregon State University Extension Service.

**Sidney Clouston is a Consultant with Clouston Energy Research in Beaverton, Oregon.

Introduction

There are many reasons in science, for the conservation and enhancement of the landscape from the upland forested zones on down to the top soil of lower valley floors. In the Pacific Northwest, a myriad of geographic and hydrological features exist that expresses the interrelation of the ecology in the region, transcending man made boundaries. Unique to the region, a four state council was established by the Congress of the United States. The Northwest Power Act was passed in 1980. "The Council is an interstate compact. Its members are appointed by the Governors of the Northwest states. The Council is not a federal agency. Its program is developed under the Northwest Power Act, not the National Environmental Policy Act nor the Endangered Species Act. However, most of the program's specific measures are implemented by federal agencies."(1). This group known as the Northwest Power Planning Council has two divisions, a power and a fish and wildlife division. Because of the Hydroelectric dams, a mitigation program was developed. The Columbia River Basin Fish and Wildlife Program contains the approved measures that are implemented. The council adopted its first Columbia River Basin Fish and Wildlife Program in 1982 and the latest revision of 1994 supersedes previous versions. "The Northwest Power Act directed the Council to develop the program and make periodic major revisions by first requesting recommendations from the region's federal and state fish and wildlife agencies, appropriate Indian tribes (those within the basin) and other interested parties. These recommendations are to include measures that Bonneville and other federal agencies can implement to protect, mitigate and enhance fish and wildlife affected by hydroelectric dams in a way designed to protect, mitigate and enhance fish and wildlife, and coordination of fish and wildlife management, research and development (including funding)."(1)

Expanded Focus

"The endangered species listings for Snake River salmon dramatically underscored the need to make preserving diversity of salmon runs a higher priority. This renewed focus also affected the Council's own role. Previously, the Council's fish and wildlife program had addressed primarily the effects of the hydropower system on salmon and steelhead. With the endangered species listings, it became clear that a realistic recovery effort had to be broader, involving all river users: power production, flood control, agriculture, navigation, water supply, recreation, land development practices and fishing. When the Northwest Governors, Congressional delegation and the National Marine Fisheries Service looked to the Council to product a comprehensive recovery plan, they also asked the Council to assume this broader role. The Council has done so. It developed an integrated plan that seeks contributions from all river users." (1)

Water Rights Maintained

The Northwest Power Planning council and the Bonneville Power Administration are affected by a treaty with Canada's government. From this source of water and sources in the states of Washington, Oregon Idaho and as far away as Montana a water budget is created. The past two years in Oregon record rain fall and huge snow pack has stressed the flood control aspect of the dams in the region. There are discussions about "breaching" several of the Snake River dams and draw down of the John Day Dam in Oregon as being ways to restore endangered species of fish by faster river flows. "Congress and the Council recognize that this program must be implemented within a complex scheme for allocating rights to use Columbia River Basin water. As noted in the Northwest Power Act, and in of this program, nothing in this program authorizes appropriations of water, affects rights to water or jurisdictions over water, or establishes the respective rights to water of the federal government, individual states, Indian tribes or individuals. The Council assumes that the federal implementing agencies will work hard to develop cooperative and creative ways to implement the program's water flow measures with those requirements in mind."(1)

Concern over the water diversion of the water resource has prompted Bonneville Power Administration to fund several fish screen construction shops in the several states. That is because of the water rights for irrigation and stock watering that can adversely affect the endangered species of anadromous fish as well as resident fish and wildlife mitigation requirements. Larger fish screen designs from the Bureau of Reclamation and smaller diversion screen by the shops in the member states and the private sector offerings have helped the program greatly. However much work is yet to be done. The program has not achieved all of the desired results to date.

In this complex environment the resource of life giving water and its quality as well as quantity for so many of the mentioned uses requires a focused examination. The analysis of the development of upland, Rangeland and riparian zone improvement by efficient use of this resource with the policy tools and an enabling technology will be discussed presently.

The Forest Service And Bureau Of Land Management Policy Support

Uplands

The proposed salvage timber removal from wildfire sites and controlled burns can benefit the forests health. In addition, commercial thinning programs is widely thought to benefit the forest health. There can be both economic and social benefit as well due to the above mentioned programs. Because of the damage of those wildfires that affect upland forested riparian zone or other activities close to the streams, great concern has been expressed regarding that and how it affects the spawning condition of endangered species of fish and/or wildlife refuge. "The streamside forest functions as a SOURCE when it provides energy to streams in the form of dissolved carbon compounds and particulate organic detritus. These materials are critical to processes within the stream itself, helping to restore and maintain nature's equilibrium. In small, well-shaded upland streams, as much as 75% of the organic food base may be supplied by dissolved organic compounds of detritus such as fruit, limbs, leaves and insects that fall from the forest canopy. Benthic detritivores (the stream bottom bacteria, fungi and invertebrates that feed on the detritus) form the basis of the aquatic food chain. They pass on this energy when they are, in turn consumed by larger Benthic fauna and eventually by fish. Thus the streamside forest functions as an important energy source for the entire aquatic food chain from headwaters to estuary."(2) Thus mitigation and restoration ought to be focused on the forested riparian buffer zones to no only reduce erosion or green house gas, but the health of stream and aquatic life. The quality of water will be positively affected. A significant quantity of water can be collected from mist vapor that condense into drops of water that fall off of the tree needles, thus contributing to the trees own needs. In addition, the forested riparian buffer lowers stream temperature, which is preferred by the fish and reduces evaporative loss.

Rangeland

In Oregon, the high desert supports Rangeland grazing. The area near Burns, Oregon gets as much solar energy as Dallas, Texas. Stream and river drainage feed into the Snake River in a circuitous route to the Columbia River and out to the Pacific Ocean. Many private cattle ranches are there and grazing on Public Rangeland occurs. This area is a part of the vast Western Rangeland. "Domestic livestock grazing is permitted on almost 307 million acres of federal land in 11 contiguous western states. This grazing affects approximately 159 million acres of land administered by the U.S. Bureau of Land Management (BLM) and 132 million acres administrated by the Forest Service (FS). Grazing also occurs on nearly 212 million acres of private land. Overgrazing by domestic livestock has damaged riparian and stream ecosystems throughout the nation. Problems from overgrazing are particularly acute in the West, where lush vegetation is confined to stream corridors. Livestock tend to concentrate in these areas, especially in the hot seasons, where they can overgraze and damage habitat." (3)

The need for Rangeland improvement by livestock grazing management has have extensive review by the U.S. Department of Interior. It has been suggested that Rangeland improvements ought to be the responsibility of the FS and BLM before any grazing unit fee increase. All of this requires not only water development on Rangeland, but mindfulness of conservation of this valuable resource in every opportunity.

Riparian Zones And Cost Share Opportunity

Mitigation programs as in the case of Bonneville Power Administration ought to have a policy for Rangeland and Forest Riparian Buffer Zone enhancement. The Northwest Power Planning Council's decision to promote the "duel-purpose project" which it favors for that which helps both fish and wildlife. An example could be a duel benefit of a mitigation project that established a forested riparian buffer zone in a wildfire decimated area. This would benefit wildlife and water quality for spawning conditions in many locations. Another could be electrical energy resource entities compensation for the carbon emission by tree planting in a fish and wildlife mitigation project that is a benefit to this region and globally. "Wetland Mitigation Banking" can be a dual purpose project that Bonneville funds when it benefits wildlife and provides feeding sites for improved development of salmon before they return to the ocean.

Approved Measures For Possible Funding

Cooperative actions are encouraged by the Northwest Power Planning council. Section 7 of the Columbia River Basin Fish and Wildlife Program is titled "Coordinated Salmon Production And Habitat". Within that section the Council advises Bonneville to fund the measures if ranked high enough in funding cycle. 7.8A Land Management U.S. Forest Service (Regions 1, 4 and 6) and Bureau of Land Management (Idaho and Oregon/Washington Offices) Subsection 7.8A.2 "In streams where either water quality objective or federal land management plan objective for fish habitat and water quality are not being met, initiate actions needed for recovery. Through the Columbia river Basin assessment and Eastside and Upper Columbia River Environmental Impact Statements, identify fish restoration measures and forest health concerns, and develop strategies to enhance the aquatic habitats for the production of salmon and steelhead. Special attention should be given to insect infestation as it relates to catastrophic fire danger that may threaten salmon and steelhead habitat. 7.8.A.3 Review and, as necessary, amend existing land management plans to incorporate the Council's habitat goal, policies and objectives. In the immediate future, evaluate and develop a range of alternatives that display PACFISH riparian management objectives through the Eastside and Upper Columbia River Basin Environmental Impact Statement. 7.8.A.4 As a condition for ratepayer funding of habitat protection or improvement projects on federal lands, demonstrate that federal land management activities are consistent with and, therefore, will not undermine the benefits of any project implemented through this program. 7.8.A.5 Continue to improve livestock management by developing, updating and implementing livestock management plans. Provide adequate staff and funding to monitor and supervise all livestock permits in salmon and steelhead production areas consistent with the Council's habitat goal, policies and objectives and to address enhancement of riparian areas and compliance with state water quality standards and best management practices. * Through the Eastside and Upper Columbia River Basin Environmental Impact Statements, incorporate PACFISH riparian management objective, standards and guides, and riparian habitat conservation strategies into livestock management plans."(1) Thus a mandate with possible funding in cost share projects. These may be inherently dual-purpose or multi-purpose. Best management practice suggest that economic and social considerations be given. Considering these aspect can create opportunities for improved "leverage of money" in social and economic goals.

Eastside Draft Environmental Impact Statement

"Several overarching factors were considered in the identification of the Preferred Alternative. Alternative 4 aggressively reduces the risks of wildfires to life, property, and resource values. In addition, it actively addresses other issues, such as deteriorating fish and aquatic habitat, road related sedimentation problems, and the spread of noxious weeds. By actively restoring and maintaining ecosystems, this alternative contributes throughout the project area. Sustainable ecosystems result in sustainable communities."(5)

* "Best management practices are a practice or combination of practices that are the most effective and practical means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with state water quality goals. The practically of these efforts should include technological, economic and institutional considerations. The development and evolution of best management practices requires the input of experts on each resource that may be impacted in order that all values are appropriately considered." (1)

In many cases, these projects for replacement, enhancement and mitigation can benefit with the technological advancement in supportive equipment. The Mobile Solar Powered Stock Watering System is one of the supportive equipment that has improved Rangeland grazing conditions and riparian zone restoration.

A Pilot Project Statement

"Riparian zones are essentially the narrow strips of land that border creeks, rivers or other bodies of water. Because of their association with water, riparian zones support unique and biologically diverse plant communities. Although riparian zones account for only about two percent of the land in Eastern Oregon (.05% on BLM lands and 4% on Forest Services lands) they tend to receive disproportionate use by grazing livestock and wildlife. Readily available water, highly palatable forage, shade and relatively level ground make these areas especially attractive." (4)

"Livestock grazing in riparian zones creates the potential for both real and perceived conflicts. Of 2,580 miles of streams on the Malheur National Forest 235 miles have been inventoried as being in undesirable condition. On the BLM Three Rivers Resource area 68 miles out of 84 total miles of streams are listed in undesirable condition. Current emphasis on riparian management and rehabilitation is focused on controlling cattle use in these highly visible areas. Construction of riparian corridor fencing and/or significant reductions of allowed livestock numbers are most often suggested. Large reductions of livestock numbers have a large negative effect on the profitability of ranching operations and may not achieve the desired riparian improvement anyway. Corridor fences do provide the livestock control and management flexibility to achieve many riparian zone improvement goals. However, fences are expensive to build and maintain and can impede recreational use of these areas. Many also find fences inconsistent with the natural visual appeal of riparian zones. the use of socially acceptable and relatively low cost alternative method of reducing livestock impacts on riparian zones is needed if ranching opera-tions are to remain viable into the future. Solar powered livestock watering systems may add considerably to this needed livestock control." (4)

"Historic research and experience has shown that stock water developments do divert livestock use, improving grazing distribution and forage management flexibility. Recent research (Miner, et.al 1992) indicates that stock water tanks placed near streams will divert up to 80% of the cow use of the stream during the winter feeding period. Work ongoing at the University of Nevada (Balliete and Garrett, 1990) and at the Utah Energy Office (Reed, 1989) indicate the potential of solar powered livestock watering systems in terms of costs competitiveness, technical feasibility and field practicality." (4)

Objectives

1. Demonstrate the use of available technology. (i.e. a mobile solar powered livestock water system and temporary electric fence.)

2. Evaluate the practicality and effectiveness of an off stream water source in diverting livestock use from the riparian zone.

3. Take advantage of the educational opportunities generated by the demonstration to deliver programs on riparian habitat and watershed improvement implementation.

Procedure

"A solar powered livestock water pumping system was constructed on a small trailer. The system consists of a solar array of six 33 watt panels wired in parallel and a 12 watt submersible pump."(4)

"The system was installed at strategic location on the creeks in the cooperators pastures wither or without temporary electric fence. The water system and the electric fence were moved along with the cooperator's cattle through each successive pasture during May through October of 1994, 1995 and 1996."(4)

"Specific locations for installing the stockwater system were identified through the ongoing allotment manage-ment (AMP) planning process with the cooperator, BLM and Forest Service personnel. The water system is placed at those sites where the cattle traditionally congregate. The temporary electric fence is used to protect small areas of the riparian area but is also designed to direct cattle movement away from problem areas."(4)

Results

"The system does work and does actually divert cattle use in the riparian zones. In conjunction with strategically located temporary electric fence, the off stream water has proven very effective in protecting riparian areas that have historically been heavily used by cattle. At several sites, having the water system and electric fence in place has reduced the cooperator's labor costs significantly. Because the pastures are very large, (2-3000 acres) and the riparian zones are a very small percentage of the area, it has been standard practice for the cooperator or his employees to ride the riparian areas two or three times each week to move cattle onto the uplands and prevent excessive use of the stream banks. This method has not only been expensive for the rancher, but has also been less than successful at protecting the riparian areas while allowing full use of the pasture."(4)

"In 1993, Sawtooth Creek was rated in unsatisfactory/fair condition with a static to downward trend. Reevaluation in 1996 found Sawtooth Creek to be in satisfactory/good condition with a definite upward trend.

"Even at those sites where a temporary electric fence was not used to protect the riparian area, having clean water available at 50 to 100 yards from the stream diverted a lot of the cow use. As long as the grass was green on the uplands, the majority of the cows stayed on the hillsides and came down only to water and loaf. After the upland grass dried, use of the riparian areas increased, as expected, but the cows still used the water tanks and loafed near the tanks, away from the riparian area. Any use of off site water is use that does not occur in the riparian area."(4)

"Additionally, because these pastures are on public land, BLM and Forest Service and on a major recreational visual corridor, the overall effort and visual improvements have significantly reduced conflicts. Public and agency interest has been very positive. so, not only has the cost to the producer been reduced, the reduction of "hassle" has been a large but unmeasurable benefit to everyone."(4)

Present Developments

A Business Energy Tax Credit is available to Oregonian citizenry for the solar livestock watering system. After a talk with the Oregon Corrections Department regarding trailer manufacturing by prisoners, it was considered to be feasible. In Oregon, as in other states, a mandate to have prisoners work exists. In addition, works are in progress to have at risk youth learn how to assemble the system, provide community service when Juvenile court Judges select the boot camp alternative to hard prison time. The law requires inmates to work in Oregon and in other states. It was suggested to David Chamberlain that the social program for at risk youth be developed. Here, Judge Dale White for an example, could assign some youth that he meets in juvenile court to go to a boot camp to learn to become technical assistants in the program. Within the program for the Rangeland grazing enhancement and the riparian zone enhancement, etc. needs assembly of the trailers with the solar panels, water pumping,, hose, pipes, tank installation, fish screen, landscape work and growing the plants in nurseries.

It is suggested that as in the case of Harney County the state economic development department may provide funding some aspects. The results of social and economic actions will be determined at many levels. Socially, a lower recidivism rate when these technician assistants do not enter the state's corrections system. A lower rate of pain and cost to society is the expected result of lower recidivism."(6)

Irrigation certification can be earned, landscape and Rangeland or forest restoration technical skills can give social and economic benefit to the youth and benefit the citizenry.

The BLM has a program in place for solar powered pumps coordinated by Trent Duncan in Utah. Constructive talks with the Blue Mountain Natural Resource Institute (FS) for collaboration is encouraging.

An active effort to establish Federal, State, Local governments with private sector entities to collaborate in a project, that would qualify for a Department of Justice grant (Weed and Seed program) is spearheaded by Clouston Energy Research, a Beaverton, Oregon company.

Conclusion

Legal, policy and tools for analysis exist and suggest collaborative action can support mission statements of the Forest Service and Bureau of Land Management. Bonneville Power Administration's ratepayer funds can, through cost sharing, accomplish primary and interrelated secondary goals. Supportive technology employment and the refinement of the system ought to occur. There ought to be an examination of social and economic oppor-tunities in which adaptive management* processes may implement the best management practice. "In other words, the strategy provides for managing the whole and not just fixing the parts."(5)

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* "Adaptive management provides a method that allows managers to proceed in the face of scientific uncertainty. Adaptive management is an explicit commitment to learning while a system is being actively managed." "Learning about ecosystems as we attempt to manage them leads inevitably to the consideration of an adaptive management strategy. Our experience suggests that adaptive management itself must be adapted to meet the needs of an ecosystem level management program. Its fundamental feature remains the commitment to learning as a part of management. We have suggested that this can be facilitated through an explicit learning plan that links goals, questions and actions. Adaptive strategies for the management of ecosystems will be developed even as the concept of ecosystem management is developed."(7)

PUMP CAPACITY

DS-Q-128			
Total Dynamic Head	**Flow Rates**	**Current**	**8 Hours**
FEET	FLOW RATES	AMPS	GPD
0	**3.70**	**1.68**	**1776**
10	**3.55**	**1.68**	**1704**
20	**3.40**	**1.95**	**1632**
30	**3.28**	**2.15**	**1574**
40	**3.16**	**2.59**	**1478**
60	**3.00**	**2.85**	**1440**
70	**2.90**	**3.11**	**1392**
80	**2.84**	**3.38**	**1363**
90	**2.78**	**3.63**	**1334**
100	**2.70**	**3.88**	**1296**

Non shaded areas = two 40 watt wired in series.
Shaded area a 60 and 70 feet = two 60 watt wired in series.
Shaded area at 80-100 feet = four 40 watt wired two parellel strings of two in series.

NOTE: Outputs will very according to area sun insolation, panel current, and system voltage.

ESTIMATED COSTS

Pump (Solar jack SDS-Q-128)	$ 795.00
Controler (Solarjack PB-10-28H)	195.00
Solar Panels (ARCO 16-2000) 6 @ $169	1014.00
Hardware, Plumbing & Wiring	240.00
Trailer (Used)	100.00
Hose Reel (Used)	100.00
Hose (300 ft. @ .40/ft.)	120.00
Water Troughs 2 @ $190	380.00
TOTAL	$2944.00

TOTAL	$2944.00

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4. U.S.D.A./Oregon State University Extension Service. 1997 David Chamberlain, Harney County, Oregon. Mobile Solar Powered Livestock Water Riparian enhancement Demonstration. p.1-2.

5. U.S.D.S.A-Forest Service and U.S.D.I.-Bureau of Land Management. 1997 Eastside Draft Environmental Impact Statement. Preferred Alternative. p.2.

6. Clouston Energy Research 1997 Comments To The Eastside Draft Environmental Impact Statement. p.2.

7. Willis e. McConnaha and Peter J. Paquet. 1996 Adaptive Strategies for the Management of Ecosystems: The Columbia River Experience p.412, 420 American Fisheries Society Symposium 16:410-412.

ADDENDIUM

1. Coorespondence from Congressman Bob Smith (Oregon).

2. Letter from the Blue Mountain Natural Resource Institiue's Dr. James McIver.

CHAIRMAN,
COMMITTEE ON RESOURCES

Congress of the United States

September 22, 1997

Mr. Sidney N. Clouston, Jr.
Clouston Energy Research
7846 SW 171st Place
Beaverton, Oregon 97007

Dear Sidney:

Thank you for sending me a copy of your paper entitled Rangeland Restoration Utilizing Mobile Solar Powered Livestock Watering Systems. It is apparent that you and Dave Chamberlain have put a lot of time into this worthwhile study.

It is important to me that we maintain a positive trend in the health of our rangelands and riparian areas. Alternatives to fencing, such as your solar water tanks, can obviously play an important role in riparian management as your study has demonstrated.

I want to thank you, Sidney, for providing me with this valuable information. Please feel free to contact me at my Medford district office if you have additional information regarding livestock watering systems and riparian areas.

Sincerely,

ROBERT F. (BOB) SMITH
Member of Congress

RFS/ljs

ASHINGTON OFFICE
[illegible] Building
[illegible], DC 20515-3702
202 225-6730

BURNS OFFICE
707 Ponderosa Village
Burns, OR 97720-2315

MEDFORD OFFICE
843 East Main S[illegible]
Medford, OR 97504
(541) 776-4646
Toll Free: 800-533-[illegible]

United States Department of Agriculture | Forest Service | Pacific Northwest Research Station | Blue Mountains Natural Resources Institute
1401 Gekeler Lane
La Grande, OR 97850-3399

Reply To: 4000

Date: September 15, 1997

Mr. Sidney N. Couston, Jr.
Clouston Energy Research
7846 S.W. 171st Place
Beaverton, Oregon 97007

Dear Mr. Clouston:

I wanted to thank you for informing us of your plans to combine the development of a desirable technology with work for "at-risk" kids.

The Mobile Solar Powered Pump is indeed state-of-the-art technology for improving the dispersion of cattle over our landscapes out here in the dryland west, and has great potential for management of cattle involving riparian areas. As a matter of fact, we are exploring other techniques that have similar intended results, because we believe that through technology, we can substantially improve cattle management practices. While we are currently experimenting with a hydraulic ram to move water to the uplands, your Solar Pump would work in a similar fashion. It would of course be interesting to compare the two with respect to efficacy and cost.

Your idea of involving "at-risk" kids in the process of using the Solar Pump technology also has great potential. One can think of a metaphor of improving rangeland health through better health for our kids, especially those who happen to fall through the cracks for one reason or another. While we here at the Institute cannot take the lead in such an endeavor, we would be interested in cooperating, primarily through our partners.

Please keep us in the loop with respect to how your plans develop.

Sincerely yours,

James McIver
BMNRI Research
(541) 962-6528

A New Method for Improved Wildlife Access to Livestock Watering Tanks in Southern New Mexico

Sanford D. Schemnitz[1], Carol A. Evans[1] and John T. Moen[2]

Abstract: Steep-sided metal and cement watering tanks are death traps for avian and mammalian wildlife on southwestern rangelands. Members of Southwestern New Mexico Chapter, Quail Unlimited launched a program in cooperation with the Bureau of Land Management to construct concrete access and escape ramps on livestock watering tanks on public rangelands in three counties in southern New Mexico. Details of construction procedures and economic costs are presented, and benefits to wildlife and livestock permittees are discussed. Ranchers have welcomed the addition of the concrete ramps since there is no interference with livestock watering, and contamination of water from decomposing wildlife carcasses is diminished. Low cost ($30) and rapid installation (4 hours) using volunteer sportsmen and non-existent maintenance costs are other desirable features of this improvement to existing rangeland water development.

INTRODUCTION

The water requirements of scaled (*Callipepla squamata*) and Gambel's (*Callipepla gambelii*) quail have been much discussed. No in-depth and detailed studies have been conducted, but several anecdotal reports have been published. Grinnell (1927) first suggested water as a prime factor limiting quail in arid areas, and described lowering of the water table and deterioration of springs due to overuse by livestock.

The necessity of open water for suitable desert quail habitat has been a matter of

[1]Department of Fishery and Wildlife Sciences, New Mexico State University, Las Cruces
[2]New Mexico State Chairman, Quail Unlimited

controversy. Leopold (1959) found scaled quail many miles from water and suggested that birds obtained adequate moisture from greens, succulent fruit and dew. Schemnitz et al. (1997) found green herbaceous matter to be of major importance in the fall and winter diets of scaled quail (4th of 20 top foods eaten) and Gambel's quail (5th of top 20 foods).

Other early biologists noted that Gambel's quail could survive without free water (Vorhies 1928, Leopold 1933, Gorsuch 1934, Lowe 1955). Gullion and Gullion (1964) stated that Gambel's quail in Nevada can maintain normal weight and thrive without drinking water where succulent vegetation and insects are readily available. Brown et al. (1998) summarized existing information on water requirements of Gambel's quail as "a subject of much debate."

The availability of existing water throughout the year can be improved for purposes of increasing wildlife numbers and expanding the use of habitat. Water in dry desert sites is a basic requirement and often the hub of wildlife activity. Such sites should be designed, modified and maintained to be usable for most species of wildlife. Thousands of water tanks are scattered over the Southwestern desert landscape. Although built primarily for the needs of domestic livestock, they can accommodate wildlife with only slight modification.

Bond (1943) first referred to the need for escape of wildlife from stock troughs. His ramps were made of wood or wire mesh and were not durable. Wilson (1977) and Yoakum et al. (1980) summarized recommendations for design and modification of livestock watering development to facilitate safe access by wildlife. They suggested concrete ramps or rock ramps capped by concrete into livestock troughs which can withstand trampling by large ungulates.

METHODS

Ramps can be built and installed rapidly and economically with a small crew of people. Two vehicles are essential to haul the gasoline-operated concrete mixer and the bags of "ready mix" concrete. Four people can work efficiently. Nearby rocks can be collected and piled to form a substrate for the concrete which will fill rock interstices. The ramps are built at an approximate 45-degree angle with a 24-30 inch base gradually tapering to the lip of the tank.

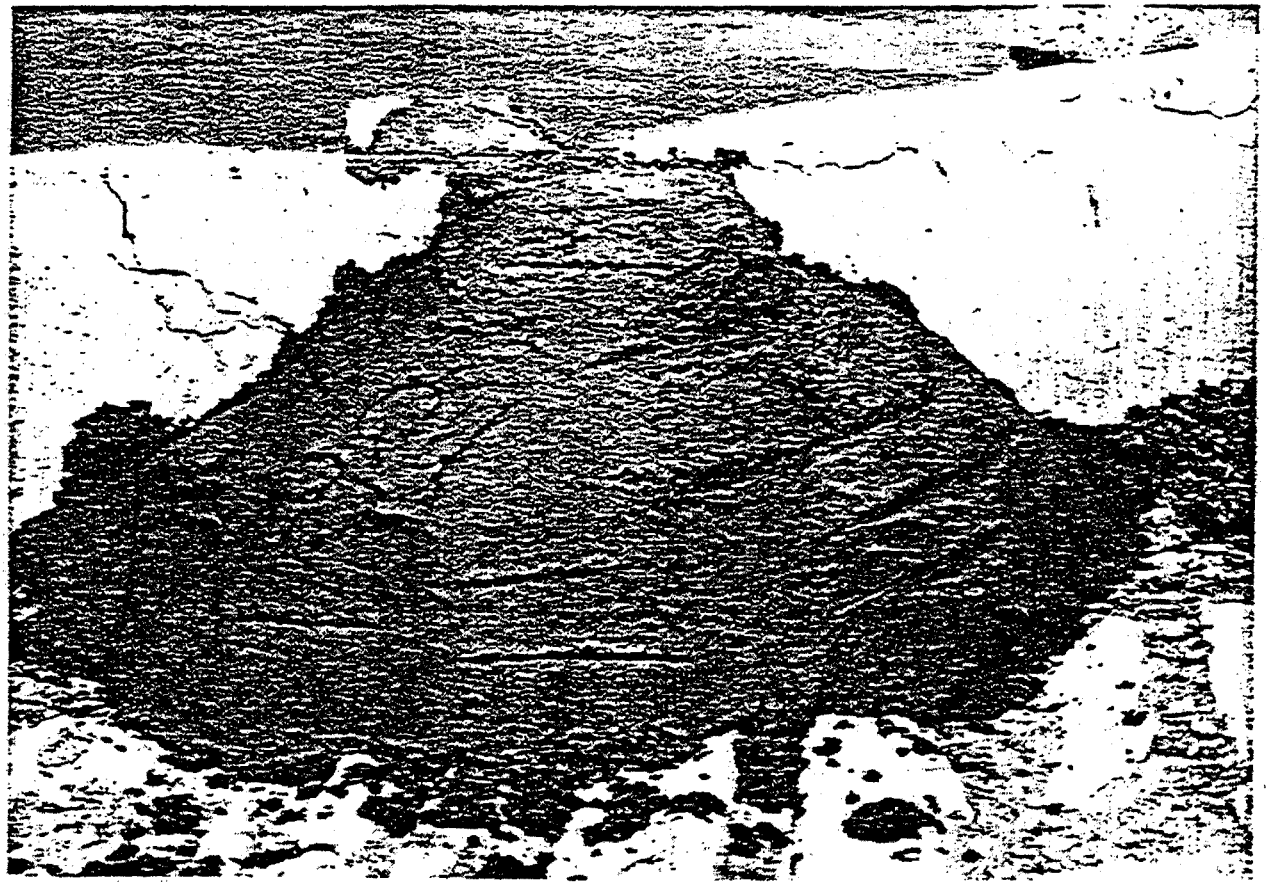

Figure 1. Completed access ramp on a livestock watering trough made of concrete with underlaying rocks with roughened surface for animal traction.

The surface of the concrete ramp is scarified to provide traction for the birds and mammals ascending and descending the ramp. If the tank contains water, an unopened sackof concrete can be immersed at an angle over a rock substrate to provide a suitable escape ramp after the concrete hardens.



Figure 2. Escape ramp built on a livestock watering trough consisting of a sack of concrete on a substrate of rock. After the concrete hardens the paper sack will disintegrate.

The paper sack will eventually disintegrate. A precaution to avoid possible adverse response from ranchers is to build the concrete ramps at the opposite end of the water trough away from the float valve, water level adjustment.

RESULTS AND DISCUSSION

Research findings by Evans (1977) provided the impetus to provide accessible water to

enhance scaled quail chick survival. During the extremely hot (19 days over 100°F) and dry summer of 1994, 7 radioed, scaled quail females successfully nested and hatched 97 chicks. By the age of 16 days all young birds had perished. Several dead chicks were found drowned in stock watering tanks. In contrast, during the more normal summer of 1995 with cooler temperatures (2 days over 100°F) survival of chicks hatched by 8 radioed hens was 49.6%.

Based on a sample of 67 ramps installed by members of the Southwestern New Mexico Chapter of Quail Unlimited during summer, 1997 the cost per ramp was $30 (cost of concrete mixer rental, concrete, and gasoline for vehicles). Times to construct an access and escape ramp at each tank site was 4.0 hours.

Anecdotal information by Gorsuch (1934), Greenwalt (1955), and Gullion (1962) suggested movements by Gambel's quail of 550 m to <2 km. Scaled quail are even more mobile ranging from 4.8-25.6 km from nearest water source (Schemnitz 1997). Using a conservative distance of 0.8 km (0.5 miles), the 67 ramps installed during 1997 summer, available water was provided for quail over an area of approximately 12,864 ha (32,160 acres).

Ranchers have been very supportive of our ramp project on water troughs. Cleaner water free of contamination by drowned animal carcasses provides more suitable drinking water for livestock.

CONCLUSION

Scaled quail have been declining in the United States at an average rate of 3.8% since 1982. Gambel's quail population have been declining (1982-91) at 4.6% per year (Church et al. 1993). Hopefully our water access project will contribute to a curtailment in the rate of population decline of these popular game birds. Priorities for research include a better understanding of the bird's water requirements and effects of providing water on population levels.

ACKNOWLEDGMENTS

We are indebted to Roger Wells, National Habitat Coordinator, Quail Unlimited, and the National Fish and Wildlife Foundation for facilitating our project funding. Quail Unlimited and the Bureau of Land Management (BLM) were primary financial supporters. Bill Merhege, BLM wildlife biologist, provided liaison and approval with rancher leasees. He located project water troughs and tanks on maps which expedited travel.

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HYDROLOGY OF STOCKWATERING PONDS IN ARIZONA

Don W. Young, Ph.D.[1/]

ABSTRACT—General water rights adjudications, involving approximately 80,000 water rights claims scattered over 50,000,000 acres of land, are now taking place in Arizona. These are among the largest court proceedings ever undertaken in the United States.

There are an estimated 22,800 stockponds in the Gila Basin alone. To eliminate such numbers of claims from individual litigation would tremendously reduce the burden on the courts and parties in these trials. Some parties have proposed to summarily adjudicate stockpond, stockwatering, and domestic uses which comprise the majority of water rights claims, and which may also have a negligible (or *de minimis*) impact on watershed hydrology. The State of Arizona, as a claimant in the adjudications, has developed and long endorsed the *de minimis* status of certain water uses, especially stockwatering, thereby attempting to shorten these proceedings.

This paper tracks the research by the State toward quantifying the impact of stockwatering ponds on the hydrologic regime. Since 1977, the Arizona State Land Department and the Arizona Attorney General's Office have conducted research projects to (1) measure the capacity of stockponds, (2) determine the effective retention (ER) of stockponds, and (3) model the effects of stockponds on watershed hydrology. The results of this endeavor are summarily presented in this paper.

In addition, his paper explores certain natural phenomena such as climatic and vegetative changes, and earthquakes, as well as human activities, that can affect watershed production. Range conditions in the southwestern United States have exhibited dramatic changes over the past 140 years. These changes are often attributed singularly to grazing of domestic livestock. However, it is important to look at all possible changes, both natural and manmade, that affect watershed hydrology.

INTRODUCTION

General water rights adjudications, involving approximately 80,000 water rights claims scattered over 50,000,000 acres of land, are now taking place in Arizona. These are among the largest court proceedings ever undertaken in the United States (Milne and Young, 1989) (Figure 1).

There are an estimated 22,800 stockwatering ponds and over 7,200 stockwatering uses (springs, streamside use) in the Gila River Basin alone. Considering that each stockpond (also referred to in Arizona as stockwatering ponds or stocktanks) and stockwater use may have a unique priority date, each could potentially be tried as an individual case. If small claims, such as those for stockwatering, could be considered *de minimis* in their impact on higher priority uses, they might be adjudicated as one class of use, thereby forestalling a case-by-case trial of each individual claim.

[1/] Chief Forensic Hydrologist & Water Resource Manager, Office of the Arizona Attorney General, Water Rights Adjudication Team (WRAT), Phoenix, Arizona.

HYDROLOGY OF STOCKWATERING PONDS IN ARIZONA

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To eliminate such numbers of claims from individual litigation would tremendously reduce the burden on the courts and parties in these trials. Some parties have proposed to summarily adjudicate stockpond, stockwatering, and domestic uses which comprise the majority of water rights claims, and which may also have a negligible (or *de minimis*) impact on watershed hydrology (Young and Dozer, 1988; Milne and Young, 1989; Young, 1994).

The Arizona State Land Department (ASLD) holds in trust approximately 9.5-million acres of land in Arizona, the majority of which is leased for cattle grazing. Tens of thousands of stockpond and stockwatering rights are associated with these trust lands, as well as with federal and private lands within the state (Table 1).

Table 1: Number of Statements of Claimant (SOC) Filed in the Adjudications.

Watershed	SOC's (39's)	Stockponds	Stockwatering	Domestic	Totals
LCR	10,990	5,977	89	3,228	
GILA	67,727	22,812	7,249	27,028	
Totals	78,717	28,789	7,338	30,256	66,383
					84.3%
Salt	6,369				
San Pedro	8,309				
Agua Fria	3,858				
Verde	16,500				
U. Gila	8,853				
L. Gila	14,390				
Santa Cruz	9,448				

An advocate of stockpond and stockwatering uses being *de minimis*, the State of Arizona first suggested to the Gila steering committee that such uses might be treated in some summary fashion and excluded from further needless litigation. The State did not propose that small claims such as stockwatering uses be ignored, dismissed or exempted by the court, but that such uses be summarily adjudged as a class or classes of use—their jurisdiction being retained by the court. Water rights associated with such small uses should be granted under the decree and monitored by the Arizona Department of Water Resources (ADWR) for future compliance with the law.

A major obstacle in granting special treatment to small claims lies in demonstrating to litigants that some small water uses do not have a discernible impact on claims far downstream. Opponents retorted that there was little or no scientific evidence to support the *de minimis* bases of such uses.

Since 1977, technical personnel of the ASLD and the Arizona Attorney General's Office (AGO) have conducted research and devised methods to (1) accurately measure the capacity of stockponds, (2) determine the effective retention (ER) of stockponds, and (3) model the effects of stockponds on watershed hydrology, in an attempt to establish with scientific credibility that such uses are *de minimis*.

Range conditions in the southwestern United States have exhibited dramatic changes over the past 140 years. These changes are often attributed singularly to grazing of domestic livestock. However, it is important to look at all possible changes, both natural and manmade, that affect watershed hydrology. Field personnel of Arizona's land and resource agencies in contact with the ranching industry understand the relationships between grazing and land and resource management. Research in this area has indicated that certain natural phenomena such as climatic and vegetative changes, and earthquakes, as well as human activities, can affect watershed hydrology to an even greater degree than human activity. These areas will be discussed later in this presentation.

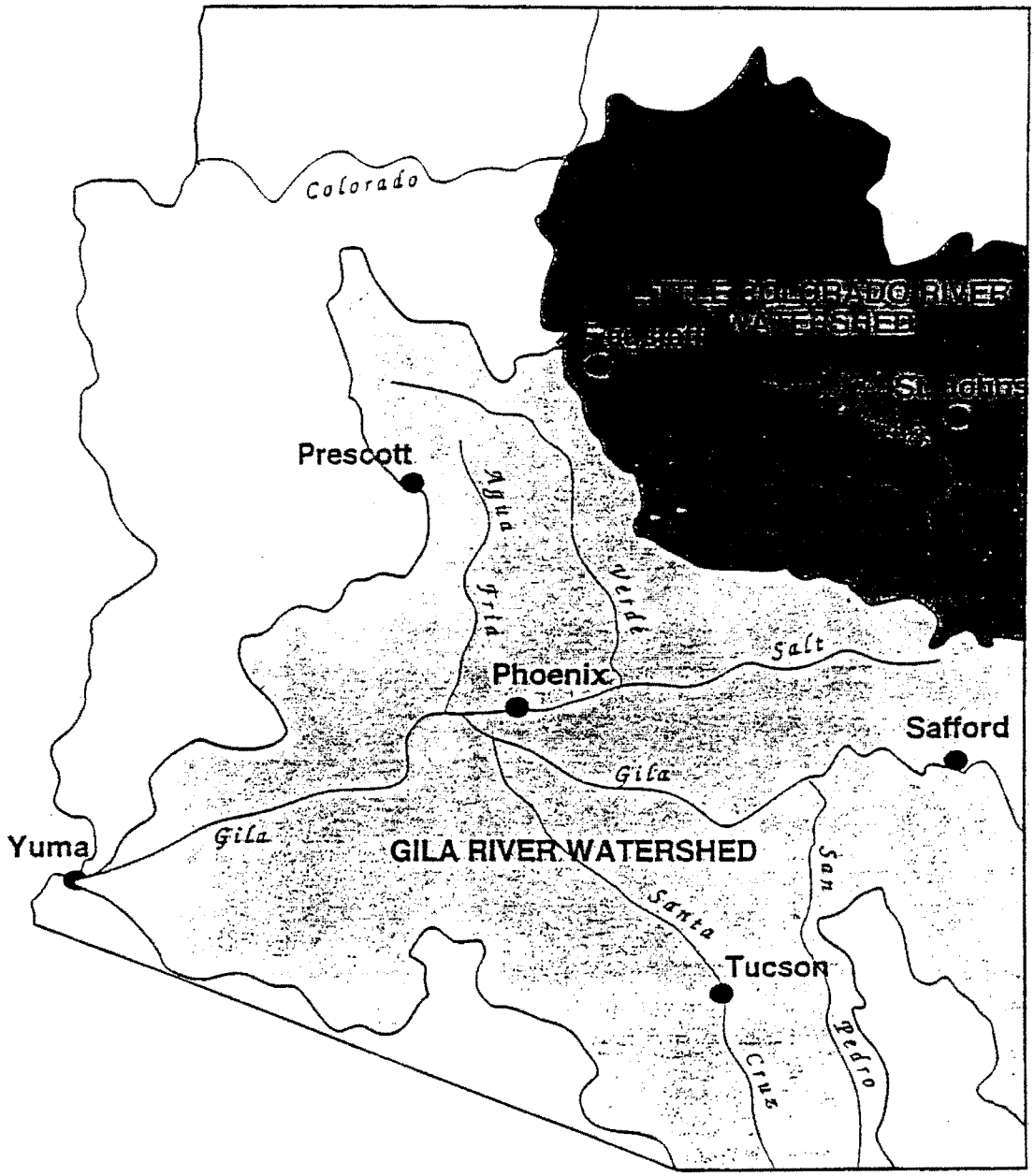


Figure 1: State of Arizona Showing Gila River and Little Colorado River Basins Presently Under Adjudication.

DE MINIMIS—WHAT DOES IT MEAN?

The term *de minimis* is not used in this presentation in the legal context of *de minimis non curat lex* ("The law does not take notice of very small or trifling matters"), but in its lay connotation of "small" or "insignificant." *De minimis*, for this presentation, is defined as "those uses of water that are cumulatively insignificant, and individually unmeasurable relative to their impact on other downstream users" (Young, 1994). The operative word here is *insignificant. De minimis* impacts are not only a measure of the volume of diminution from a stream course, but also include the *value* (both in real and social costs) of the associated volume of water. If adjudication and administration costs associated with a particular water right, or class of water rights, are greater than the value of the water for its highest and best use, then those rights must be *de minimis* (Young, 1994).

MEASURING THE CAPACITIES OF STOCKWATERING PONDS

In 1977, ASLD staff devised a method for estimating the capacity of stockponds. This method, known as the **Estimated Maximum Volume [EMV]**, employs the geometric surface shape and three-dimensional configuration of ponds found in the field. Shapes and dimensional relationships used to develop this method were derived from the experience of field personnel who had visited and measured numerous stockwatering ponds, as well as actual field measurements (Young, 1994; Young, 1996).

Field observations led to the recognition of nine basic geometric surface shapes: [1] square, [2] rectangular, [3] triangular, [4] trapezoidal, [5] circular, [6] semicircular, [7] elliptical, [8] semielliptical, and [9] ellipsoidal ("egg-shaped"). Most stockponds conform to one, or a combination, of these surface shape categories (Figure 2) (Young, 1996).

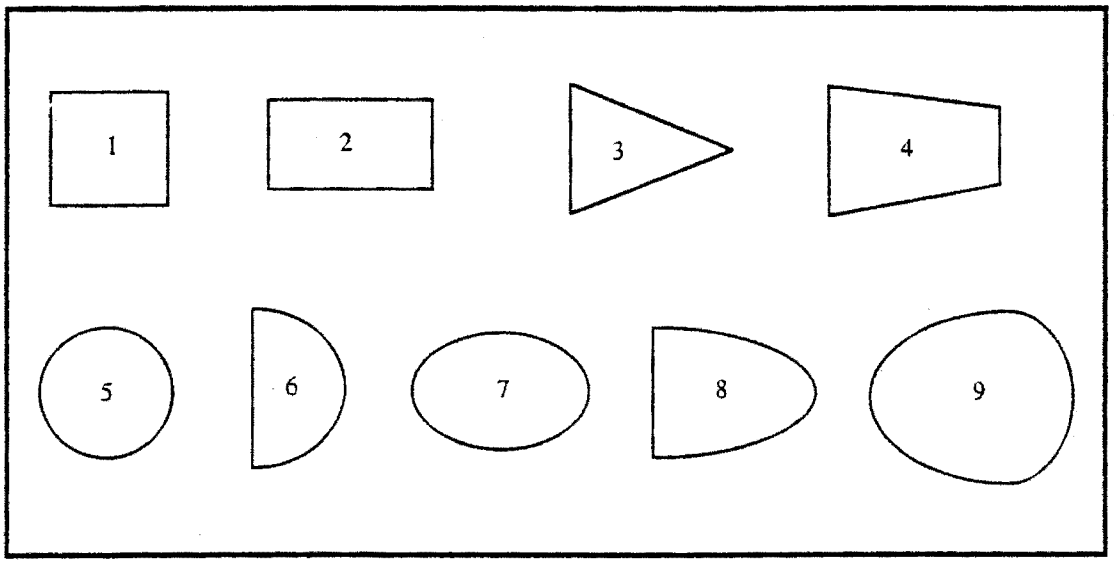


Figure 2: Basic Surface Configurations of Stockponds Identified in the Field (from Young, 1996).

The second phase of this project involved representation of the bottom configuration of the stockponds to develop their three-dimensional contours. Sampling of bottom configuration was accomplished through the use of a casting reel and fishing pole

with a bobber modified to hold a clip through which the line would pass. An Alka-Seltzer© tablet was inserted in the clip to keep it open, allowing the line to pass freely through the clip until the sinker reached the bottom of the pond. When the Alka-Seltzer© tablet dissolved, the clip closed on the line. The line was then reeled in, and the length of line from bobber to sinker was measured, thereby indicating the depth of the stockpond at the point measured (Young, 1996).

Numerous stockponds with surface configurations shown in Figure 2 were gridded and measured to develop a sample representative of bottom configuration for each shape. Other stockponds were instrument-surveyed when empty. Thus, contours began to form and the the three-dimensional configurations of the ponds began to take shape (Young, 1996) (Figure 3).

The next phase of the project was the most tedious. Each three-dimensional configuration had to be expressed mathematically. Geometric shapes within geometric shapes were drawn with angles and slopes, with relationships to each other carefully noted. The researchers then constructed complex mathematical formulae to express the total geometric design of each representative stockpond configuration. These formulae were simplified and put into pamphlet form for distribution (Young, 1996).

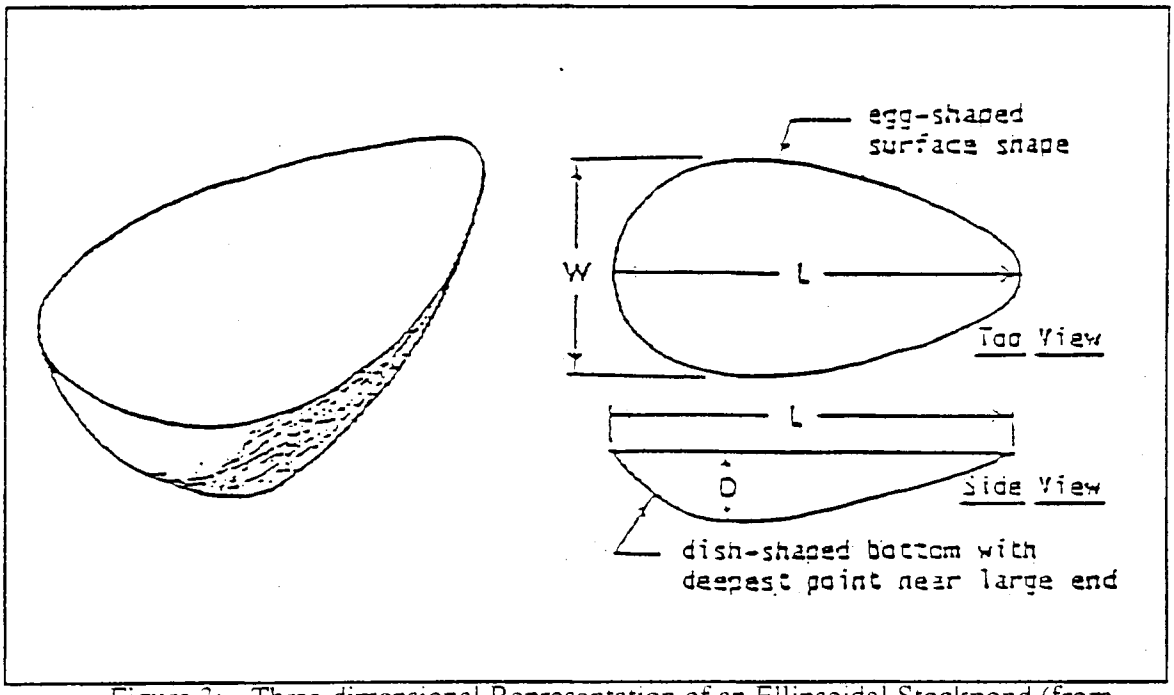


Figure 3: Three-dimensional Representation of an Ellipsoidal Stockpond (from Young, 1996).

The EMV method was originally published in 1979 and disseminated for public use by the Arizona Water Commission (predecessor of ADWR), and later published in "Hydrology and Water Resources of the Southwest" (Young, 1996).

EVALUATION OF EMV METHOD

In September 1991, the AGO and the U.S. Fish and Wildlife Service (USFWS) entered into a cooperative agreement to perform a research project on the Buenos Aires

National Wildlife Refuge (BANWR), located approximately 40 miles southwest of Tucson, Arizona, to evaluate various methods of measuring stockwatering ponds (Young, 1994; Young & Cunningham, 1996).

The survey instrument used by USFWS to perform stockpond measurements is a laser-based system operating in the infrared mode to protect the eyes of the surveyor. Computer functions incorporated into the instrument permit collected data to be downloaded to a PC. Once the data are downloaded, the geodimeter surveying software permits the user to compute various survey parameters. The computer generates a contoured map of the stockpond and computes the inside volume from the spillway elevation (top contour at the spillway) to produce the maximum volume (in acre-feet) of water that can be contained in the stockpond (Young, 1994; Young & Cunningham, 1996).

Table 2 is a summary of the data derived from the geodimeter-contoured plots and the ASLD field sheets for the stockponds surveyed. The calculated EMV of each stocktank is shown for both methods, as well as the error between the methods.

STOCKPOND NAME	Vol (af)-ASLD	Vol (af)-GS400	Difference (af)	% Error
Ashcroft East Tank	0.47	0.34	0.13	27.7
Ashcroft West Tank	1.64	1.51	0.13	7.9
Ashcroft West Sandtrap	0.02	0.02	0	0
Halloween Tank	0.14	0.1	0.04	28.6
Herman Tank East	0.7	0.66	0.04	5.7
Herman Tank West	0.44	0.49	-0.05	-11.4
Horse Tank #1 (lower)	0.53	0.48	0.05	9.4
Horse Tank #2 (middle)	0.49	0.48	0.01	2
Horse Tank #3 (upper)	0.53	0.48	0.05	9.4
Jane's Tank	0.7	0.6	0.1	14.3
Lopez Tank	18.23	14.81	3.42	18.8
Lower Wilber Tank	0.89	0.89	0	0
McKay "A" Tank	2.48	1.99	0.5	20.2
Marijuana Tank	2.75	2.25	0.5	18.2
Marijuana Tank Sandtrap	0.82	0.68	0.15	18.3
Snake Tank	0.85	0.73	0.12	14.1
Tequila Tank	12.67	10.2	2.47	19.5
			7.66/n*	1225.5l/n*
Totals	44.35	36.71	0.45	113.3l
* n = 17				

Table 2: BANWR Stockpond Volumes Measured Using ASLD-EMV and GS400 Methods, Showing Associated Error (adapted from Young & Cunningham, 1996).

Table 2 shows the average percent error (absolute) between the two methods at just over 13%. In hydrologic terms this is acceptable. It must be remembered that the ASLD method utilizes capacity formulae relating to the as-built geometry and depth of stockwatering ponds. As a pond silts in, the geometry and the depth change dramatically. However, with the ASLD method the geometry would appear to remain the same. Of course, all instrument survey methods measure the *existing* geometry and depth of a stockpond (Young, 1994; Young & Cunningham, 1996).

In addition, the average difference in volumes of all stockponds surveyed is only 0.45 af—an insignificant volume of water when considering the potential impact of all stockponds upon a hydrologic system (Young, 1994; Young & Cunningham, 1996).

This study concluded the following (from Young & Cunningham, 1996):

- Utilizing the EMV method allowed ASLD field personnel (as well as ranchers and other property owners) to estimate stockpond capacities quickly and reliably. Most importantly, it required only one person to make the measurements—an asset when manpower is limited. The EMV method was utilized by ASLD in making water rights filings on the majority of its stockpond claims. Certain federal agencies and private individuals also utilized the EMV method in quantifying stockwatering ponds.
- The ASLD method produces an accurate estimation of the original as-built capacity of stockwatering ponds over a wide range of sizes and configurations—an important consideration when quantifying stockponds for water rights filing purposes. Arizona statutes permit an owner to periodically clean out stockponds that have silted in, as long as the original capacity of the tank is not increased. It is to the water right holder's benefit to file for the original capacity of the stockponds so they may be cleaned without penalty of exceeding the water right amount. This gives the ASLD method the advantage over survey methods for estimating the capacity of stockponds.
- The ASLD method is reasonably simple to perform, with a minimum of training required for field personnel.
- The ASLD method has limitations, however, with respect to impoundments that are nonconforming to standard geometric shapes and/or are very large in size (>15 af). Such unusually configured tanks would be more accurately measured by an instrument survey method.
- The ASLD method was scrutinized by the special master in the general streams adjudications in Arizona during *de minimis* hearings, and was considered by the Maricopa County, Arizona, Superior Court to be consistently accurate for its intended purpose (Superior Court Memorandum Decision, 1994).

HEURISTIC (OR PRAGMATIC) APPROACH

In view of the enormous scope and complexity of the Arizona adjudications, additional mechanisms for streamlining the process seem essential to the public interest. Costs to date are estimated to be in the hundreds of millions of dollars. In 1989, Milne and Young proposed a pragmatic water balance screening method to evaluate the potential effects of a given category of water use on the supply of water available for other uses. It was demonstrated that the *cumulative* impact of many small water rights claims within a given category is negligible, and that the impact of an individual claim within that category is very difficult, if not impossible, to discern. Therefore, if efforts to pinpoint the impacts of individual claims are unproductive, then rigorous efforts can be focused on quantification of those claims which appear to account for the bulk of water use. Application of this heuristic approach has the potential to reduce quantification time and costs by 50% or more (Figure 4).

It would seem that a small diversion of flow from an event occurring on a small ephemeral channel would have an imperceptible impact on the perennial flow of the mainstem river. Due to spatial and temporal variations of precipitation and flow events across a given watershed, coupled with antecedent conditions of the watershed and the stocktanks themselves, and the variable hydraulic continuity of flow in the ephemeral channels with the flow of the mainstem river, quantifying the impact of any one stocktank at any point in time on the perennial flow of a river several (tens, or hundreds of) miles downgradient would seem to be impossible (Young, 1994).

In 1989, hydrologists for the ASLD published an analysis of stockponds located on the upper Little Colorado River, near St. John's, Arizona, and the upper Gila River near

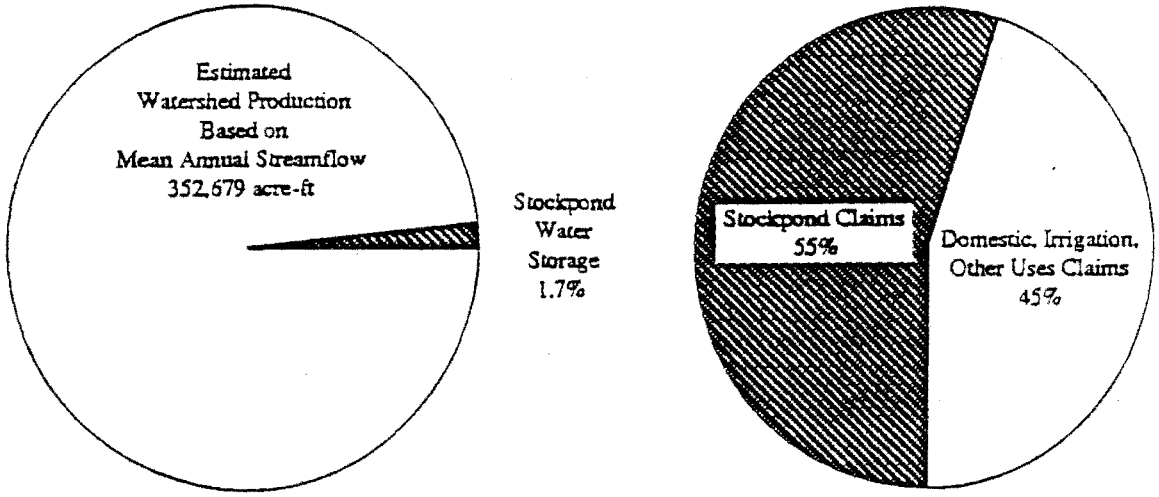


Figure 4: Comparison of Stockpond Storage as a Percentage of Estimated Watershed Production, Gila River Basin Above Soloman vs. Estimated Percentage of Stockpond Claims.

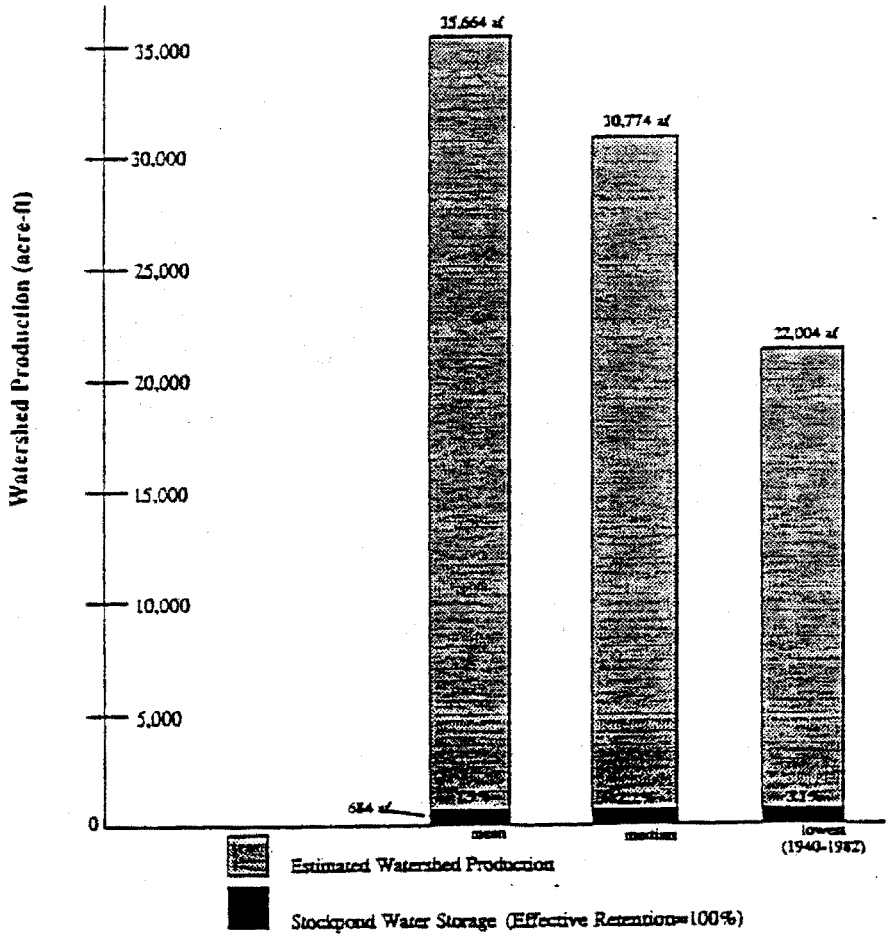


Figure 5: Stockpond Water Storage as a Percentage of Estimated Watershed Production Based on Mean, Median, and Lowest Recorded Annual Streamflow: Little Colorado River Above Lyman Lake.

Safford (Milne and Young, 1989). One finding of this 1989 study is that the impact of these small reservoirs on watershed production cannot be detected by downstream measuring gages on either stream. Therefore, it was argued, these uses can be summarily adjudicated as a class, without investigation of their individual sizes or priorities (Milne and Young, 1989; Young, 1994) (Figures 5 & 6).

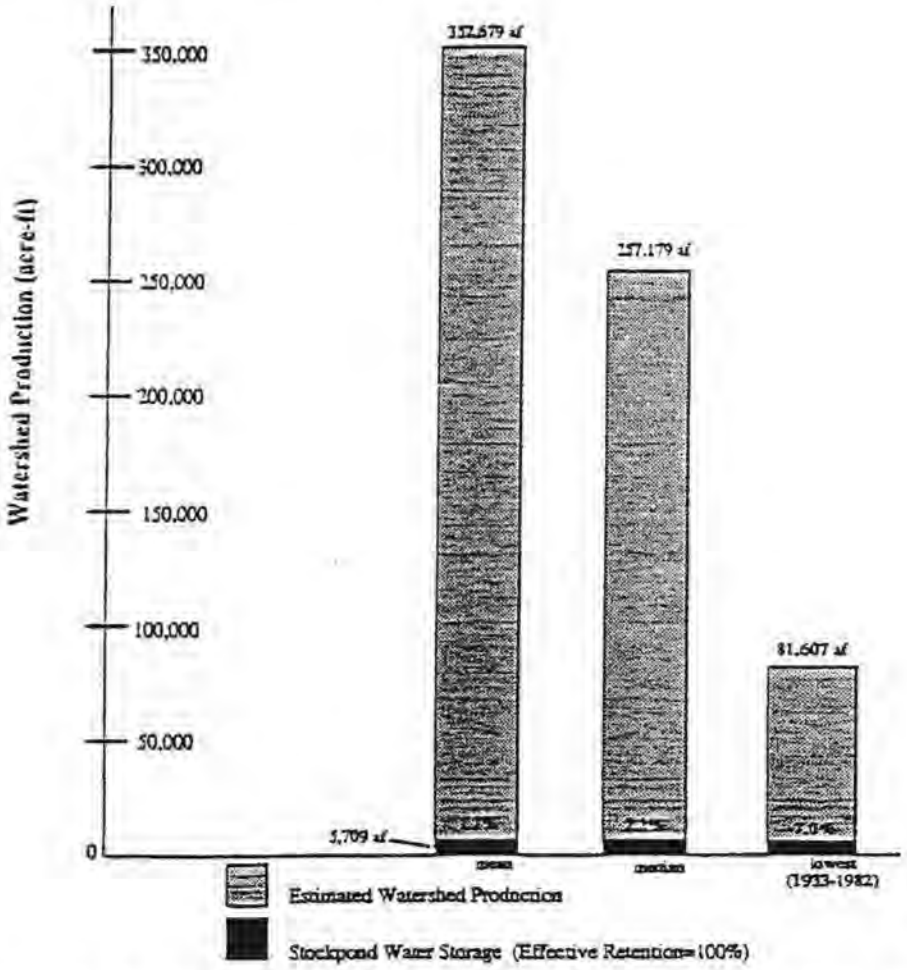


Figure 6: Stockpond Water Storage as a Percentage of Estimated Watershed Production Based on Mean, Median, and Lowest Recorded Annual Sreamflow: Gila River Above Soloman.

EFFECTIVE RETENTION (AKA "FILL FACTOR")

Effective retention (ER) is defined as the percent of decrease of annual discharge from a watershed which can be attributed to the effects of water storage impoundments within that watershed (Culler, 1961). It is usually expressed as a percentage of the maximum volume of a stockpond or of the cumulative volume of all stockponds on a watershed. ER is sometimes looked upon (incorrectly) as the volume of a stockpond (or as a cumulative volume of all stockponds on a watershed), multiplied by the number of times the impoundments fill, or partially fill, over the course of the year (effective storage).

To determine the impact of stockponds on the hydrologic system, it is first important to quantify their effective retention (ER). If the number of times stockponds fill on the average per year (fill-factor) can be determined, then an estimate of cumulative average annual ER can be made. This eliminates the need to employ sophisticated mathematical models to determine ER for individual watersheds (Young, 1994; Young & Sejkora, 1995).

Analysis of Soil Conservation Service (SCS) Data

Due to lack of definitive studies on ER of stockwatering ponds in Arizona, it was necessary to examine available long-term data. Two sources of that proved useful to this study are: (1) U.S.D.A.-SCS water supply reports and (2) water level stage recorder data from the Walnut Gulch Experimental Watershed (WGEW) at Tombstone, Arizona (Young, 1994; Young & Sejkora, 1995).

The State of Arizona is broken down into separate conservation districts by the SCS, with each district under the jurisdiction of a district conservationist who reports directly to the Phoenix regional office. Data are provided in the form of narrative summaries, or short answers to prepared questions, covering the following topics:

[1] reservoir storage
[2] small ponds or impoundments
[3] necessity of supplemental water hauling
[4] groundwater usage
[5] direct stream diversion
[6] crop acreage/livestock number changes due to water supply
[7] general range conditions
[8] limit of water use due to energy costs
[9] water quality problems
[10] flood damage to delivery systems (if any)

From this information, the state water supply specialist prepares statewide summary maps for each of the above topics, and an annual report on the general water supply conditions in Arizona (Jones, 1993; Young, 1994; Young & Sejkora, 1995).

The SCS water supply records from 1978 through 1992 for six districts in southern Arizona (Sells, Tucson, Willcox, Safford, San Carlos and Douglas) were examined with a focus on small impoundments (stockponds). Information pertaining to small impoundments consisted of short answers to the prepared questions: (a) *"Did the impoundments fill at any time?"* and (b) *"Did the impoundments provide an adequate water supply?"* Additional information was obtained by reviewing answers to the topics of water hauling [3], use of groundwater [4], changes in livestock numbers due to water supplies [6], and general range conditions [7]. Notations on the summary maps, together with narrative comments from the district conservationists, provided a basis for assigning a numerical value (which we refer to as "fill index") for the impoundments during each year of record as follows (Young, 1994; Young & Sejkora, 1995):

0.0 =	DRY	[No fills during the year]
0.5 =	POOR	[Partial fills during the year]
1.0 =	ADEQUATE	[Tanks nearly filled or spilled once]
1.5 =	GOOD	[Tanks filled once + partial fills]
2.0 =	EXCELLENT	[Tanks filled at least twice]

Table 3 shows annual fill index variability and mean fill index for all impoundments within each of the six districts. It is inherently difficult to quantify narrative data—especially from subjective sources. However, lacking more definitive studies, this

approach at least demonstrates the variability of stockpond filling from year to year and region to region.

Analysis of WGEW Stockpond Data

Gaging records for four stockwatering ponds within Walnut Gulch Experimental Watershed (WGEW) were examined to determine if there might be a correlation between the statistics derived from the SCS water supply information and the more objective data available from actual gaged stocktanks. The stockponds chosen for examination have different elevations and contributing drainage areas, ranging in size from ±60 acres to ±440 acres, in order to provide some range in size of the contributing drainages being investigated. The stocktanks themselves range in volume from just over two acre-feet (2 af) to just under fifteen acre-feet (15 af). None of the reporting SCS Districts is located in the Walnut Gulch study area, however three SCS Districts (Tucson, Douglas and Willcox) are in close proximity to Tombstone, Arizona, and should be representative of weather patterns and range conditions occurring at WGEW (Young, 1994; Young & Sejkora, 1995).

Table 3: SCS Impoundment Fill-Factors for Sells, Tucson, Willcox, Safford, San Carlos and Douglas, Arizona, Stations (from Young, 1994; Young & Sejkora, 1995).

	STATION NAME					
YEAR	SELLS	TUCSON	WILLCOX	SAFFORD	SAN CARLOS	DOUGLAS
1992	1.0	0.5	--	1.0	1.5	1.0
1991	1.0	1.0	0.5	1.0	1.0	0.5
1990	1.0	1.0	1.0	0.5	1.0	0.5
1989	0.5	0.5	0.5	0.5	0.5	0.5
1988	1.0	1.5	1.5	1.0	1.0	1.5
1987	0.5	0.5	1.0	0.5	--	0.5
1986	1.0	1.0	0.5	1.5	--	1.0
1985	1.0	1.0	0.5	1.0	--	0.5
1984	1.5	--*	1.0	1.5	--	1.0
1983	2.0	1.0	0.5	1.5	--	0.5
1982	1.0	0.5	0.5	1.5	--	0.5
1981	1.0	--	0.0	1.5	0.5	0.5
1980	0.5	0.0	0.5	0.5	--	0.5
Total/n=Mean Fill Index	13/13=1.0	8.5/11=.77	8.0/12=.67	13.5/13=1.	5.5/6=0.92	9.0/13=.69

* data not available

These records were analyzed by reviewing continuous recorder charts and noting daily water levels within each of the four stocktanks. Similar to the procedure applied to SCS data, an annual fill index was assigned to each stock tank based on these data (Table 4). Notations on the charts made by Walnut Gulch personnel were taken into account when assigning a fill index value to the condition of the tanks for each year of record (Young, 1994; Young & Sejkora, 1995).

Multiple spills were not common to the four Walnut Gulch stocktanks, nor was the frequency of multiple spills sufficient to raise the average number of fills per annum to an ER greater than one (Young, 1994; Young & Sejkora, 1995).

The mean fill index for each WGEW stockpond was calculated (Table 4), and it appears that the number of fills per year is independent of tank capacity This is probably related to the larger stockpond (#214) having a greater drainage area supplying it. Ranchers tend to size stockponds according to the volume of water that can be captured; this, of course, is directly related to the drainage areas supplying the tanks (Young, 1994; Young & Sejkora, 1995).

Examination of the records for the four WGEW stockponds reveals trends that correspond to the SCS water supply data for the Tucson, Douglas, San Carlos, Safford, Sells and Willcox Districts in that all show a fill index of 1 or <1. This supports the Milne and Young 1989 study in which a conservative ER of 1.0 was used to estimate the cumulative impact of stockponds relative to watershed production (Young, 1994; Young & Sejkora, 1995).

In summary, this project shows that both SCS water supply reports and Walnut Gulch stockpond gage records indicate that stockponds averaged less than one fill annually. If the fill index of stockwatering ponds is independent of stockpond size, and is generally ≤1.0, it follows that ER must also be <1.0; therefore, the impact on outflow from a watershed must be less than the cumulative storage capacity of the tanks (Young, 1994; Young & Sejkora, 1995).

Table 4: Fill Index Data for Stockponds From WGEW (from Young, 1994; Young & Sejkora, 1995).

YEAR	SP #213 [Vol.= 2.11af]	SP #214 [Vol.= 14.92af]	SP #216 [Vol.= 2.90af]	SP #223 [Vol.=2.53af]
1992	-*	0.5	-	-
1991	-	-	1.0	1.0
1990	-	0.5	1.0	0.5
1989	-	0.5	0.5	0.5
1988	-	0.5	0.5	0.5
1987	-	0.5	0.5	0.5
1986	0.5	0.5	1.0	1.0
1985	0.5	0.5	0.5	2.0
1984	1.0	0.5	0.5	-
1983	1.5	1.0	1.0	-
1982	1.0	1.0	2.0	-
1981	1.0	0.5	1.0	-
1980	0.5	1.0	0.0	-
1979	-	-	0.0	-
1978	-	-	0.0	-
Total/n=Mean Fill Index	6.0/7=0.86	7.5/12=0.62	9.5/14=0.68	60./7=0.86

* data not available

This study demonstrates that the cumulative volume of all stockwatering ponds on a watershed can be utilized as a conservative estimate of the average annual diminution (ER) of watershed production by the stockponds, reducing—perhaps even eliminating—the necessity for lengthy, costly hydrologic modeling studies to determine the impact of stockponds on watershed hydrology in Arizona (Young, 1994; Young & Sejkora, 1995).

THE MODEL

The impact of stockponds on the hydrologic production of a watershed is determined using a model designated TSPLOSS, an adaptation of the empirically derived TLOSS6 model developed by Southwest Watershed Research Center for the Walnut Gulch Experimental Watershed (WGEW) located in southeastern Arizona on the San Pedro River Watershed. By applying the model to a wide range of precipitation events, both with and without stockponds present, the range of rainfall events having a significant level of impact on watershed production can be demonstrated.

PHYSIOGRAPHIC SETTING

WGEW was developed as a research facility by the United States Department of Agriculture (USDA) in the mid-1950's. Scientists and engineers in USDA selected Walnut Gulch for a demonstration/research area which could be used to monitor and develop technology to address the influence of upland conservation on downstream water supply. Southwest Watershed Research Center (SWRC) located in Tucson, Arizona, was created in 1961 to administer and conduct research on the Walnut Gulch Watershed (Renard, et al., 1993; Young, 1994).

While the WGEW encompasses approximately 58 square miles (mi^2), the entire watershed to the confluence with the San Pedro River is 60 mi^2 and includes the historical town of Tombstone (See Figure 7). This watershed is representative of over 148 million acres of brush and grass-covered rangeland and gently rolling hills found throughout the semiarid southwest, and is a transition between the Chihuahuan and Sonoran Deserts. Elevation of the watershed ranges from 4,100 feet to over 6,000 feet mean sea level (MSL). Cattle grazing is the primary land use, with mining, limited urbanization, and recreation making up the remaining uses (Renard and Keppel, 1966; Renard, et al., 1993; Young, 1994).

The watershed hydrology is, in places, controlled by past geologic events and structures. Soils, vegetation cover, and climate are representative of the Chihuahuan and Sonoran Deserts, and specifically of the majority of the San Pedro Watershed.

The initial rainfall and runoff instrumentation on the WGEW was installed in 1954-55. The initial network of 20 precipitation gages was expanded in the early 1960's to the 85-gage network currently in place on the watershed (Renard, et al., 1993; Young, 1994). Five supercritical, precalibrated flumes were constructed prior to 1955 to measure runoff from the larger channels. These were subsequently destroyed and replaced, together with six additional flumes, bringing the total number to eleven. The largest flume, at the outlet of the WGEW, has a flow capacity of 23,000 cubic feet per second (cfs) (Renard, et al., 1993; Young, 1994).

Runoff from ten of the smaller subwatersheds is measured using a variety of gaging structures, including broad-crested V-notch weirs, H-flumes, and supercritical flow flumes (Renard, et al., 1993; Young, 1994).

MODEL MECHANICS

Representation of Watershed Geometry

The model used in this study (TSPLOSS) is based on, and calibrated to, empirical data collected over many decades from the WGEW (Lane, 1972; Lane, 1983; Young, 1994). TSPLOSS represents the watershed with three types of elements: upland areas, lateral areas, and channel segments. The elements are numbered sequentially beginning at

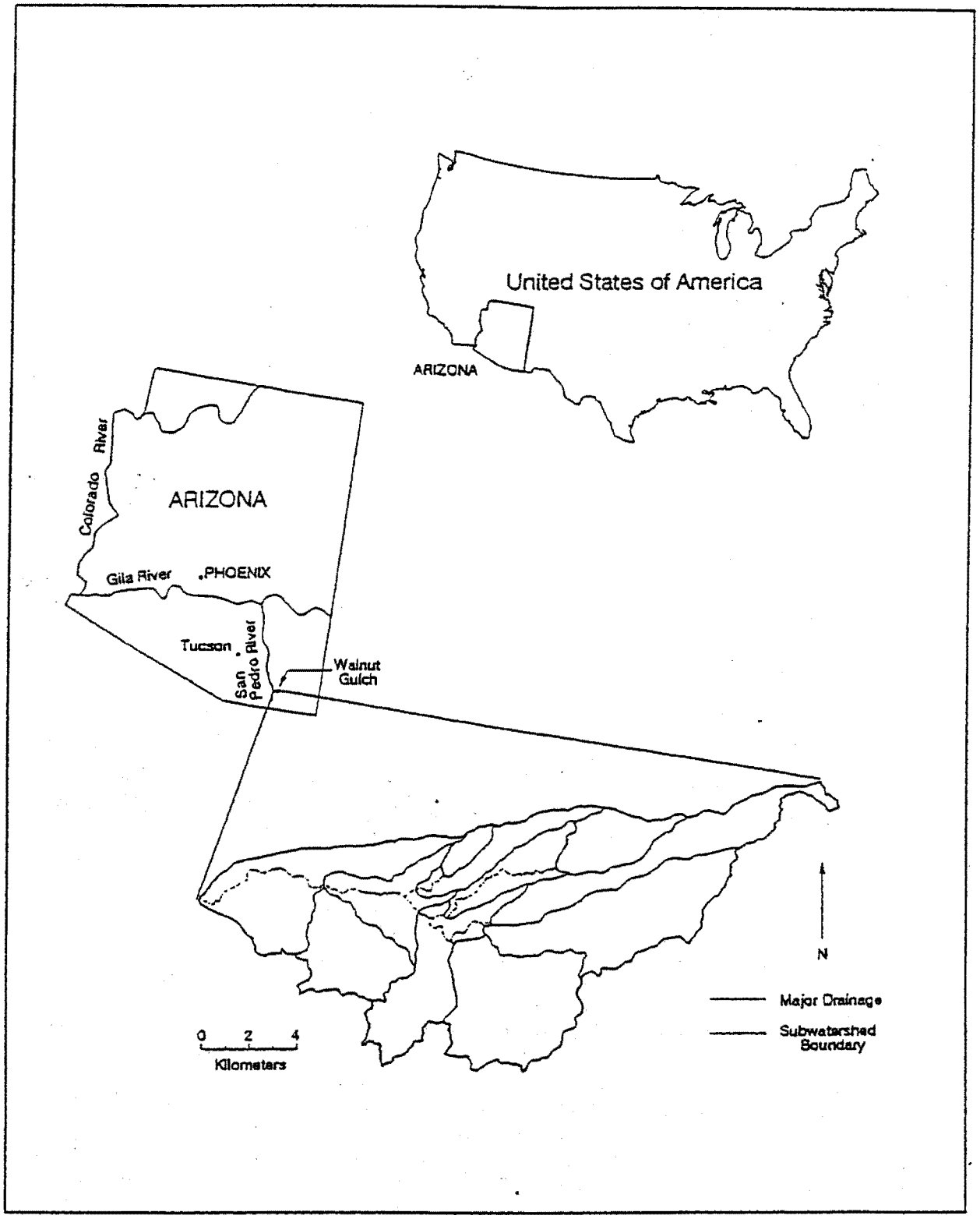


Figure 7: Map Showing Location of Walnut Gulch Experimental Watershed (WGEW) - U.S. Department of Agriculture (Adapted from Renard, et al., 1993).

the head of the watershed and finishing at the mouth. Each channel segment is associated with two lateral areas which contribute runoff to the channel from its right and left banks, and either an upland area which contributes runoff at the head of the segment, or two upstream channel segments which also contribute at the head of the segment (Figure 8) (Young, 1994).

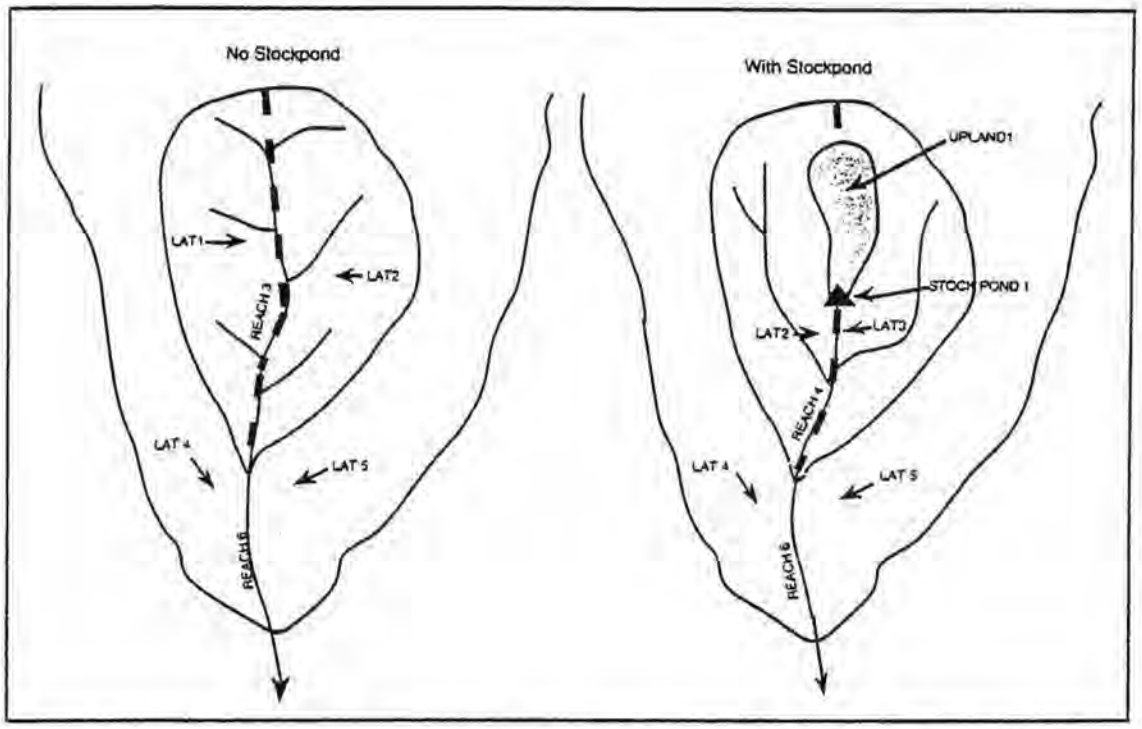


Figure 8: Typical Contributing UPLAND, Lateral [LAT] and Channel [REACH] Configuration Used In TSPLOSS Model (from Young, 1994).

In this manner the watershed is divided into several small drainage areas which are linked through channel segments. An SCS Curve Number (CN) is given to each designated drainage area to quantify the effects of storage factors, interception losses, infiltration losses, and evapotranspiration losses. Runoff from excess rainfall over a drainage flows from the upland area to the head of the channel segment, and uniformly from the laterals into the channel along its reach. Because of infiltration losses into the channel alluvium, the total volume of runoff decreases as water flows down a channel reach (Peterson, 1962; Renard and Keppel, 1966; Lane, 1983; Lane, 1985; Young, 1994).

Each lateral and upland area is described by its acreage and an SCS Curve Number. The channel segment is characterized by its length (in miles), its average width (in feet), and the effective hydraulic conductivity of its bed material (in inches per hour). Each channel segment can be associated with one upland area, two lateral areas, and two inflow channels. Each stockpond in the watershed is associated with a specified element (either a drainage area or channel segment) and described with a retention volume (Young, 1994).

The 60 mi^2 Walnut Gulch Watershed used in this study contains an ephemeral stream which is part of southeastern Arizona's San Pedro River drainage system. The model represents the watershed with 151 elements: 46 channel segments, 13 upland areas, and 92 lateral areas. The drainage area contains 14 stockponds (Table 5) which are, with one exception, associated with upland areas; the single exception is associated with a lateral area [LAT 56] (Young, 1994) (Table 5 & Figure 9).

Calculation of Runoff Volume From a Drainage Area

According to the SCS method, direct storm runoff (Q), in inches, from a drainage area is calculated from the relationship (Branson, et al., 1981; Young, 1994):

$$Q = \frac{[P - I_a]^2}{[P - I_a + S]} \quad \text{for} \quad P \geq I_a, \text{ where} \qquad [1]$$

P is storm rainfall (inches);

I_a is initial abstraction, or rainfall before runoff is initiated (inches); and

S is available watershed storage (inches).

During the development of the SCS method it was found that an average condition for many small watersheds was $I_a = 0.2S$. Using this relationship, equation [1] becomes:

$$Q = \frac{[P - 0.2S]^2}{[P + 0.8S]} \quad \text{for} \quad P \geq 0.2S, \text{ where} \qquad [2]$$

$$S = \frac{1000}{CN} - 10.$$

Otherwise, Q = 0 (Branson, et al., 1981).

Table 5: Data for Stockponds Located on WGEW Used In TSPLOSS Model (from Young, 1994).

SP #	VOL (af)	CONTRIB UPLAND	WTRSHD (acs)	CN NO.	COMMENTS
201	3.44	U143	53	87	
207	8.73	LAT56*	268	89	*Functions as an UPLAND area.
208	4.59	U82	278	90	
210	7.80	U96	163	90	
212	19.29	U50	806	89	
213	2.11	U46	365	89	
214	14.92	U78	386	90	
215	4.59	U26	80	91	
216/	3.90	U71**	385	93	**In-line tanks; total contrib. area=365 acs
218	9.40	U71**	<385>	[93]	**Can be treated as one tank w/ 13.3 af capacity
220	1.95	U36	128	95	
221	10.90	U4	164	91	
223	2.53	U130	110	92	
226	0.37	U61	85.1	89	

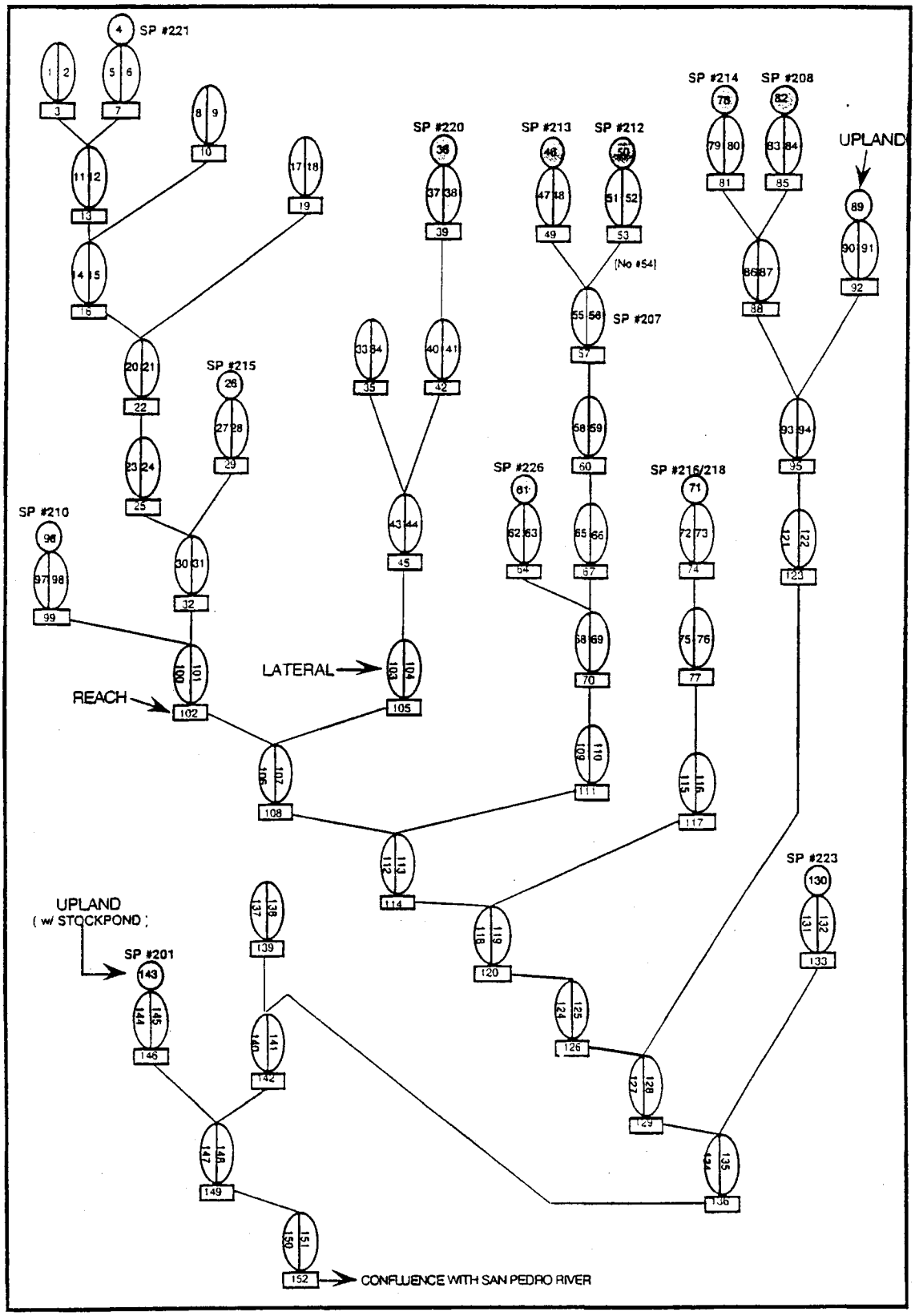


Figure 8: Schematic of Walnut Gulch Experimental Watershed.

Calculating Watershed Runoff With and Without Impoundments

Total runoff volume from the watershed is determined using the following input data: rainfall amount, drainage area and corresponding curve numbers, storage volume of channel alluvium, streamflow duration, and stockpond retention volumes. Equation [2] is used to determine overland runoff volumes, and the methodology described in "Transmission Losses," Chapter 19 of the *National Engineering Handbook 4* (Lane, 1983; Renard, 1979) is used to determine channel abstractions. Presented below is a description of the algorithm used by the model to determine the total volume of storm runoff leaving a watershed composed of several smaller drainages:

(1) The recorded channel segment data (length, width, and effective hydraulic conductivity) are used, together with mean streamflow duration and mean runoff volume parameters for the entire watershed, to compute the streamflow duration (D) and the mean runoff volume of the drainage area (V) for each channel segment. D and V are then used to compute regression constants for each channel segment.

(2) Beginning at the head of the watershed and working toward the mouth, the model calculates the runoff volume from each overland area using equation [2], subtracts any retention resulting from the presence of a stocktank, and then dumps the remaining runoff into the channel segment.

(3) A regression is then performed which calculates the total discharge volume at the mouth of the channel based on the discharges coming from upland areas, upstream channel segments, and lateral areas, and from the transmission loss regression parameters previously calculated. If a stocktank is associated with the channel segment, water is removed at its mouth (i.e., retention occurs at the end of the segment, after transmission losses).

(4) Steps 2 and 3 are repeated for successive downstream channel segments until the mouth of the watershed is reached.

Description of Model Output

For the entire range of precipitation events, two runs are performed: one with *no* retention and one *with* retention (assuming empty ponds). The program presents the results from each run and calculates (1) the total possible retention, (2) the volume effectively retained, and (3) the retention as a percentage of undisturbed runoff (Young, 1994).

Even though losses to the water budget for a given storm may be attributed to stockpond retention, if all the water would have been lost anyway to another sink, such as transmission loss, then the volume effectively retained would be zero. Undisturbed Runoff is the volume of runoff produced in the absence of stockponds. The Percent of Runoff Effectively Retained is the percentage of undisturbed runoff that was effectively retained by stockponds (Young, 1994).

RESULTS OF MODEL RUN

The model was run to simulate the full range of rainfall events occurring over the entire area of the watershed, having the following three properties: (1) the area receiving rainfall (38,607 acres); (2) the area receiving rainfall that drains to stockponds (3,271

acres); (3) the percentage of area being rained upon that drains to stockponds (8.5%); and (4) the ratio of cumulative stockpond volume to the area receiving rainfall (2.45)—a measure of "stockpond density" (Young, 1994).

❑ *What are the effects of stockwatering ponds on watershed production for specified rainfall events?*

Figure 9 presents the following model simulation output as a function of rainfall: (1) watershed production, (2) stockpond retention, and (3) the percent of watershed production lost to stockpond retention. Watershed production (top graph) quantifies the potential a watershed has to produce water for downstream users. How much of that water is *effectively* retained (middle graph) in stockponds quantifies the effect the tanks have on the hydrologic system. The third (bottom) graph displays the percentage of loss of watershed production due to the presence of stockponds (Young, 1994).

Note that a spike in the percentage of watershed production retained occurs as the system begins to produce water, and at its peak the percentage is large. As the watershed begins to produce water, most or all of the water is lost to the impoundments on the watershed. However, for this range of rainfall events (0.38-0.52 inches), the total volumes of water remain small (0-±50 af) (Young, 1994).

Retention of a volume of water that falls below some specified upper limit may have an insignificant (*de minimis*) impact on downstream users. What that volume is must be determined by the courts having jurisdiction in these water rights adjudication cases (Young, 1994).

❑ *What is the Effective Retention (ER) for specified rainfall events, and how do transmission losses affect stockpond retention?*

Figure 9 illustrates two points: (1) that there exists a rainfall depth at which stockpond retention reaches a maximum, and remains constant as rainfall depth increases further; and (2) that ER for a single event is always less than one. This is due to the effects of channel transmission losses. Effective retention is only 35% of the cumulative volume of stockponds present on the watershed (ER = Volume of Water Retained / Cumulative Volume of All Tanks) (Young, 1994).

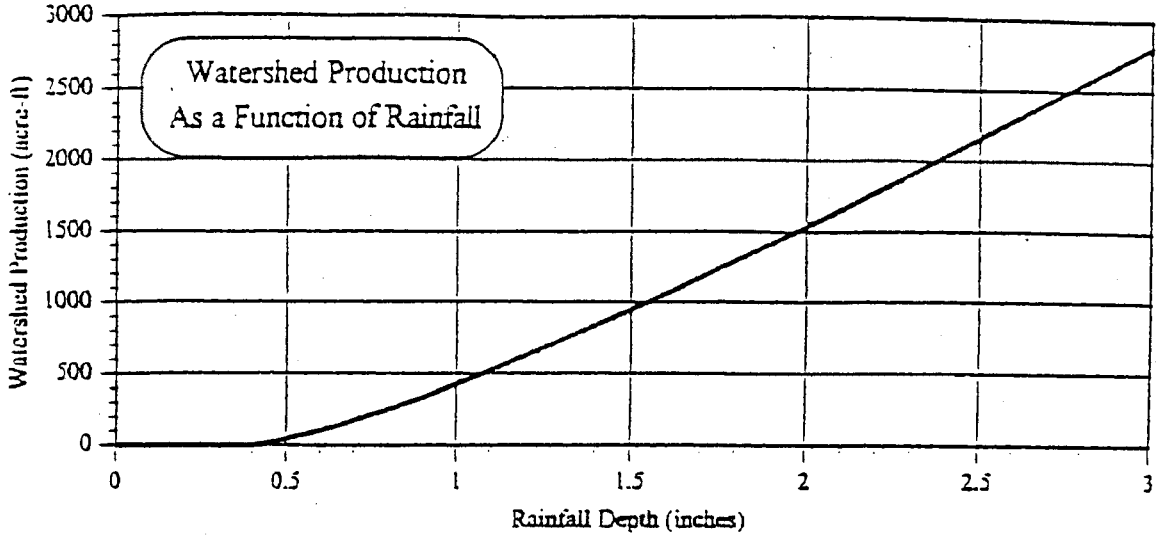
The model results show that to whatever degree the stockponds fill—even if they completely fill and spill over—some of the water they retain would be lost to channel bed infiltration if the stockponds were not there. This implies that simply looking at the cumulative volume of the tanks in a watershed and assessing how many times they fill during the course of a year to determine ER may overestimate the actual retained water. At best, this method yields a rough estimate of the upper limit of potential annual retention (Young, 1994).

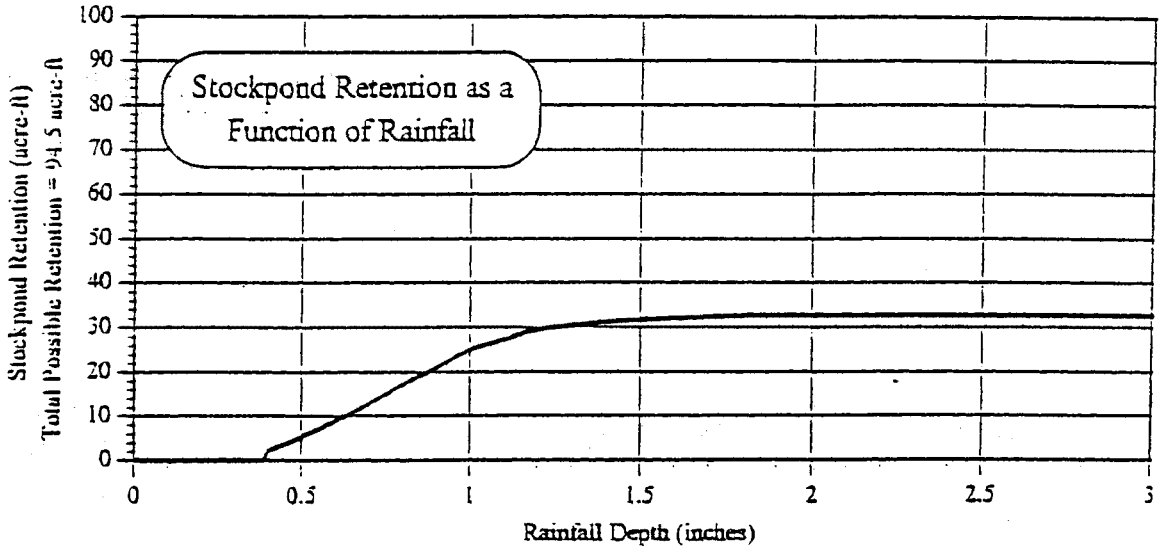
In summary, results of the modeling effort are (from Young, 1994):

- For any watershed, there exists a range of rainfall events that (1) produce no runoff due to natural system losses; (2) produce an amount of runoff that is hydraulically disconnected to flow in the mainstem channel (i.e., water that would not have reached the mainstem channel whether the stockponds were present or not); or (3) produce runoff that is hydraulically connected to flow in the mainstem channel.
- Due to the effects of transmission losses, the maximum ER for any given event will not exceed 0.35. Although this analysis was conducted on the WGEW, the results may be reflective of most watersheds in southeastern Arizona.

PAST AND PRESENT GRAZING PRESSURES

"The Livestock Industry in Arizona is almost as old as the white man's interest in and occupation and colonization of the territory" (Peplow, 1958). Neither cattle nor horses





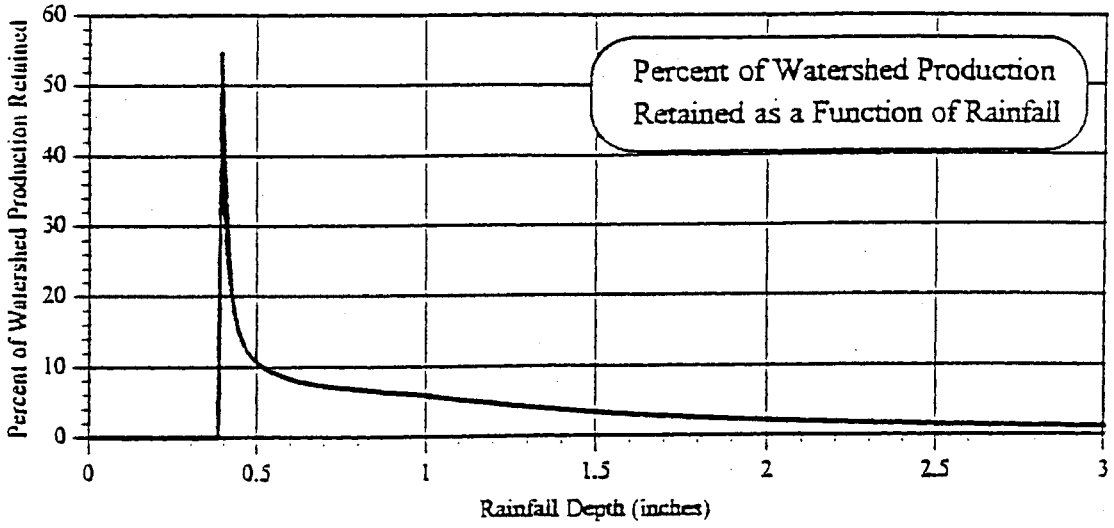


Figure 9: Model Results for Rainfall Over the Entire Watershed

are indigenous to the American continent. So far as is known, the first horses were brought to the continent by Cortez in 1515 (Barnes, 1926), and the first cattle were imported to Mexico in 1521 by Gregorio de Villalobos (Peplow, 1958). Padre Eusebio Kino stocked his missions in what is now southern Arizona with sheep, goats, horses and cattle in the early 1700's (Roberts, 1963; Peplow, 1958). There are reports of active ranching of Andalusian (Longhorn) cattle in the region of La Aribac (Arivaca), as well as in other portions of southern Arizona in 1751 (Peplow, 1958).

Between 1771-1811, missions on the Santa Cruz River reached the zenith of prosperity with the development of stock ranches on the *haciendas* (Peplow, 1958). Peplow (1958) writes:

> *Most important of the ranches were those at San Bernardino, Babocomari, San Pedro, Arivaca, Calabasas, Sapori, Radenton, San Rafael de la Zanje, Sonoita and Tubac in addition to those in the San Simon Valley, Agua Prieta and Pueblo Viejo. Sierra Bonita was perhaps the largest of the ranches, though they were all great plantations.*
>
> *Most of the haciendas were on Spanish land grants which were originally made for the purpose of mining. However, livestock was brought to supply the miners with food, clothing and work animals . . . .*

This prosperity came to an abrupt end with the resumption of Apache depredations in 1811, and the commencement of war against the Spaniards by the Navajos in 1818 (Peplow, 1958). In the intervening years, the *haciendas* were abandoned and vast herds of feral cattle roamed free throughout that portion of Sonora that is now Arizona.

One hundred forty years ago the ranges of Arizona were considerably different from what they are today. An abundance of water and grass sustained the large herds being driven across the state from adjoining states and territories to California. Water was plentiful, feed was abundant, and range was almost unlimited in the 1860's and 1870's (Peplow, 1958).

Between 1860 and 1870, a few "white men" tried to establish themselves in the stock business in Arizona. They were doomed to failure, however, since the Indians would kill the new settlers or drive off their stock. It was not until the period 1871 to 1873, when General Crook rounded up all Indians in Arizona and placed them on reservations, that the stock industry flourished in Arizona. Shortly thereafter (1874-1875), the Mormons, among others, pioneered the agriculture and stock industries in the state (La Rue, 1918; Peplow, 1958).

According to the census of 1870, there were only 5,132 head of cattle in Arizona, but during the 1870's and 1880's the industry grew rapidly (Peplow, 1958). From 1880 to 1900 there was a rapid increase in the stock industry in the West. Pioneer stockgrowers increased their herds to the full limits of the rangeland. By the mid-1880's, Arizona ranges were nearly all taken up and the flow of cattle into the state gradually came to an end (Haskett, 1935). By the late 1880's, rangelands in both northern and southern parts of the state were beginning to show the effects of overstocking (Poling, 1991). Range which had naturally been stocked with a few hundred game animals was now expected to support thousands of cattle. The grasses which for ages had grown to the height of a horse and had been cut as wild hay by early settlers, were so decimated by the vast herds that they had little possibility of reseeding themselves. Periods of drought in the 1880's which became acute in the early 1890's also contributed to the demise of the lush grasslands (Peplow, 1958).

It was not until after the creation of the U.S. Forest Service in 1905 that there was any attempt to limit grazing on public lands. With the enactment of the Taylor Grazing Act in 1934, rangeland management changed from ranchers having free access to and use of

public range to the practice of controlled (fenced) grazing allotments (Poling, 1991). The Bureau of Land Management (BLM) was established in 1946, during a period (1934-1976) of further controls on grazing through enactment of rules and regulations by the district advisory boards, and the careful expenditure of monies for range improvements, selection of knowledgeable personnel, and other routine management decisions (Poling, 1991).

Modern rangeland management increased during the 1960's and 1970's, culminating in the National Environmental Policy Act (NEPA) of 1969. NEPA imposes a procedural requirement that federal agencies consider the effects of their actions on the quality of the environment, including preparation of Environmental Impact Statements (EIS) on the effects of proposed grazing on public lands (Poling, 1991).

The Wild Free-Roaming Horses and Burro Act (1971) was an effort to improve rangeland conditions by controlling the proliferation of these animals. The Endangered Species Act (1973) requires federal agencies to consult with the U.S. Fish and Wildlife Service before making any decisions relative to rangeland management, to determine whether there would be any adverse impacts on threatened or endangered plants and animals.

The Federal Land Policy and Management Act of 1976 requires management of public lands on the basis of multiple use and *sustained yield*. The emphasis of the Public Rangeland Improvement Act (1978) is the inventory and management of public lands "so that they become as productive as feasible for all rangeland values" (Poling, 1991).

Comparison of Stock Numbers: 1918-1991

What effects have these changes in rangeland policy had on rangeland management in Arizona over the past 90 years? From 1911 to the present the number of cattle grazed on federal, state, and private lands in the western states has decreased. The actual number of head on public and private lands in Arizona has decreased from 1,511,492 in 1918 to 840,000 in 1991.

Similar comparisons can be made for the number of other stock animals. La Rue (1918) documents the number of horses in Arizona in 1918 at 136,648; the number of sheep at 1,713,064; and the number of goats at 418,370. The number of horses currently in Arizona is 166,000 (Gumm, 1993). Even though the number of horses has increased, the number of "range horses" has decreased over the last 75 years. The U.S.D.A. (1991) reports the current number of sheep at 262,000, and goats at 108,000. Other than a 21% increase in the total number of horses, there has been a reduction in the number of grazing/browsing animals (85% fewer sheep and 74% fewer goats) in the state. Changes in rangeland policy, coupled with increased environmental awareness on the part of cattle growers, have aided in reducing the number of animals foraging on Arizona's rangelands over the past ninety-five years.

CLIMATIC CHANGE AND VARIATION

Arizona's climate is changeable, varying from periods of persistent drought to periods of frequent flooding. The state can be divided into three hydroclimatic zones that are defined mainly by physiography: the plateau uplands, characterized by few perennial streams, with annual precipitation ranging from 10 to 25 inches; the central highlands, a mountainous band of continuous rock types, with an annual precipitation ranging from 15 to 30 inches; and the basin and range lowlands, characterized by alluvium-filled valleys bounded by steeply rising mountain ranges and ephemeral or intermittent streams, with an annual precipitation ranging from 4 to 12 inches (Eychaner and Rehmann, 1991; Anderson and White, 1986).

The coefficient of variation of annual precipitation is larger in Arizona than in the rest of the United States due to the aridity of the state. Arizona and western New Mexico

receive most of their rainfall in the summer and/or winter, with the largest amounts occurring in July and August. At any point in Arizona, winter precipitation will be more variable from year to year than summer precipitation. Winter precipitation is also more closely correlated to annual precipitation than is summer precipitation (Sellers, 1960).

Significance of Channel Entrenchment

Hereford (1992) presents a detailed report of the history and possible causes of channel entrenchment of the San Pedro River in southern Arizona. This study evaluates the mechanisms which initiated the entrenchment of this river channel in the late 1800's and early 1900's, and discusses the possible effects of land use, climate change, and variability. While it is known that a series of floods initiated channelization, the mechanisms responsible for the flooding are subject to debate.

Early researchers attributed entrenchment initiation to overgrazing of grasslands by livestock in the late 1800's.

> *When the rain did finally come it fell in torrents, and there was no grass to slow the runoff nor hold it long enough for the water to sink into the ground. The resulting rushing water stripped the topsoil from the land* (Peplow, 1958).

Following degradation of the rangeland, a period of erosion of land and stream channels occurred due to the inability of the land surface to retard and absorb flow. This caused runoff volumes and velocities to be higher than normal for the established natural gradient. One result of such higher flows was the backcutting (headcutting) and deepening of the channels and the formation of new stream channels. This served to intercept the groundwater table to a greater degree than previously in many places, thus increasing the flow of water from the underlying aquifer and lowering the water table. Also, decreased infiltration through the soil surface and percolation to the groundwater table reduced the available groundwater to feed the streams. Together with decreased recharge into the groundwater table, this headcutting of the stream channels depleted the groundwater which provided the source for perennial baseflow at a faster rate than could be replenished. Thus, streams that were once perennial became ephemeral or intermittent, having flow only during certain periods of the year or only during storm events (Young, 1994).

Historians regard the missionary era as the beginning of the cattle industry in Arizona. If so, then cattle have grazed the open ranges of Arizona in economically significant numbers for more than 300 years. Reports indicate significant grazing in the Upper San Pedro River Valley 40 or more years prior to documented entrenchment. In 1831 the Babocomari Ranch on the Babocomari River (a tributary of the San Pedro) had 40,000 head of cattle and a large number of mules. Reports beginning in 1846 describe evidence of extensive grazing and the presence of large herds of feral horses, donkeys and cattle. Cooke (1964) reported evidence that cattle were as abundant as buffalo on the Great Plains. In the 1870's and early 1880's the population of Tombstone exploded, bringing with it an era of large-scale cattle ranging in the area. Estimates of cattle during the mid-1800's within the San Pedro drainage area range from 50,000 to 100,000 head (Hereford, 1992). It has been disputed that such a large number of livestock could not be supported without the aid of developed water sources, but Hereford (1992) suggests that developed water sources were probably unnecessary in the early to mid-1800's (Young, 1994).

These historical accounts, along with other information, undermine the hypothesis that grazing was the sole factor in the heavy flooding of the late 1800's. With the date of initial entrenchment estimated around 1890, reports of heavy grazing at least 40 years prior to this date cast some doubt on grazing as the single cause of entrenchment of the San Pedro River. In general, estimation of past range conditions is inadequate to quantitatively assess the hydrologic impact of grazing on rangelands, making it difficult to assess the

precise effect grazing had on channel entrenchment of the San Pedro River. Adverse range conditions in the late 1800's may have been caused by adverse climatic conditions as well as grazing practices (Young, 1994).

It is hypothesized that the climate at the end of the 19th century may have been different than that of the previous 300 years, and that entrenchment of river channels in the region during this period may have been the response of alluvial systems that were not in equilibrium with the large floods that occurred in the late 1800's and early 1900's. Channel morphology is controlled by the frequency of channel-forming floods, and climate directly controls flood frequency through rainfall (Young, 1994).

Climate Fluctuations

Records of the annual flood series of the Santa Cruz River at Tucson show a lack of uniformity in the seasonality of flood peaks. These shifts on the Santa Cruz coincide with apparent shifts in flood seasonality and magnitude elsewhere in the Gila River Basin. The frequent occurrence of floods on the Santa Cruz in recent years has led many experts to the conclusion that the annual flood series for this river is nonstationary, and that all floods on this river are not derived from the same population of hydroclimatologic conditions (e.g., El Niño Southern Oscillation (ENSO) versus non-ENSO conditions). Changes in land use have been blamed for this nonstationarity, but this does not explain why larger floods are also occurring in the headwaters of the Santa Cruz, where land use changes have been minimal. Another hypothesis is that there are low frequency shifts in the climate on a time scale of decades that have led to changes in the type, intensity, and/or frequency of storms that cause flooding (Webb and Bentancourt, 1992).

In analyzing hydroclimatic records of the Santa Cruz River for the periods of 1900-1929, 1930-1959 and 1960-1986, it was discovered that the amount of precipitation at the University of Arizona in Tucson changed after 1960. From 1930-1959, summer floods accounted for 97% of annual flood peaks, while summer floods accounted for only 61% of annual peaks from 1960-1986. Winter and fall floods on the Santa Cruz accounted for 53% of annual peaks before 1930, 3% from 1930-1959, and 39% after 1960 (Webb and Bentancourt, 1992).

A study of precipitation records in Arizona and western New Mexico determined that from about 1921-1924 until 1956, the 20-year average annual precipitation in Arizona and western New Mexico decreased by about 25%. The sharpest drops during this period occurred in the northern half of the region under study. In Jerome, Flagstaff and Natural Bridge, the 1960 20-year average precipitation was about five inches lower than it was in the early 1920's. It was also discovered that from 1850 to 1956, precipitation in the region of study passed through two wet and two dry phases. This represented a statistically significant recurrence cycle between 40 and 67 years (Sellers, 1960). Another study based on paleoflood analysis of sites on more than 20 rivers in central Arizona and southern Utah indicates periods of large flooding around 800-1000 A.D., 1400-1600 A.D., in the late 1800's, and at the present. This study also concluded that the last 100 years is a period of relatively high flood activity (Ely and Baker, 1990).

Tree Ring Studies (Dendrochronology)

Two tree ring studies have looked at climatic variation in Arizona and the Southwest to the 14th century. Tree rings provide a continuous record of both vegetative and climatic change. Narrow rings can represent years of extreme drought, or, if persistent during the early growth period of the tree, they may indicate early growth in a highly competitive environment. Tree growth depends upon the abundance of soil moisture, which in turn can be affected by climatic variability (Phipps and McGowan, 1991).

Smith and Stockton (1981) reconstructed streamflow for the Salt and Verde Rivers, using tree ring data to extend annual season runoff records back to 1580. The assumption

in this study is that the sample trees used responded to and recorded the same climatic input that affects streamflow discharge. Their study indicates that several periods of sustained low flow occurred in the two river basins that were more severe than anything since 1890.

The Salt River Basin study (Smith and Stockton, 1981) calibrated reconstructed discharges to October through March, April through December, and total annual observed discharge. The study discovered that the means for the 80-year periods from 1740-1819 and 1900-1979 were significantly greater than those for the remaining three 80-year periods (1580-1659, 1660-1739 and 1820-1899). These two periods, however, were not significantly greater than the 400-year mean. There was an above average number of high seasonal flows from 1900-1979 in comparison to the 400-year period, and several periods of sustained high and low flows were noted. The period of 1902-1920 was the wettest period in the entire reconstruction, and the only periods that came close to this occurred from the mid-1780's to the mid-1790's. A sustained low flow from 1728-1739 dominated the long-term low flow means. During this period annual discharge was only 43% of the annual mean. The driest 5-year period ended in 1670. This drought is known to have occurred over the entire Southwest, causing considerable hardship to the Pueblo people living in the area. A return period of roughly 22 years was calculated for extended low flow periods.

The Verde River Basin study (Smith and Stockton, 1981) reconstructed the October through April and December through March flows only. This was done for calibration purposes to avoid complications brought about by surface water diversions for agricultural purposes during the period of recorded flows. There were differences during the low flow ends of the October-April reconstruction which were attributed to spring-fed baseflow on the Verde River. In this study, high flows in the early 1900's dominated the 5-year to 25-year means. The greatest 50-year mean occurred in the mid 1800's. The most severe period of low flow on the Verde occurred from the mid-1770's to the mid-1880's. In general, periods of flow on the Verde River were found to match those of the Salt River.

Another study by Stockton and Jacoby (1976) reconstructed water supply and streamflow trends on the Upper Colorado River Basin (UCRB). This reconstruction similarly found that the period from 1906 to 1930 was the greatest extended period of high surface runoff in the entire 450-year reconstruction period. Low flow periods from 1868-1892 and 1564-1600 were of longer duration and greater magnitude than any other period during the entire gaging record. Throughout the period from 1896 to 1971 there were no extended periods of drought comparable to those of the late 1500's or late 1800's. From the 1930's to the 1960's, all subbasin reconstructions showed downward trends that were more pronounced than at any other period in the reconstruction.

The El Niño Southern Oscillation (ENSO)

Precipitation patterns in certain parts of the world are teleconnected, or related over long distances. A typical example of this is the southwestern U.S., which occasionally has abundant rainfall, while the northwestern U.S. undergoes drought. The climate in southern Arizona is teleconnected with the equatorial Pacific Ocean.

Teleconnections are particularly pronounced during the ENSO which involves the appearance of unusually warm water (called El Niño—"The Child") in the equatorial eastern and central Pacific Ocean. This phenomenon occurs about every 3 to 5 years and is associated with abnormally low sea level pressure near the equatorial Pacific Ocean. Worldwide meteorological and oceanographic conditions are affected by ENSO, and indices have been developed to determine its presence. One index measures precipitation in the Line Islands of the equatorial Pacific Ocean; another, the Southern Oscillation Index (SOI), measures the difference in sea level pressure between Darwin, Australia, and Tahiti (Webb and Bentancourt, 1992).

During ENSO conditions, the hydroclimatology of the southwestern U.S. experiences increased variability. The probabilities for generation and recurvature of

tropical cyclones change during ENSO conditions, and the advection moisture needed to fuel monsoonal storms is reduced. In theory, ENSO conditions might reduce the number of monsoonal storms and increase the number of frontal systems and tropical storms that affect Arizona.

VEGETATION CHANGES

Causes of Vegetation Change

Historical accounts verify that prior to 1880, southeastern Arizona consisted primarily of grasslands. In 1870 the Santa Cruz Basin "bottom-lands resembled meadows being covered with luxuriant grass and but a few trees." In the San Pedro Basin in 1846-1847, the journal of the march of the Mormon Battalion noted that "the Majority of the valley has good grass . . . the bottoms having very tall grass." In 1878 Sulphur Spring Basin was "without either running streams or timber, but covered to a great extent with fine grass," and the San Simon Valley was "covered with grama grass" (Cox, et al., 1983). Along the San Pedro River, marshy areas, or *cienegas*, were continuous along the stream course. The sparsity of riparian vegetation along the San Pedro river bottom during this period is attributed to a high water table and the marshy conditions associated with *cienegas* (Hereford, 1992).

Today, the regions described above are dominated by shrubby plants or dense groves of riparian vegetation. Around 1880 to 1890 the entrenchment of many rivers and streams in southeastern Arizona was initiated by severe flooding. The entrenchment of these channels is associated with widespread and dramatic change in vegetation cover throughout the region from 1880 to 1930. Changes in vegetative cover continued from 1930 to the present, but at a slower rate than prior to 1930 (Cox, et al., 1983; Hereford, 1992). Since channel entrenchment is closely associated with vegetative change in many causes and effects, it will be included in this presentation to enhance historical and technical perspective.

Channelization aids in eliminating the process of natural shallow groundwater recharge, and can therefore be directly connected to vegetation changes. Prior to channelization in lowlands, water moving into channels was spread over broad areas through dense stands of grasses. This condition resulted in slow water movement into channels and continuous annual aquifer replenishment. The effect of channelization is to rapidly convey water away, giving it less time to recharge shallow aquifers. Today, runoff in southern Arizona is characterized by brief periods of intense flooding separated by long periods with no flow. Rapid urbanization led to further lowering of water tables through increased pumpage of shallow aquifers. A deeper groundwater table results in a favorable environment for the proliferation of riparian vegetation at the expense of grasslands along river bottom lands. The development of riparian forest along the San Pedro River in conjunction with channelization is an example of this process.

The effects of grazing on vegetation cover in Arizona from 1890 to the present are blamed on overstocking of rangelands during wet periods, followed by the reduction of livestock in dry periods. This continuous cycle reduces perennial grass productivity and the livestock-carrying capacity of the land. Continuous and excessive use of perennial grasses slows plant recovery and brings about a favorable environment for the invasion of woody plants (Cox, et al., 1983). The presence of range animals is associated with compacted soil surfaces (Branson et al., 1981) and larger areas of bare soil (Lusby, 1970), resulting in less infiltration and greater runoff.

Climate variations, such as changes in the seasonality of precipitation, also affect vegetation cover. In general, high intensity rainfall events weaken vegetative cover by damaging litter and soil stability, while low intensity rainfall events strengthen vegetation.

Grass production and survival is particularly sensitive to variations in precipitation (Hereford, 1992).

EFFECTS OF EARTHQUAKES ON THE HYDROLOGIC REGIMEN

Earthquakes have the potential to alter the surface and groundwater hydrology of entire regions. Some effects are immediate, while others take time to manifest themselves. Faulting in alluvium can produce groundwater barriers that affect the existing flow regimen (Bell and Katzer, 1987). Compaction and tilting of valley floor sediments can force groundwater from storage, showing itself in discharges from wells, springs and fissures (Bell and Katzer, 1987). Changes in the land surface can affect stream gradients, leading to increased channel erosion (Bell and Katzer, 1987).

Documented Cases

The May 3, 1887, earthquake in San Bernardino Valley, Sonora, Mexico (estimated 7.2 on the Richter scale), caused 51 deaths in northern Sonora and major destruction of property in southeastern Arizona. Effects on the hydrology include accounts of "geysers" of water bursting forth from fissures, the appearance of new springs or the disappearance of existing ones, permanent changes in wells, and the augmentation or depletion of streamflows. Numerous wildfires sparked by falling rock may have permanently affected regional hydrology. The overall effects of this earthquake on the hydrologic regime of southern Arizona and northern Sonora may best be described by Goodfellow, who in 1888 stated:

> *Of the effects of the tremblor, none have been of greater interest or more importance than the modification of the water-supply of the shaken district. During the first shock, all over the area of severe and even moderate vibration, the phenomena of water-craters were exhibited. This however, was merely a temporary affair, the flow ceasing as soon as the violent shaking was over. It is the permanent re-arrangement of the water distribution which we have to consider. Many apocryphal stories have been told of the wonderful increase of water in the Yaqui and other streams immediately succeeding the earthquake. In addition to the outpouring of the crater water, many springs were made. The latter effect was not, however, an instantaneous one. In most of the rivers and springs where there has been increase, at first they were almost dry; then in a few days or weeks there was a gradual augmentation of water, this antedating the rainy season. At the present time there is an alteration in the water supply, with others, of the following streams and springs; the rivers of the Fronteras, Yaqui, and San Bernardino, the springs of Penuelas and several others with uncertain names; the arroyos of the passes, Elias, Elisu, and Cabellera. Most important is the Yaqui River. This gradually gained in volume after the first diminution, until the flow equaled its winter amount. The San Bernardino is now flowing from head to mouth, a thing never before known at this season of the year, and is said to be gaining. Several important springs on the eastern side of the mountains, opposite Babispe in Chihuahua, were increased in size, notable is Penuelas on the Carrettas Ranch. A number of entirely new springs were started. In fact over the entire seismic region, the water supply has visibly augmented* (DuBois and Smith, 1980).

Accounts of Changes in Hydrology

In Tucson, it was noted that "the deep well in the back of the McKay house dried up soon after the [San Bernardino Valley] quake. Previously the well had ample water" (DuBois and Smith, 1980).

In addition to those cited above by Goodfellow, numerous other accounts are cited of changes in stream baseflow resulting from the 1887 San Bernardino Valley, Sonora, Mexico, earthquake. In St. David, Arizona, the San Pedro River changed from "a creek narrow enough to jump across to a wide river bed." In the Huachuca Mountains of Arizona, "canyons which had small streams dried up. Some had water return in 12-15 years, but some never did return." In the San Bernardino River Valley in Arizona, the "river swelled to a volume usual in the rainy season of summer . . . . Fields had become green and the air moist with prevailing fogs" (DuBois and Smith, 1980). These are just a few examples of the accounts of this earthquake.

In Babocomari, Arizona, "a spring sufficient for the ranch house and for irrigation of a large garden dried up and never returned" as a result of the San Bernardino Valley earthquake. In Charlestown, Arizona, "spring fed streams suddenly stopped flowing." In Cochise County, an account claims that "Bear Springs, near Ft. Bowie, are no more, the earthquake having knocked the bottom out of them" (DuBois and Smith, 1980).

A few accounts exist of the disappearance of lakes and swampland resulting from the 1887 San Bernardino earthquake. In Cochise County, Arizona, "a lake covering a number of acres between the San Bernardino and Batetto ranches disappeared entirely almost immediately after the shock. The lake was known to contain many fish, but none were left on the bottom." In the San Pedro River valley, a small lake was reported "closed up," and in St. David, Arizona, "swamps seemed to be swallowed up. Clay colored and sandy washes had taken the place of some scum covered areas" (DuBois and Smith, 1980).

Interestingly, the disappearance of the marshy *cienegas* of the San Pedro River and its eventual entrenchment coincide with the occurrence of this earthquake. Hereford (1992) and others date the initiation of channel entrenchment on the San Pedro River around 1890. The channelization of many other streams and rivers in southwestern Arizona also occurred in this time period. Hereford hypothesized that the earthquake may have lowered the water table in the region, preconditioning the channel for subsequent entrenchment. This is somewhat supported by the disappearance of swamps cited above.

Accounts of Other Physical Effects

Falling rocks from this earthquake sparked wildfires. In Bavispe, Mexico, "the hills flamed up, burning the grasses almost totally. Every mountain range within sight of Bisbee (Arizona) was on fire." Evidence suggests that the fires may have resulted in permanent vegetation change. In Charlestown, Arizona, "rains which came later washed soil from fire weakened grass roots. Thorny brush replaced it, the land was no longer suitable for cattle ranching, and the cattlemen soon left." In the San Pedro River Valley of southeastern Arizona, "falling rock caused sparks which started fires which burned out the entire valley; 50,000 head of cattle died in the fire, or from starvation after it. Torrential rains washed ashes and topsoil into the San Pedro several months later. Brush replaced the grass and the loss of topsoil was followed by erosion. The range never came back and will not carry a quarter as many cattle as it did in 1887" (DuBois and Smith, 1980).

Seismic events have a substantial effect on the hydrologic regimen of large regions through changes in groundwater levels, stream baseflows, spring discharges and channel morphology. The 1887 San Bernardino earthquake clearly displays the potential effects of seismic activity on the hydrology and water resources of Arizona watersheds in the future. This earthquake may have been partially responsible for entrenchment of many southeastern Arizona streams and rivers through its alteration of the shallow groundwater

table and starting of wildfires, both of which may have brought about long-term vegetative change and subsequent changes in rainfall/runoff relationships.

In 1940 John Culley wrote of his life on the range in *Cattle, Horses and Men of the Western Range*. He addresses the deterioration of the western rangelands as follows:

> *There has been a vast ideal of publicity given by the press and magazines of the country during the last few years to the wide destruction of our western ranges. Government departments too have dealt exhaustively and sometimes spectacularly with the subject. And the burden of blame seems to have fallen on the cattlemen. But most of what has been written has been the work of professional journalists without any first hand knowledge of what they were writing about, or else the rather aloof comment of the scientific investigator.*
>
> *There is no question but the range was disastrously overstocked. Nevertheless not too much blame should be laid on the cowman for this condition. In the first place the system of open range and community grazing which prevailed afforded him little opportunity for estimating the capacity of range pasture . . . . [The] depletion of the range has proceeded by fits and starts. It is generally ascribed to overloading on the part of the stockmen. Yet there are instances in which the evidence is shaky, to say the least.*

Culley (1940) goes on to address the invasion of foreign weeds and the breaking up of range sod by "grangers" (farmers) as having dire effects on the rangeland — *"And they've broken up the grama, and our lives, our hearts."*

So, who is to say what exactly was the cause of changes in the watersheds of modern Arizona. Obviously, man's activities can exacerbate and possibly accelerate such changes. However, such changes may occur as a result of natural phenomena over time, without the presence of man's activities. Attempts to predict what conditions might be like today without man's intervention, or to predict what conditions might have prevailed prior to man's arrival are speculative, at best.

CONCLUSIONS AND DISCUSSION

1. Water rights adjudications on the Gila River and Little Colorado River watersheds in Arizona have been ongoing since 1975. These litigations are enormous in scope simply by the number of individual claims and claimants. Determination that certain classes of uses, e.g., stockwatering and stockwatering ponds (stockponds), are *de minimis* in character would eliminate over 60% of claims from litigation.

2. The ASLD-EMV method produces an accurate estimation of the original as-built capacity of stockwatering ponds over a wide range of sizes and configurations. Thousands of stockpond uses have been filed in the adjudication utilizing the ASLD-EMV method of measurement, thus an accurate cumulative volume of existing stockponds is known.

3. Based on an average ER of ≤ 1.0, the cumulative volume of stockponds on various watersheds throughout Arizona has been shown to be $<10\%$ of total watershed production, even during low flow years. Such volumes are smaller than stream gage error, and the impact of any single stockpond is impossible to determine.

4. Modeling studies indicate the impact of stockwatering ponds is negligible (*de minimis*) on downstream water users.

5. Other physical changes (changes in climate, earthquakes, etc.) have greater impact on watershed hydrology than stockponds.

6. Early researchers cited overgrazing of rangelands as the primary cause of vegetation change and channelization. A series of floods in the late 1880's and early 1900's initiated channel entrenchment. It is now believed that both land use and climate change contributed to both vegetative change and channelization.

7. Arizona climate—southern Arizona in particular—is teleconnected to the equatorial Pacific and influenced by the El Niño Southern Oscillation. Regional changes in the seasonality and intensity of rainfall in southern Arizona are recorded in many studies. Speculation that the early years of this century have been the wettest in the last 450 years coincides with channel entrenchment and vegetative change throughout southern Arizona.

8. A large earthquake epicentered at Batepito in Sonora, Mexico, on May 3, 1887, disrupted the water table in many areas of southern Arizona and preconditioned channel systems for rapid flood-induced entrenchment. This earthquake had documented hydrologic effects, including changes in water table elevations, streamflow discharges, and the development of fissured zones.

9. Real and social costs of adjudicating individual stockponds are far greater than the value of the water rights associated with such uses. A decision must be made as to whether it is in the best interest of all claimants to individually litigate small uses such as stockwatering.

10. The *de minimis* issue is presently before the Arizona Supreme Court awaiting ruling on appeal from the lower court.

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RESEARCH NEEDS

Research design considerations to evaluate efficacy of wildlife water developments

James C. deVos, Jr., Warren B. Ballard, Steven S. Rosenstock. Arizona Game & Fish Department, 2221 W. Greenway Rd., Phoenix, AZ 85023

Abstract: The Arizona Game & Fish Department (AGFD) initiated a wildlife water development program in 1946. The first developments were targeted to increase population levels of game birds; primarily Gambel's quail (*Callipepla gambellii*) and to expand populations of desert wildlife into arid, unwatered areas. More recently, wildlife water developments have been constructed to benefit populations of mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*), desert bighorn sheep (*Ovis canadensis mexicana* and *O. c. nelsoni*), and other species. The premise for this development program was that water was a key component of wildlife habitat and in the arid Southwest, water was limited. Further, natural water resources were thought to be declining as evidenced by the widespread practice of water diversions for agricultural and municipal purposes. For nearly 40 years, the need for and benefits from these developments went unchallenged. Beginning in 1986, resource managers and those interested in desert environments began to question the benefit and environmental impacts resulting from these developments. In response, the AGFD initiated a literature review to assess the impacts and benefits from wildlife water developments. In all, over 220 peer-reviewed or agency reports were evaluated and few were found with empirical evidence on benefits or impacts of these developments. We found that most studies were correlative, failed to consider confounding factors such as weather, or were of short duration. Also, few studies were originally designed to assess impacts of water developments. As a result of this review, we believe it is essential that resource agencies conduct research to address the criticisms of developing water sources to benefit wildlife. To do this, there are experimental design considerations that need to be incororated into future research.

Key Words: benefits, experimental design, impacts, water development, wildlife

Introduction:

That many early resource managers believed water was important to maintaining or enhancing wildlife populations is not surprising. Few people who have observed wildlife in free-ranging settings have failed to see animals drink free-standing water. Further, early wildlife scientists such as Leopold (1933) wrote that water was a fundamental component of wildlife habitat. At the time, this thinking was extended to conclude that otherwise suitable habitat that lacked water would either lack wildlife, or if wildlife were present, the populations were at low densities (Wright 1959).

Based upon the pervasive view of the importance of water to wildlife populations, the AGFD initiated a management program to provide water for wildlife in 1946 (Schadle 1958). These first wildlife water developments were built to provide water for gallinaceous birds; primarily Gambel's quail. Subsequently, water developments have been designed and placed to benefit a wide range of wildlife including: mule deer, pronghorn, elk, and desert bighorn sheep. More recently, water developments have been used to aid in management of native ranid frogs (*Rana* spp.).

The AGFD water development program continues to the present. In all, nearly 900 water developments have been constructed since the inception of the program. This program requires considerable expenditure of funds to maintain or develop new sites. The cost of wildlife water units vary due to different design and logistic requirements, however, the current average cost per unit is approximately $35,000 (Mouton and Lee 1992). In 1995, AGFD expended $360,000 to construct 7 new developments and renovate 8 previously constructed units. Maintenance of other wildlife waters cost $397,000. In addition, hauling water to units that failed to recharge due to drought conditions cost approximately $194,000 for a total project expenditure of nearly $951,000 (AGFD unpub. data).

For many years, the wildlife water management program continued without controversy and was supported by most Federal land management agencies. Recently, Tunnicliff et al. (1986) questioned the need for additional artificial wildlife water developments in southwestern Arizona. They posed the possibility that wildlife water developments were resulting in adverse impacts to wildlife and their habitat by expansion of non-endemic plants and animals, and that there was no basis for the belief that benefits were derived from these artificial waters. Subsequently, Sanchez and Haderlie (1990), Broyles (1995, 1997, and Brown (1997) raised similar questions.

Evaluation of previous research:

In response to the concerns expressed regarding impacts from and efficacy of wildlife water developments, we conducted an extensive review of existing literature pertaining to the effects of these developments. We examined over 220 published and agency reports (Rosenstock et al. in prep.) and found few sources that provided empirical data on the benefits or impacts of wildlife water developments. Our evaluation of the literature identified 3 major limitations in water development research conducted to date.

Correlative studies:

Many of the water developments built in Arizona have been built to benefit desert bighorn sheep. Much of the published literature pertaining to desert bighorn sheep and water use, correlate movement patterns with water distribution. Leslie and Douglas (1979) reported that desert bighorn movement patterns were affected by the placement of newly developed, artificial water sources in the River Mountains of Nevada. Similarly, Wakeling and Miller (1989, 1990) documented that movement patterns of a transplanted population in the Superstition Mountains in central Arizona were non-random in relation to water. These studies suggest that desert bighorn were found closer to water, at least seasonally, than if the movements were random. The opposite pattern has also been documented in the literature. Krausman and Leopold (1986) studied an endemic population of desert bighorn sheep in western Arizona and found that areas used by sheep were 3 times farther from free water than areas not used by bighorn. Krausman and Etchberger (1995) found that desert bighorn home ranges and habitat use were not influenced by development of several water developments designed as mitigation for construction related to the Central Arizona Project.

Several other wildlife species have been reported to use habitat in proximity to water disproportionately to areas farther away from water. Biggs et al. (1997) reported that 75% of the elk locations they obtained were within 1.6 km of water, with only 10% >3.2 km from water.

Rautenstrauch and Krausman (1989) found that desert-dwelling mule deer moved to areas with water and were restricted to portions of their home range in proximity to water. In a study in central Arizona, Ticer and Miller (1994) documented that pronghorn fawns selected bedsites 400-800 m from water and avoided areas >1.2 km from water.

In our opinion, these studies, and many others that relate movements and habitat use to water distribution fail to consider alternate habitat-related factors for these selection patterns. For example, Wright and deVos (1986) reported that Sonoran pronghorn (*A. a. sonoriensis*) movements were non-random in relationship to water sources. During summer months, Sonoran pronghorn were found closer to water than other seasons. Although not quantified, observation of Sonoran pronghorn during the summer found extensive use of large ironwood trees (*Olneya tesota*), apparently to assist in thermoregulation. An alternate explanation for the pattern Wright and deVos (1986) observed was that it was the shade from ironwood trees that attracted Sonoran pronghorn to more mesic areas rather than free water as originally reported.

Hunter success and hunter effort are other correlative measures used to assess efficacy of water developments in benefiting wildlife that has been reported and refuted in the literature. deVos and Clarkson (1990) reported a positive correlation between the number of artificial water developments and hunter participation in southwestern Arizona. In contrast, Brown (1997) failed to find a correlation between artificial developments and deer hunters in another desert area of Arizona. Webb and Gallizioli (1963) indicated that they could measure no difference in the number of Gambel's quail harvested in areas with or without water developments. It is possible that these studies used a measure (hunt participation or success) that may be unsuitable for evaluating wildlife response to water developments.

We conclude that the correlative studies provide valuable information in assessing the responses of wildlife to water developments, but that few provide more than inference to any benefit/impacts from this management program.

Short duration studies:

Most of the water-related studies we reviewed were of relatively short duration. Studies that had been done by graduate students usually entailed 2-3 years of fieldwork. Agency reports seldom exceeded 5 years and were often shorter. The short-term nature of these studies could account for some of the conflicts we found in the literature. These studies often did not include more than 1 environmental extreme such as drought, above average rainfall, or timing of rainfall that we believe are important in understanding wildlife use of free water. For example, Leopold (1977:183) suggested that quail can survive desert conditions without drinking water if succulent insects and vegetation were present, or when cool weather reduced water requirements. He added the caveat that "normally, however, arid land quail require drinking water to survive periods of sustained heat and drought." Studies conducted in periods of climatic extreme, would likely lead to erroneous conclusions. In our review, we noted that few studies took into account the climatic conditions that occurred during the study period.

Narrow focus:

Many of the criticisms of water developments have implicitly raised issues related to broad-based ecological processes. We did not find published literature that reflected investigations of such processes, but rather, studies focused on a single organism or at best a

small suite of allied organisms in relationship to some aspect of water use. In the absence of a research effort that incorporates a wide variety of floral and fuanal components into the experimental design, understanding the potential interactions between organisms will not be possible. Additionally, many of the studies we reviewed used relatively small study areas that we consider a limitation, particularly in understanding the influence of water developments on wide-ranging animals such as mule deer or mountain lions (*Puma concolor*).

Recommendations for future studies:

Based upon the limitations we identified in our review, we formulated a set of guidelines should assist in answering questions regarding the efficacy of building waters for wildlife that persist. We point out that these guidelines are general in nature and any research should incorporate these considerations into a site-specific experimental design.

Manipulative studies:

Based upon our review of the literature, we believe there are few empirical data available to evaluate the efficacy of water developments on wildlife. We believe that such data can only be obtained from manipulative studies. There are 2 primary approaches that could be used to assess the benefits/impacts of wildlife water developments.

One approach would be to develop an artificial wildlife water in a location that has no perennial water source. Additional design considerations that need to be incorporated into the experimental design are:

1. Paired areas that will allow for a treatment (artificial wildlife water) and control. The paired areas need to be matched to minimize confounding factors such as different vegetation type, terrain, or wildlife densities.

2. The area selected should support a diverse suite of wildlife to allow evaluation of differential responses to water development. This will also allow for assessment of interactions between wildlife species/groups.

3. Land ownership/management needs to be secure for the duration of the study, which will likely require a minimum of 10 years. Changes in management will add a confounding factor making data interpretation difficult, if not impossible.

4. The study area needs to be large enough to encompass a radius at least equal to the home range of the most mobile wildlife species studied.

5. The study area needs to encompass sufficient area to establish similar habitat blocks to allow for establishment of treatment/control areas.

6. Predevelopment studies will need to be constructed to ensure an adequate baseline of existing flora and fauna is obtained prior to the treatment.

An alternative to development of a new wildlife water would be to remove an existing water from an area. This experimental approach was used by Hervert and Krausman (1986) and a response by mule deer was detected. If this approach is taken, the 6 factors listed above need to be incorporated into the study design.

Long-term studies:

To detect wildlife response to artificial water development will require long-term studies. We believe that rather than set a predetermined length of time for these studies, a set of environmental criteria be should be established that would guide study duration. To be effective, such a study would need to be of sufficient duration to include both above and below average rainfall. An alternative to using rainfall would be to use a measure such as the Palmer Drought Severity Index (PDSI) which is a more accurate measure of climatic conditions than rainfall alone. Regardless of the index used, it is important that the study participants agree *a priori* on the decision points guiding the project.

Study team approach:

To be efficacious, and to be able to quantify floral and faunal responses and interactions, a wide variety of organisms need be included in the research. To best accomplish this, we suggest that a team focused on particular taxa be used in the data collection phase of the project. To evaluate interactions between wildlife species and their habitat the following taxa should be studied: ungulates, including at least mule deer, desert bighorn, and pronghorn; passerine birds; small mammals including bats; reptiles and amphibians; carnivores, particularly coyotes (*Canis latrans*) and mountain lions; invertebrates, particularly native and exotic pollinators; and native and exotic plants. To accomplish this diverse study in a scientifically sound fashion, would require expertise in such varied areas that we believe a study team for each of these plant/animal groups would best meet study demands. Each team would be responsible for developing sampling protocols for their area of expertise. Each team would collect, archive, and analyze data independent of the other study teams. A project manager will coordinate the work efforts of each team to avoid data collection conflicts or impacts on other teams. A steering committee comprised of at least 1 member from the following agency/organizations should oversee the project to avoid criticisms of researcher bias: the state wildlife management agency, a federal land management agency, an academic institution, and an interested private citizen or non-governmental organization.

Conclusions:

We conducted an extensive literature review and found few studies that provided empirical data on the impacts/benefits derived from water developments. The primary reasons for the lack of results are related to inappropriate experimental design to address this question. The recommendations that we make here will minimize some of the problems that we identified. It is important to note, however, that this research will be difficult to conduct for several reasons. First, finding a suitable study area that meets the recommendations we have made will be difficult. Further, all of the land/wildlife agencies in the study area will need to make a commitment to maintaining the existing management of both land and wildlife resources for the duration of the study. Any modification in management approaches will introduce sources of

confusion making data interpretation difficult. Regardless of the difficulties associated with this research, it is important that the stakeholders in the water development program do whatever is possible to further the initiation of this project.

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PANEL DISCUSSION

Ray Lee, Moderator
Dr. Robert Ohmart
Professor David Brown
James deVos
Professor James Collins

Joe Feller: I am going to hand over the moderator role to Ray Lee. Ray Lee is another person who has made this Symposium work. The other panel participants will be three people you have heard from earlier in this Symposium: Jim deVos, of course; Jim Collins, from the Biology Department here at ASU; and David Brown, also from the Biology Department here at ASU. There is also going to be a fifth person on the panel, who you haven't yet heard from, who I am very pleased to have here, because I have worked with him a lot as my favorite and most admired expert witness: that is Professor Robert Ohmart, of the Biology Department and the Center for Environmental Studies here at ASU. Professor Ohmart is both an ornithologist and a riparian ecologist and has done very extensive research on a broad variety of wildlife in the southwest, so we are very appreciative that he will be joining us on the panel. Why don't people come on up.

Ray Lee: Thank you, Joe. I always wonder if I should preface my comments here with a disclaimer, because I noticed yesterday that when all the lawyers got up they were always making disclaimers. They were making disclaimers about their subsequent performances. I just kinda wondered what a couple of lawyers were talking about just before their moments of intimacy.

We started the Symposium yesterday with opening remarks made by four resource management agencies. Two of these agencies, the Arizona Game and Fish Department and the Bureau of Land Management, essentially said that, biologically, water developments were good and we are going to continue building them, but we are willing to look at them a little closer than we have in the past -- actually, like Jim was saying, start doing a little bit more research on them. Two of the agencies, U.S. Fish and Wildlife Service and U.S. Forest Service, indicated that water developments may not have been good and they could not show that there had been any beneficial effects from them; they may indeed have been disruptive and there was even mention of removing waters.

In the recent past, perhaps Friday's papers titled "Water for Wildlife," "Faith Versus Science," " Do Livestock Waters Help Wildlife?," "Reckoning Real Costs of Artificial Game Waters," probably would have been considered blasphemous. Now with the paradigm shifts in wildlife management from single species to biodiversity it is essential that we consider a much broader spectrum of impacts. We must now look at all of these species both before and after construction. Jerry Holechek came up with a great data set, the day before, talking about domestic animals -- how they were significantly impacted by distributions and distance from water. Now this data could very easily have been applied to wildlife, showing the unequivocal benefits of water to wildlife. On the other hand, Dave Brown used data sets to show that the investment in water developments had not been rewarded with increases of wildlife harvest. We

had a couple of spokespeople come up and talk about robbing Peter to pay Paul. What was the effect of capturing water, removing it from one place to another, and then what was the impact in the areas where those waters were removed from?

This brought us into yesterday afternoon's conversations, the legal aspects of rangeland water developments. During these discussions and probably, particularly during the cross examinations, the differences between the scientific method and the legal process became rather obvious to us.

What I would like to do is give each of the panel members the opportunity to make a few comments that some have prepared, some have not. What we are going to try and do then is -- we realize that the answers to what we have come up with in this Symposium are not going to just come out of the heads here. They are going to come out of, hopefully, many of the heads here. We have a recorder that we are going to be able to put down some of the comments that you come up with. For those of you who have been here since Friday, you have been here for a long time. I realize that you have been here and invested that much time . . . are here for a lot of reasons. Not the least of which is to get to get your opinion, your input brought forth. That is what we also would like to do.

The last thing, because I know these four gentlemen, I realize that if I don't say it now I'm probably very likely never going to be able to say it once the microphone passes, Jim deVos is talking about long-term research. I went to a meeting a couple of years ago over in California, where a biologist had been working with big horn sheep, deer, and mountain lions. He had been collecting data for twenty-three years, and it was great. He was able to show this curve that went like this (demonstration), and all the points running into it. It was perfect. Now the question was, did that curve reproduce itself this way or this way? Was the population now going to increase or decrease? One-hundred-eighty degree turn of events. Twenty-three years of data. He couldn't tell whether it was going to go up or down. Now, he has to continue collecting that data, twenty-three years wasn't enough. I wonder where would we be with Mendelian genetics now if Gregor had gotten a three-year government grant. With that, I think what we will do is we will start down at the far end and give Dr. Robert Ohmart the opportunity to discuss needs for future research.

Dr. Robert Ohmart Thanks. I feel a little like a fish out of water in that I have spent most of my career looking at riparian habitats, although I have worked some in the uplands, but I am struck by the similarities and parallels between developing water holes for wildlife and removing phraeatophytes in riparian habitats. Both of them intuitively seem like they should be done. Yet, when we really start looking at them under a microscope, one begins to see blurriness, one does not see the clarity that was there prior to it.

Now I am not saying that removing phraeatophytes for water salvage is a good thing. Intuitively, from an engineering standpoint they can see massive water salvage by doing this. Obviously it doesn't work out that way, but at the same time intuitively it seems worthwhile. I think this Symposium has been interesting in that it has brought together what we know and what we don't know about water holes. Like I say, working in riparian habitats, to me, a water hole is

something different than where wildlife gets water. It is where I always went to get a beer. It certainly has educated me, since I have never looked at water holes and worried about what wildlife was using them. Also, I think it brings out this intuitiveness and also it brings out some of our own thoughts as we look at wildlife, because unquestionably to you and I water is one of the, if not the, most limited resources in arid environments for us and for our existence. It may well be that we are, if you would, transferring our own thoughts and our own desires thinking that, yes indeed, we are helping wildlife.

The general information that Dave Brown presented day before yesterday I thought was extremely interesting, and although not rigorous in its approach, it is kind of interesting and compelling to me, and I have spent a lot of time looking for sheep out of helicopters as well as wild burros. When you see ten to twelve sheep per helicopter hour in some habitats, and you see forty or so sheep in other habitats -- and I understand that sheep can hide, and as we go out and monitor sheep with helicopters we scare them and many times they will simply run under a tree or run into a cave. So, maybe we have conditioned our sheep to the point of where we are only seeing two-thirds of them instead of however many we would see if they all ran when the helicopter came. Maybe we are seeing a little less. But even still, that is still a large disparity between the numbers observed on helicopter flights in Mexico versus numbers observed in helicopter flights in Arizona, based on an hourly basis. From this information that Dave presented he says that these habitats in Mexico that they were looking at, have high sheep numbers, are essentially waterless. I think that is probably real, because they are essentially waterless, or there is so little water it is probably insignificant as far as developing a water hole. If there was a water hole down there, I am sure, or even a potential for a water hole, I am sure that some Mexican rancher would have developed it and would have livestock grazing in those communities. All of the communities that I am aware of here in Arizona have been grazed for many, many years by domestic livestock, and the ranchers down there are just as aggressive in expanding grazing opportunities for their cattle as our ranchers are here in the United States. If these differences in numbers of sheep per helicopter hour are real, I think one has to ask the question, "what are the differences in Arizona habitats versus Mexican habitats?" I think in Arizona habitats we have penetrated into desert bighorn sheep habitat much more than they have necessarily in Mexico. We have penetrated with roads, with vehicles, and of course, our own presence in these habitats.

Well, are those penetrations enough to make the disparity, if there really is a disparity, in population densities between Mexican habitats with bighorn sheep and U.S. habitats with bighorn sheep? I suspect they are not. Another thing that has happened here, at least in Arizona, with tremendous numbers, is decades of overgrazing by domestic livestock. You just don't put an animal out the size of a cow that requires a thousand pounds of forage per month, dry weight, and not expect, especially in very arid habitats like we have here in Arizona, and not expect some dramatic changes in foliage volumes, plant species diversity, and plant species competition and these types of impacts to these environments. I mean, you can put them in riparian habitats and you can see dramatic changes in those kinds of situations. In arid habitats where productivity is less, it is all upland type of situations, you have got to be having some kind of tremendous impact on forage production, on forage composition and things like this. This could well be one of the major differences if there are truly differences between these numbers of bighorn sheep per hour of helicopter time.

Now, I think that if there are paired opportunities that we can gain much more information relative to bighorn sheep, their needs, waterhole developments, these kinds of things, by conducting paired experiments in Arizona versus Mexico, if indeed we can get some mountain ranges with some very tight both geological as well as size and adjacent to one another. I think that might provide more answers relative to what is going on relative to the value of sheep dependence on waterholes. I agree with Jim deVos it would be a long term thing. When I say long term I agree with him it should look at some cycles, dry cycles, wet cycles, these types of things. Ten years might be long enough, I am not sure, but I think the answers would be much more valuable than just sitting out here and studying a waterhole trying to see if indeed these animals. . . I don't know how you would ever assess that. I agree with Jim as well that you would want a team effort. I think you would want a plant ecologist, certainly people looking at sheep habitat, quantifying the habitat. You would want to look at food habits, and you would want to look at a very tight number of variables and try to control as many variables as you can by having paired study plots. Sheep biology, I think would be advanced tremendously because to my knowledge there is not a lot of information been generated from sheep in Mexico, certainly not using radio collared animals, certainly not using opportunities such as this to get at answers. You would also build a very strong or better relationship between Mexican biologists and U.S. biologists. Obviously, we would be carrying most if not all of the financial burden.

I think there is a lot to be learned in these dry mountain ranges or waterless mountain ranges, however you want to call them, if we compare them with mountain ranges in Arizona. I am still not convinced after hearing the data that bighorn sheep are desperately dependent on waterholes. I think prior to us coming, sheep populations thrived in areas where there simply weren't any waterholes. I think they still thrive there today. I think that is one area where we can make a lot of progress by using paired study plots.

Deer, I am convinced, are aided by waterhole development, especially does and fawns. My question on building waterholes for deer is more in my mind one of ethics. None of us had a say regarding the presence or absence of livestock in the west when we were born. They were here, we inherited them and we still have a hell of a lot of them, and there will be a lot of them probably when I die, hopefully less in riparian habitats before I die. It is my opinion that we have adequate deer habitat and deer range in Arizona without building waterholes to disperse those animals further. I haven't seen the data sets that have been supposedly done, and I assume that this is with regard to the Central Arizona Project. I am familiar enough with birds to know that anytime you start modifying or reducing foliage volumes you are going to have direct impacts on birds. I think you are going to have direct impacts on herbivorous lizards; I think you are going to have direct impacts on small mammals. I find it unbelievable that you can bring in more deer, consume more forage, and not have impacts on these little guys. I would suggest before we continue to develop deer watering holes we should definitely look at the pre-situation and follow that with monitoring in the post-situation.

As a deer hunter and someone who enjoys hunting wildlife, at the same time I have a very serious concern with the diminishing resources out there in the way of desert. For example, around Phoenix here we are losing an acre an hour or more. A hundred years ago those impacts were not very great, today we see that they are finite; and I think that we have got to take better

care of the resources we have or there simply are not going to be any for future generations.

Ray Lee: Thank you very much, Bob. The only protection we are going to provide these people is the fact that we are going to give each one of them the chance to speak before people start having the input on this point. David Brown from Arizona State University.

David Brown: Thanks, Ray. I just jotted down a few things that I thought should be in a research project to evaluate the effects of water developments, while eating my Burger King. I can talk a little less than Bob, because I think four or five of them were covered by either Jim or Bob.

One of them was pretreatment database, we heard about that. It has to be long-term, ten plus years. Jim talked about that; so did Bob.

A broad based approach, that was almost the same words, and then Bob said it has to be in the United States, or should be. I think I agree with that, because you are going to have to have some control over both areas, because it has to be a paired site. You can't have one area that is going to be far from another; they have to be relatively close because they have to have the relative same climatic pattern. You don't want some area that you can argue, "Well, that area has moisture available from the Gulf moisture versus this area that has both winter and summer precipitation, this area has winter precipitation only." It is another variable, you can't get into that. These sites should be paired, they should be fairly close and they have to be a lot larger than just a waterhole. I would think a whole mountain range is necessary. I think this is where we get into the difficulties. This is going to be an extremely difficult thing to do.

Another thing that has to be done is it has to be conducted in an unbiased manner. That is going to be hard to do, because if Jim does it he has an agency that has been committed for fifty years to building these things. Forest Service, BLM, the same thing. Maybe this multiple approach might be, I would have a very difficult time myself doing an unbiased study. You have to be very careful that way, because you have to get rid of all of these preconceived ideas. But I also think that the study area, besides being large and fairly close to each other, it has to be reversible. In other words, you have to be able to have a treatment area and a control area and after a certain length of time reverse those and treat one the way you treated the control area. That would imply that you would have to have some kind of public land management for a long term study like that, and that besides being close they should have the same land management operative.

Of course they have to be typically arid. You couldn't have a lot of other land use problems, changes, or other factors. In other words, you can't have one area that is going to be grazed, and the other area not grazed, or one that is grazed some time, and one that is not grazed ever. That is another variable that is going to be very difficult to work up against.

The last thing would be, where is this place? Where can we find a place in Arizona or New Mexico or Southern California that would meet these qualifications, because if you are going to have a pre-treatment program all these mountain ranges that I can think of, except those perhaps in Organ Pipe National Monument, are already developed for waters for wildlife. You

would have to either find a mountain range in which the water has not been developed or dry up an area where you have. One time I thought a possibility might be to pair the Harcuvar and the Harquahala Mountains. They are about the same size, but they both have water developments, but that would entail drying one of them up, and I don't think that it is politically possible to do that. You have too much commitment from the last umpteen years to manage the wildlife in there with waters. It is not going to happen.

One possibility might be to compare areas which are closed to grazing with areas that are also closed to grazing. In that light you might be able to pick a mountain range on a place like Organ Pipe National Monument, where you have no developments or grazing, not recently anyway. You used to be able to dry up the one you had, or two, and then compare that with an area on the Cabeza Prieta, which is a game range next door, which has had a lot of water development. The trick there will be to reverse the situation in ten or twelve years to see if you can track that in a reverse way. That may not be possible with the difference between park policy versus national wildlife refuge policy. Maybe the gunnery range might be a possibility there. That is going to be a real difficult thing to do and it may be no matter how much we come to agreement on the design, the actual practicality of finding the site that is going to be big enough, arid enough, and similar enough is going to be real, real tough.

Ray Lee Thank you, David. Jim deVos, from Arizona Game and Fish Department and hopefully from Arizona State sometime. Do you want to add something to what you began your talk with?

Jim deVos: Just a couple of points. Basically I said everything I knew about research already and probably then some.

One of the things I would like to expand on just a little bit from what Dave said, is he talked about the need to do the research in an arid location. One of the things I spent a long time trying to figure out, where one would do such a study. I think that the site needs to have dense enough wildlife populations that you are not dealing with some of the sampling problems that you have when looking at extremely rare organisms. That would compound the research design immensely. Haven't done a lot of looking, but some area around Hillside, Bagdad, some of those areas there, I don't know if they are devoid of water, but certainly have dense enough wildlife populations. My concern about Organ Pipe is that finding wildlife there of virtually all descriptions is a rare event. I have some nagging concerns in the back of my mind about doing it where wildlife populations are in fact very low.

The other thing that I think Dave said that is really important is whether anyone would approach research as biased or not; certainly everyone in this room would carry that stigma. I think one of the ways to get around the concern of bias in the design, is to have a strong oversight group that entails a group of experts, again hydrologists, maybe a lawyer, plant ecologist, etc., that sit and view the study design, the implementation, and the report preparation start to finish, kind of a government watchdog, not a government watchdog, but a watch beast, if you will, with many heads. They will keep the research not on the straight and narrow, because everyone would approach it that way, but we need to get past the perception that Game and Fish would be biased,

that Arizona State University would be biased or that anyone who did the work. There is always going to be the concern about bias in the approach. The way to get past that is have a strong oversight group that is well put together.

Paired sites are important, didn't mention it. It would also be nice to have a replicate in addition to the paired sites. Your thought about switching the design after a period of time is excellent. What we had talked about is four quadrants where you did research. Two where you did treatments and two where you used them as control. After some period of time you swap your treatments with controls. I think this is an important consideration. It is difficult to accomplish because once waters are built, trust me, it is more difficult to dry waters than it is to build them. You have some administrative hoopla to deal with that.

Ray Lee: Jim, thank you very much. Our last panel member will be Dr. James Collins, from Arizona State University.

Professor Jim Collins: Thanks, Ray. I always find these sorts of discussions and conferences really pretty tough. The image I have sort of had over the last couple of days is the classic parable of the blind man and the elephant, and depending upon where you start on these sorts of problems you often get to a pretty different answer. I don't disagree with many of the things that were said by these three gentlemen. I started from a somewhat different place, though, in that I think that if we look at the history of dealing with environmental questions, there isn't any sort of environmental issue where science has been put on the table or a particular scientific conclusion hasn't been overridden by other sorts of considerations, be they political or be they economic or be they humanitarian. It is rarely the case that the scientific answer in and of itself will carry the day, regardless of how good under any set of circumstances those data may be.

The case that we are dealing with, the set of issues especially with respect to water development in the west that sit at the intersection of law, science, politics and public policy. I think we used to think that scientific decisions could be made independent of law, politics and public policy. In fact, it is increasingly the case that it is clear that just isn't true. It used to sort of be true during the second world war. The notion of the scientific expert and the role of the scientific expert within society sort of began to emerge during the second world war within this country. There was a degree to which policy issues and political issues, especially legal issues, were put on the back burner, although it was quite clear that even with the development of the atomic bomb and then the H bomb, the scientific community had one sort of view later in the game, especially with respect to the hydrogen bomb. Political issues began to override even the best scientific advice that our Presidents were receiving at that time.

We have to keep, I think, that sort of framework in mind as we begin to think through then how the role of the scientific expert emerged within this society and was really fused with a variety of social issues during the cold war, especially. With the end of the cold war in the late 1980s we have had a particularly bright light thrown upon the role of the scientific expert — increasing needs for scientists to justify their role within this larger complex of legal issues, economic issues, political issues, and especially policy issues.

Increasingly it has sort of been economics that has been driving the special role for the scientific expert. As I begin to sort of think through the problems of water developments in the west, you really begin to start the argument, it seem to me, with interest groups. You can have public interest groups and you can have private interest groups with respect to the use of this particular resource. These interest groups will bring a particular ideology, they will bring a particular value system to the table as they begin to set up to work through what these problems are. I think we understand very little in the terms of basic research as far as how an individual's ideology will begin to then play out. In terms of how they are likely to respond to different sorts of confrontations, different sorts of data sets as they work through these particular kinds of issues.

In this country, in particular, since we are working within a democratic society we also bring another sort of baggage with us. Conservation questions are real easy often times within a dictatorship, as long as the dictator agrees with you. When the Sultan of Oman decided that he wanted to protect the Arabian Oryx it was pretty clear that that animal was going to be protected. There weren't any questions on the table from that point on, and all kinds of resources were available to protect that particular resource because of the nature of the society within which those decisions were being made. Our decisions are being made within a democracy. I think Fritz was right on this morning in terms of bringing us back to the traditions that began this country in terms of the Jeffersonian democracy. We begin to drag those traditions with us through all kinds of arguments and all kinds of interpretations of data sets as we sit down at the table and begin to try to negotiate these extremely complex issues within a society that takes individual rights, such as privacy, when you begin to work these things through and by the time you get to the end you are kind of wondering how did we sort of get to where we are and how do we negotiate our way out of these things?

Within our system we begin often looking as far as procedures and methods to work through these questions like water rights within the west. We can look to the legal system, and I think increasingly in interesting ways we are beginning to look towards alternative dispute resolution, things like coordinated resource management programs that John Brock talked about this morning. This is interesting to me personally, how they begin to emerge within a democracy as a way, especially at a local level, increasingly at a local level to begin to solve problems perhaps before they begin to get influenced by external forces. It is a way to keep control at the local level. I don't think we understand very well the role of local forces with respect to external forces in terms of controlling environmental questions and the resolution of environmental questions like water resources in the west. It is a place that seems to be wide open as far as social scientists are concerned. Again, I think that scientists tend to delude themselves that if you have yet another data set on a particular question then we will be able to clarify this issue to the point where it is going to be just absolutely unambiguous and no doubt everyone is going to wind up with me on this side of the table. When they don't we stand there and say, what happened? Where did it go wrong? I have the data, it is quite clear that the globe is warming up, why don't people want to listen to me?

Well, there are all sorts of other forces at work as to why people don't want to listen to you. I think then, as you look from law, you look from law to alternative dispute resolution, you look to scientists as a role of experts within society. This juncture begins to raise a variety of

questions. How to legally defend rights, for example, like property rights, alter research practices in types of scientific information that is accessible to researchers. How are the rights of information acquisition determined within these kinds of contexts? These are researchable questions as far as the legal community is concerned, as far as the social science community is concerned. What are the special problems of scientific access that arise when environmental issues like water rights cut across borders of multiple sovereign entities, whether they be private rights, whether they be public federal organizations, state organizations, different sorts of organizations. How does the scientific information get filtered from one group to another? What are the variables that are at work under these sorts of circumstances? To what extent are new kinds of legal doctrines needed to recognize scientific access to environmental data?

We heard, I think, John Brock, this morning refer to the notion that in Germany the state has a particular right as far as constitutional rights are concerned. That is real different than our constitution. That has something to say about access to environmental data in these kinds of contexts that involve, or cases that involve, water rights in the west.

We often look to scientists and to experts in general within this society as a way to deal with risks, or what we perceive as risks with respect to any particular set of decisions. In this case they have to do with water rights, whether it has to do with the loss of a taxon, whether it has to do with a loss of a certain economic gain that is likely to come from grazing organisms on public lands. It is a case it seems to me of looking at risks and researchable questions around risks that you sort of begin to sort of unpack what the value systems are that people are bringing to the table at any particular time. This kind of discussion can uncover sets of assumptions and premises that often underlie even the very best of intentions like with respect to putting watering holes out in the desert as Bob Ohmart referred to. Why do we think that is a good idea in the first place? What are the data either at an ecological level or a sociological level that lead people to think that that is a good idea in terms of intruding in nature? Why do they think that is not disturbing a natural system, or if it is disturbing a natural system, what do they then define as a natural system? We often think of anthropogenic forces as those that we want to exclude from nature but at the same time and in a very real sense over the last couple of days we have talked time and time again about manipulating nature in any of a number of kinds of ways. What is it that leads us to think that that is an initial good premise as far as starting lots of these sorts of efforts?

I don't think any amount of research in the sense of often classical scientific research will resolve that issue for you. It is a different sort of researchable question that you have to get involved in. Again, it is a researchable question that sort of sits at this interface of science, law, policy, and so on. The whole notion of who qualifies as an expert within this society, who gets to come to the table in these kinds of discussions, and how do we decide that as a society? Who gets to decide that as a society; especially within a democracy. Again, within a dictatorship it is quite clear. When the dictator says, this is who gets to come to the table, the answer is said and done. But within our society it is a much more complex issue and it is one that I think that is not often seen as the subject of research in and of itself.

Then you kind of get to the decisions themselves. The goals are often not clearly articulated as far as why we want to be doing what we are doing with respect to the environment in many of these cases. Those offer a whole other set of researchable questions that fit within sort of a larger context of science, math, engineering, and technology education within this society. What does it mean to be an educated citizen on an average basis with respect to society? What can we assume that people are bringing with them, the average individual, to the table as we begin to discuss these kinds of questions which often have a complex scientific basis to them, or we like to think we can play them out in that particular way. Yet, in fact either the individuals may not have a very deep understanding of science, or they may not care very much as far as science is concerned. They are going to make their decisions based on a whole other set of issues, a whole other value system. So where does the whole question of science, math, engineering and technology education fit within this society as far as the basic way of thinking through problems as people come to confront environmental issues? -- which I said, as these sorts of suggestions indicate, are very complex issues that have to be sorted out in a variety of different ways.

Ray Lee: Thank you. As I look around the room it is kind of interesting to me. I saw when we started this Rangeland Symposium the first couple of meetings I went to had mostly lawyers there, then I see that we have biologists coming and now as I look around the room I see mostly biologists. If lawyers are typified as being sharks, what does that make biologists if we are taking control of that program?

Some of the things that came up, just running down some factors that were brought forth: If we were going to do additional research or research needs the ideas were that we were looking for a paired sample. We were looking for it to be long term and that term being based not on years but by climatic cycles. We were looking for something that allowed us both a control and treatment, and we wanted to be able to replicate those. We wanted to have a strong oversight group. We wanted these test areas to be close enough to each other so that they receive similar climatic conditions. We needed them to be large, like an entire mountain range. We wanted the people to participate in it to be unbiased. We wanted the test to be reversible. We would do the test and we would reverse them to see the counter side of it. We felt that we needed these tests to take place where there was public land management or where there was similar management practices. Ideas of where this could be done were tossed up as Organ Pipe Cactus National Monument, Cabeza Prieta, an arid location. A second consideration on that was there may not be dense enough wildlife populations, so an idea of Hillside or Bagdad was tossed out.

That is just kind of a quick synopsis of the ideas that have been proffered at this point for research needs or, not so much, the constraints under which that research would be conducted. You have just listened to four people give their educated opinions of what they felt they should be. As I said before, you people have been sitting here for two-and-a-half-days. I have to assume it was because you wanted to have some word in this. Here is the opportunity.