APRIL 1992

WRRI Report No. 265

# PROCEEDINGS

# 36th ANNUAL NEW MEXICO WATER CONFERENCE

*Agencies and Science Working for the Future*

November 7-8, 1991
Corbett Center • New Mexico State University

New Mexico Water Resources Research Institute
New Mexico State University • Box 30001, Dept. 3167 • Las Cruces, New Mexico 88003-0001

Cover photograph courtesy of the Gila National Forest. It was taken at Stephens Creek, the Fort Bayard Forest Nursery, Grant County, after a hard shower.

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## 1991 STUDENT PAPER COMPETITION

For the first time in nearly ten years, the institute sponsored a student paper competition at the 36th Annual New Mexico Water Conference. Ten abstracts representing seven disciplines were judged by a committee comprising the university, private industry, and government agencies. Three papers were chosen to be presented at the conference. The finalists were:

- Sabir Majumder, Department of Chemistry, UNM — "Enhancement of Solar Photocatalytic Detoxification by Adsorption of Porphyrins onto $TiO_2$"
- James L. Markwiese, Department of Biology, UNM — "Assessment of In Situ Bioremediation of Cyanide and Nitrate at a Heap Leach Mining Operation in New Mexico"
- Daphne Neel, Department of Geoscience, NMTech — "Sorption of Organics to Surface-Altered Zeolites"

All three gave excellent presentations making the award decision difficult for the three judges, Fred Allen (Plains Electric G & T), Jerry Jacobi (New Mexico Highlands University), and Bob Myers (U.S. Geological Survey). Daphne Neel was awarded the $500 prize. The institute thanks all students who submitted abstracts, and to the three finalists for their excellent presentations. The papers for the finalists are contained in these proceedings.

*Master's degree candidate Daphne Neel accepts the first-place award for the student competition from WRRI Director Tom Bahr. Daphne is working under Dr. Rob Bowman in the Geoscience Department at New Mexico Institute of Mining and Technology. Daphne is from Mooresville, North Carolina and received her B.S. in Chemical Engineering from Clemson University.*

# 36TH ANNUAL NEW MEXICO WATER CONFERENCE

## Agencies and Science Working for the Future

New Mexico State University
Las Cruces, New Mexico

THURSDAY, NOVEMBER 7, 1991

**Session I: Forested Watersheds**

| | |
|---|---|
| Moderator: | **Tom Bahr, Water Resources Research Institute** |
| 9:20 a.m. | Water Resources: Global Impacts on Local Management<br>**Gerald Thomas, President Emeritus, New Mexico State University** |
| 9:55 a.m. | University Technology Transfer<br>**Averett Tombes, New Mexico State University** |
| 10:15 a.m. | A Research Half-Life: Twenty Years of Studies on Watershed Processes<br>**Tim Ward, New Mexico State University** |
| 10:35 a.m. | Break |
| 11:05 a.m. | A Historical Look at Watershed Improvement on the National Forests in New Mexico<br>**Douglas Shaw, U.S. Forest Service** |
| 11:25 a.m. | Hydrologic Responses to Fuelwood Harvest and Slash Disposal on a Pinyon-Juniper Dominated Grassland Site in the Gila National Forest<br>**M. Karl Wood, New Mexico State University** |
| 11:45 a.m. | Hydrologic Processes in the Pinyon-Juniper Vegetation Zone of Arizona and New Mexico<br>**Susan Bolton, New Mexico State University** |
| 12:15 p.m. | Lunch |

**Session II: Current Issues and University Research**

| | |
|---|---|
| Moderator: | **Bobby Creel, Water Resources Research Institute** |
| 1:30 p.m. | Current Issues in New Mexico Water Resources<br>**Eluid Martinez, New Mexico State Engineer Office** |
| 1:50 p.m. | Training Needs of the New Mexico Environment Department<br>**Kathleen Sisneros** |
| 2:10 p.m. | Assessment of In Situ Bioremediation of Cyanide and Nitrate at a Heap Leach Mining Operation in New Mexico<br>**James Markwiese, University of New Mexico** |
| 2:30 p.m. | Sorption of Organics to Surface-Altered Zeolites<br>**Daphne Neel, New Mexico Tech** |
| 2:50 p.m. | Enhancement of Solar Photocatalytic Detoxification by Adsorption of Porphyrins onto $TiO_2$<br>**Sabir Majumder, University of New Mexico** |
| 3:10 p.m. | Break |

**Session III: Sediment and Water Quality**

| | |
|---|---|
| Moderator | **Bobby Creel, New Mexico State University** |
| 3:30 p.m. | Soil Loss — Key to Understanding Site Productivity<br>**Malchus Baker, Rocky Mountain Forest and Range Experiment Station** |
| 3:50 p.m. | Decreasing Trends of Suspended Sediment Loads in Selected Streamflow Stations in New Mexico<br>**Allen Gellis, U.S. Geological Survey** |
| 4:10 p.m. | Water Quality in the Rio Costilla Watershed: Multiple Agencies, Multiplying Problems<br>**David Coss, New Mexico Environment Department** |
| 4:30 p.m. | Sewage Sludge Application in Semiarid Grasslands: Effects on Runoff and Surface Water Quality<br>**Richard Aguilar, Rocky Mountain Forest and Range Experiment Station** |
| 4:50 p.m. | Sedimentation Effects of Water Quality at Elephant Butte Reservoir<br>**Lorenzo Arriaga, Rio Grande Compact Commission** |

FRIDAY, NOVEMBER 8, 1991

**Session IV: Wildlife and Riparian Habitat**

| | |
|---|---|
| Moderator: | **Tim Ward, New Mexico State University** |
| 8:30 a.m. | The Rio Grande Initiatives — A Demonstration of Interagency Collaboration in Water Management<br>**Richard Kreiner, U.S. Army Corps of Engineers**<br>**Garry Rowe, U.S. Bureau of Reclamation** |
| 8:50 a.m. | Fire and Gila Trout Recovery in Wilderness Watersheds<br>**Bruce Anderson, U.S. Forest Service** |
| 9:10 a.m. | Hydrologic Considerations Related to Inventory and Evaluation of Wildlife Water Units at White Sands Missile Range<br>**Darren Divine, New Mexico State University** |
| 9:30 a.m. | Riparian Structures and Watershed Treatments in the Southwest: History, Status, and Management Implications — A Preliminary Report<br>**Russell Lafayette, U.S. Forest Service** |
| 9:50 a.m. | Break |
| 10:20 a.m. | Panel Discussion — Research and Training Needs of Agencies<br><br>Panel Members:<br>**Jim Piatt, New Mexico Environment Department**<br>**Gary Eyster, U.S. Army Corps of Engineers**<br>**Kirk Koch, U.S. Bureau of Land Management**<br>**Jeanine Derby, U.S. Forest Service**<br>**Charles Calhoun, U.S. Bureau of Reclamation**<br>**Wain Evans, New Mexico Department of Game and Fish**<br>**Ray Margo, U.S. Soil Conservation Service**<br>**Donald Lopez, New Mexico State Engineer Office** |

# MODERATORS

**Tom Bahr** has been the director of the New Mexico Water Resources Research Institute since 1978. He served as the secretary of the New Mexico Energy, Minerals and Natural Resources Department from January 1987 to July 1989. He also served as director of the Interior Department's Office of Water Policy under the first Reagan administration. He is a native of Wisconsin and received his undergraduate degree from the University of Idaho and a master's (limnology and biochemistry) and doctorate (limnology) from Michigan State University.

**Bobby Creel** is the assistant director of the New Mexico Water Resources Research Institute. He served as WRRI's acting director from 1987-1989. Dr. Creel's experience in resource economics includes more than 25 projects including work on the $6 million High Plains Ogallala Aquifer Study. He holds a doctorate in resource economics from the University of New Mexico and bachelor's and master's degrees in agricultural economics from New Mexico State University. Dr. Creel is a native New Mexican who grew up on a ranch near Ruidoso.

**Tim Ward** holds a doctorate in civil engineering from Colorado State University and bachelor's and master's degrees in geological engineering from the University of Nevada, Reno. He has taught at New Mexico State University in the Civil, Agricultural and Geological Engineering Department since 1980. He received the Frank Bromilow Award for outstanding research in 1987, the 1991 American Water Resources Association Board of Directors Boggess Award (along with coauthors Richard Cole, Frank Ward and Robert Wilson), and is the author, co-author, or presenter of over 125 papers.

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*Dr. Gerald Thomas retired from the presidency of New Mexico State University in July 1984 after serving 14 years in that capacity. He has maintained a special interest in world food problems, environmental issues, and natural resource management. Dr. Thomas is co-author of the books: **Food and Fiber for a Changing World, In Celebration of the Teacher,** and **Torpedo Squadron Four: A Cockpit View of World War II.** During the last four years he has served as a consultant to the Consortium for International Development, several universities, and USAID.*

# WATER RESOURCES: GLOBAL IMPACTS ON LOCAL MANAGEMENT

*Gerald W. Thomas*
*President Emeritus*
*New Mexico State University*
*Box 3BC*
*Las Cruces, New Mexico 88003*

Thank you for the opportunity to participate in this, the 36th Annual New Mexico Water Conference. It is indeed appropriate that the conference this year is held in conjunction with the Centennial Celebration of the U.S. Forest Service. After all, water is one of the most important multiple-use products of our National Forests. And since water is both **an essential and evasive resource**, any sound approach to managing water must involve cooperation between scientists, agencies, and other sectors of our economic and social system.

My first association with the U.S. Forest Service took place as the nation was struggling with the Great Depression. I was looking for a job to help pay for my college education—and jobs were hard to come by in those days. One evening in June, 1936, as I was down in the corral milking the cows, the forest ranger, a man by the name of Larry Garner, came by to offer me a job—providing I could furnish a couple of saddle horses and a team and wagon. Actually, he offered to pay almost as much for the horses as for the 17-year-old college student. I was lucky. I worked three years with the Forest Service in Idaho on the old Lemhi National Forest before it became a part of the Salmon National Forest.

Having completed a bachelor's degree at the University of Idaho in Forestry in February, 1941, I went directly to work for the Targhee National Forest. I was working with a Timber Stand Improvement Crew near Yellowstone Park in December, 1941, when the Japanese attacked Pearl Harbor. I learned about the war when I went to town for groceries. A few days later I turned in my time with the Forest Service, hitchhiked to California and joined the Navy. Then for four years I saw lots of water, including a view of the South China Sea from a rubber boat.

I have frequently interacted with the Forest Service since WWII. It was my privilege to serve for several years on the National Forest System Advisory Committee for the Secretary of Agriculture. And since moving to New Mexico in 1970, each year I had the unique opportunity to join with many of my Deans and key administrators on horseback study tours into New Mexico forests and wilderness areas. Most of these tours were sponsored jointly by the Forest Service, the Bureau of Land Management, and the New Mexico Department of Game and Fish. This program was the brainchild of Bill Hurst. Bill and I felt it was important to expose key NMSU administrators to the complex problems of natural resource management.

I believe firmly that in order to understand natural resource issues we need to get into the field—on the ground.

During this conference you will hear several presentations on agency/science/public interactions on such matters as watersheds, riparian management, and water pollution. My talk will not relate to specifics, but will focus on the broader issue of global and national pressures that are having, or will have, a significant impact on the use and management of our valuable water resources.

During the past year there has been more excitement and change in our global village than in any historical period since World War II. A new economic, political and social agenda is emerging that will have significant impacts on our everyday lives and the use of our critical natural resources. These changes include:

- A worldwide trend toward capitalism, private enterprise, and more democratic governments — The death throes of Communism unleashed a fistful of gravely ill economies in Eastern Europe. In addition, the internal conflicts within the Soviet Union, the Coup d'etat, declarations of independence by the Baltic states and the problems inherent in moving from socialism to a more capitalistic, competitive economic system has challenged both Soviet citizens and the rest of the world community.

  — The tragic massacre of students in Tiananmen Square brought an abrupt halt to China's flirtation with democracy. But, the irrational behavior of the aging leadership exposed a cancer at the very core of Chinese communism that makes its demise as a political system inevitable.

  — Our euphoria about a peaceful world following the Cold War was shattered by the Persian Gulf crisis. Suddenly, our attention was again shifted back to the role of energy in our complex ecosystems. And the deserts of Saudi Arabia and Kuwait again reminded us of our limitations under the constraints of insufficient water.
- Improved communication and transportation systems — Inadequate language training and lack of cultural awareness remain barriers to progress. I serve on the State Board of Education for New Mexico and one of the goals in our long-range plan states, "By the year 2000 all high-school graduates in New Mexico will be proficient in two languages." The new European Community aspires to be "trilingual by 1995." New technologies such as FAX will help overcome some language barriers, but many communication problems remain.
- Increased tourism — Tourism means more people interacting and the need for greater knowledge of diverse cultures as well as more opinions on how we manage our water and other natural resources.
- Increased trade among nations — This leads to a gradual reduction in trade barriers, with some unknown impacts emanating from the formation of new Economic Communities such as the EC or other "free-trade" agreements among selected nations. Recently, a member of the Federal Resource Board, promoting free-trade, stated, "However, there is also a danger that without a General Agreement on Tariff and Trade breakthrough, Europe 1992 will take more steps toward a fortress Europe." Protectionism tends to slow down worldwide economic activity and eventually impacts on local agricultural and forest production.

  — Our hemisphere is an example of the free-trade movement as we open our boundaries with Canada and Mexico. The fast-track free trade agreement with Mexico is becoming a reality. While both countries will benefit from open markets in the long-run, there will be short-term adverse impacts on certain sectors of our economy. The most widely expected winners from the Mexico agreement in the agricultural sector are food processing, grains and oilseeds. Expected losers are citrus, vegetables, sugar, and some forest products. It is obvious that many political decisions are being made (sometimes overnight) without the necessary data base or research studies that examine alternatives for economic development. Water demands, as affected by free-trade, should be studied.
- Increased capital flows — Perhaps the movement of capital and foreign investment is as significant as trade, particularly for the U.S. economy with its burdening internal debt load. At present we need that foreign investment.
- A move toward world pricing and production costs — This leads to a reduction in subsidies, particularly for the agricultural sector.

- An international labor market — New technologies make it possible to utilize cheap labor in Third World countries or at remote locations. Recently, a faculty member dictated a letter at his desk, it went by satellite, was typed by a Chinese secretary earning 90 cents an hour, and returned for signature in less than 30 minutes.
- Growth of multi-national corporations continues — With their growth, the profit motive overrides national loyalties and national borders grow vague. Some multi-nationals deal in agricultural products.
- Changing consumer demands — With significant impacts due to health and environmental concerns, consumer demands are changing. We see more "built-in maid service" using technology to replace drudgery. In some cases, the packaging costs exceed the cost of the food product contained therein. This trend indicates a need for closer relationships between the producer and consumer.
- Continued pressure from population growth — This is particularly true in Third World countries where the debt load contributes to slow economic recovery and reduces the opportunity to improve the quality of life.
- An unprecedented impact of environmental awareness — Environmental awareness is generating interest in the sustainability of ecologic and economic systems.

These worldwide trends form the back drop; they set the stage for future use of our natural resource base. Two trends deserve a more careful analysis: the continuing growth in world population and the impact of environmental awareness.

**Population Growth**

The latest global projections indicate a possible leveling of the world population by the year 2100 at 10.4 billion people, double the present number. Most growth will take place in the less developed countries. Whether or not leveling will occur at 10.4 billion will depend upon educational programs and economic development, both precursors to numbers reduction. At the current growth rate, the world is adding about 100 million new people each year, nearly one Bangladesh every year. And, unfortunately, education and economic development are not keeping pace with this population growth.

Our greatest challenge is not only to keep the status quo as population increases, but to meet the needs for a better quality of life for all people. Let me illustrate our dilemma using only one measure, perhaps not the best but one of the less-complicated measures of quality of life, namely per capita Gross National Product (GNP). These data are from the World Bank and the Population Reference Bureau in Washington, D.C.

The world average GNP per capita in mid-1991 was $3,760. Twenty countries have average incomes below $300 per year. At the time of this survey, the U.S. stood at $21,100 per capita GNP.

There are over 4 billion people in the world with annual incomes of less than $750. A worthy goal would be to bring these 4 billion people from the present $750 per capita GNP to the world average—five times their present level. But from an environmental impact standpoint, 4 billion poor people are one problem, while 4 billion wealthy or middle-class people are another. We know wealthy people utilize more resources (land, water, and energy) and place more pressure on the environment than poor people. Indeed, the problems for sustainability will increase as more and more people move into higher income brackets. Pressures will build to over-utilize our natural resource base, both at home and abroad. At the same time, the best opportunity to increase the per capita GNP in most developing countries is to strengthen the agricultural sector and more fully utilize the natural resource base.

In addition to increased numbers and income levels, other demographic changes also impact on water management. The changing age structure (more older and mobile Americans), and even the cultural and religious mix influences our approach to natural resource management. Worldwide there are now about a billion people of the Islamic faith. Desert Storm and the aftermath, the festering sores in the Middle-East and South Africa are conflicts that have increased our awareness of the major cultural differences among the world's people and have raised concerns about the separation of church and state.

**Impact of Environmental Awareness**

Ranking next to demographic changes as a factor in influencing economic development is the impact of environmental awareness. The neglect of environmental issues is now a worldwide concern and has lead to the popularization of the term "sustainability." This is a good term because it implies intergenerational responsibility.

We are now experiencing what I call, "The battle of the two great Ecos"—economics and ecology. While we seek a balance between the constraints of these two Ecos, it seems clear that economics is the more pervasive. The new world economic revolution will be characterized by private ownership and economic incentives as the key stimulus to production. But, just as surely as most countries have discovered the importance of changing policies to provide **an incentive to produce**, they have also neglected the second important segment of sustainable development, providing **an incentive to conserve**. Sooner or later the politician and the economist must add an appropriate ecological analysis to all approaches of food and fiber production.

Perhaps I should clarify my concepts of ecology. Ecology is a legitimate field of science defined as the relationship among all organisms and the environment. I emphasize "all organisms" because mankind must be considered the most important part of the formula due to human impacts on the environment and human's ability to modify the environment for specific needs.

Ecology is not a concept of environmental protection. Man has already influenced every part of the world's environment, including the most remote polar areas. The challenge now is to understand these impacts and to adjust development activities based upon research. The key to our relationships with the environment is management, not protection per se. My own field of range science could be called applied ecology.

About two decades ago, when our nation and the various states were in the process of establishing environmental protection agencies, I went before a joint meeting of the New Mexico Senate and House to talk about environmental concerns. I argued that New Mexico did not need an environmental protection agency. Rather, we needed an environmental **improvement** agency. The choice of words does make a difference. The word improvement implies research and an examination of alternatives, where as protection could exclude man from the formula. My argument in Santa Fe was followed by legislation which created the New Mexico Environmental Improvement Agency. I believe New Mexico is still the only state which has done this. Although there have been recent departmental name changes, the legislative intent of emphasizing improvement rather than protection has remained.

I believe in the axiom, *Never does nature say one thing and wisdom another*. But, to let nature take its course in a protectionist atmosphere will neither benefit mankind nor maintain the values we are trying to protect. Even wilderness areas must be managed in order to maintain the region's natural beauty and biological populations. Also, we have learned the hard way that neither deserts nor oceans are unlimited sinks for man's pollutants, but are indeed fragile ecosystems which react to man's involvement.

**Water: Under Pressure from Global and National Trends**

Water may be more critical to humankind in the long-term than either land or energy. We can, and must find solutions to the energy problem; we can, and will determine ways to operate with a smaller relative land base; but the amount of water in our system is fixed. There is no substitute for water. Water is a renewable resource. Man uses it as it moves through the hydrologic cycle, usually pollutes it to a certain extent, and feeds it back into the system. While we can reduce the dependence upon water by increasing water-use efficiency, there is a very limited supply which must be husbanded with great care as the world population increases.

As our standard of living rises so does our per capita water use for domestic, industrial, and agricultural purposes. An individual needs only about 2 liters of water daily for drinking, but water use rises rapidly with the level of income.

Our largest per capita water requirement is for food. For example, we spend about a metric ton of water to produce a pound of bread and on some of our southwestern rangelands, over 100 tons of water are associated with the production of a pound of beef. Much of the water associated with meat production is dissipated by undesirable weeds and brush or evaporates from the unprotected soil surface. Such statistics provide a convincing argument for better water management in the food sector.

Agriculture cannot compete for water against municipalities, business and industry. These other users can afford to pay more for water and will continue to purchase water rights away from the food sector. We see this transfer every year in New Mexico and in other agricultural states. These transfers move land out of food production just as surely and effectively as direct transfer to housing or highway construction. Water is a marketable quantity and "water flows uphill to money."

Irrigated agriculture is becoming much more important with time, as the world's population increases the demand for food and fiber. The recent growth in irrigated land has not only been in the traditional irrigated areas, but in the moderate to high rainfall zones as a risk reducing factor. Also, irrigation is becoming more important in the less-developed areas of the world, perhaps the major hope for many of these poor countries. Approximately a third of the total world food harvest now comes from 17 percent of the cropland that is irrigated. The trends toward more irrigated cropland will likely continue in spite of the increased energy costs, the problems of underground water depletion, and serious problems of salinity and other forms of pollution.

Vast opportunities exist for improving water-use efficiency for:

- food and fiber production
- municipal and industrial purposes
- recreation and environmental enhancement
- role in biological diversity

There are also vast opportunities for water management improvement to balance economic and ecological constraints, and obtain cooperation and consensus from interested parties.

**Developing a Response to Global Pressures**

In this paper I have tried to emphasize that there are many patterns of change on the global and national level that dictate a response from all agencies and organizations interested in water use and management.

There are five major approaches that must be examined if we truly desire to bring about change:

- We must target the education process and focus on the key actors in the process of change. Educational programs designed for the general public will not necessarily be effective for legislative bodies, students or the scientific community. Education must be viewed as a continuing process. It is never complete.
- Much more and better-directed research is needed as we add international and environmental dimensions to all aspects of natural resource management. The science of ecology can contribute substantially to the research and evaluation process, particularly through the examination of ecosystems. The challenge, however, is to involve **all** scientific disciplines in a collaborative research approach to sustainable natural resource management. I repeat, the challenge is for a wide range of disciplines.
- There is a continuing need for technical assistance and/or technology transfer specialists to help carry research results to agriculture, business and industry. This will require the cooperative efforts of universities, government, and the private sector.
- We must build conservation and environmental sustainability into our economic and political system. Economists must place a dollar value on each critical national resource and quantify the cost of resource deterioration and/or pollution. More importantly, we must create an economic incentive to conserve that tends to balance the incentive to produce that is already in place in many countries.
- Lastly, legislation and regulation may be necessary. Many groups move rapidly into the legal arena because they are frustrated with the research and education process. All too often, political decisions are made without the necessary data base or research to fully examine alternatives. Expensive time at the courthouse steps results from premature legislation and regulation.

All five instruments of change—education, research, technology transfer, incentives for sustainability, and regulatory approaches—can be influenced in a major way through cooperation between science, public agencies and the private sector of our economy. This is a challenging time to be planning for the sustained use of water—our most precious resource.

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# UNIVERSITY TECHNOLOGY TRANSFER

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Technology transfer is defined as the movement of knowledge from a laboratory where the technology is developed to the private sector where commercialization can occur. At most research universities where basic and applied research is encouraged and rewarded, it has been difficult to add the next stage of commercializing the products of this research. However, New Mexico State University has made significant progress in this area with economic growth and development occurring as a result.

Before I illustrate how this progress may occur, I will review briefly the development of land-grant universities and their role in technology transfer. For those of you who have passed through the halls of NMSU or other similar universities, you know the equal importance that is placed on education, research, and service. You may also remember that the Morrill Act of 1862 allocated public lands for the establishment of colleges of agriculture in all states with the intent of assisting farmers in utilizing knowledge created at land-grant universities. In 1914, the Smith-Lever Act created the Cooperative Extension Service which has been the principal transfer agent of the technology from universities to the agri-business community. In 1986, the Federal Technology Transfer Act was passed to enhance the flow of scientific as well as technical knowledge from federal and non-federal laboratories to the private sector. That act was fine-tuned in 1989 and is now known as the National Competitive Technology Transfer Act. Senators Domenici and Bingaman were instrumental in sponsoring these bills which will enhance the transfer of technology from all national laboratories to the private sector. In New Mexico, these laboratories are Los Alamos National Laboratory, Sandia National Laboratories and Phillips Laboratory. This process is clearly a national goal, and state universities have an important role to play.

An example of how technology may be transferred from a national laboratory to a new high-tech company can be found in the following story. A few weeks ago, a physics professor came to my office and reminded me that his research depends heavily on listening devices; the more sensitive the instrumentation, the more significant will be his research. He also believes that Sandia National Laboratories (SNL) possesses the technology, heretofore classified, which could expand the capabilities of available scientific instrumentation for his research. Therefore, he was willing to consider establishing a company in the university's Arrowhead Research Park that would fabricate more sensitive instruments if SNL would transfer the technology to his company. Given the demand for improved listening device technology and recent federal legislation which encourages the transfer of such technology, it may indeed be possible to move that knowledge from SNL to a new start-up company in

Las Cruces which would manufacture and market the instruments worldwide.

I will use this example to answer several questions which I must always consider when implementing technology transfer. First, what is the source of the technology? Second, to what organization will the technology be transferred? Finally, what will be the results of this transfer?

In the example I gave, SNL (i.e., the federal government) is the apparent owner and source, but not necessarily. Before applying for any patent application or concluding the sale of any technology, the ownership question must be resolved between the inventor and the employer. About ten years ago SNL would have owned the technology; however, since then the federal government has changed its position and now allows the inventor(s) to claim ownership and receive a negotiated percentage of all royalties and licenses. At NMSU, I always ask inventors to identify in writing the ownership of the intellectual property. If a faculty or staff member develops a patentable device, the university, and therefore the state, claims ownership. If the university obtains patent protection and also commercializes the invention, the inventor will receive fifty percent of the proceeds after covering all protection costs. We believe that this is a fair reward for the discovery and a good incentive for faculty and staff to work with us in the development and transfer of intellectual property to the private sector.

Concerning the second question, the federal government always prefers to transfer the technology to an organization that will maximize its commercialization potential. This means that SNL would rather transfer the sensing technology directly to the private sector rather than through the university to the start-up company. Even though the federal government looks more favorably on the transfer of this technology to American rather than foreign companies, a request for a proposal (RFP) will usually be published by a federal department or agency so that any company can compete. However, a private citizen also has the opportunity to request technology from any national laboratory to augment an activity already underway; i.e., a manufacturing process.

The third question concerns the results obtained following the transfer of technology. The creation of a start-up company at the university's research park, which may actively involve technology formerly dormant at a national laboratory, illustrates the economic benefit which comes from the implementation of the earlier mentioned National Competitive Technology Transfer Act. For several decades, universities have encouraged the creation of spin-off high technology companies; Stanford University and the adjacent "Silicone Valley" represent the best illustration of this relationship.

Historically, scientists at universities and national laboratories have not been interested in actively identifying and pursuing the transfer of commercially viable research results. Recently passed federal legislation, however, has changed the incentives available to federal employees, and universities are changing their policies so that faculty and staff also benefit from the commercialization of their inventions. The example of SNL's technology and its possibilities for NMSU illustrates the progress that is being made in this area. Although the negotiations with SNL have not been completed, discussions are underway, and the NMSU physics professor anticipates good results.

For decades land-grant universities have excelled in the transfer of agricultural knowledge to agri-business industries, and our success as exporters of agricultural products is testimony to that achievement. Now we must become just as successful in transferring technology from scientific and engineering laboratories to manufacturing industries so that our national competitive position is not lost to other countries.

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# A RESEARCH HALF-LIFE: TWENTY YEARS OF STUDIES ON WATERSHED PROCESSES

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## INTRODUCTION

Watershed processes are those individual and collective physical interactions and chemical reactions which control the movement of mass and energy through the biotic and abiotic components of a watershed. These processes are complex, interactive, and time and space variant. A thorough understanding of a watershed's function and health necessitates that researchers and natural resource managers have clear insights into the role and importance of each process and its interactions with other processes.

One framework for studying watershed processes is through development of conceptual and/or mathematical models of watersheds (Simons et al. 1979b; Simons et al. 1982). Once a model has been established, the role of each of the processes can be investigated with its importance to the model as a whole. Because the model is a symbolic representation or simulation of integrated watershed processes, there is always the danger that one or more processes' components may be neglected, or that the mathematical representation of the processes may be in error. Therefore, it is important for modelers to have a firm grasp on what is a reasonable outcome or result from a model simulation of watershed processes or the integration of several of those processes.

But how does a modeler acquire this firm grasp of what is reasonable? Typically, a modeler combs the literature to discover what others have found from actual field research or from laboratory studies. Although this is a reasonable approach, it is not necessarily the best approach. I believe the best approach is for the modeler to participate in field and laboratory studies so that the modeler can experience firsthand the complexity of real systems of processes.

At this point, I must confess that I am a "reformed" modeler. My first professional experience was with field data collection for a mathematical model of the Truckee River in California and Nevada. I drifted, however, and began dabbling in computer models of different watershed processes. Eventually, I came to realize that the feeble mathematical models that existed could never compare with the complexity and variability of the natural watershed processes which the models tried to simulate. That simple, but profound, realization has guided me in trying to understand processes as best as I can so that someday mathematical watershed models can better represent actual conditions.

I have spent over 20 years studying various watershed processes, and have been fortunate to receive funding from various federal, state, and local agencies to conduct my studies. One of the biggest contributors to my research has been the U.S. Department of Agriculture Forest Service, which is being honored at this conference. Other funding has come from the New Mexico Department of Game and Fish, New Mexico Water Resources Research Institute, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, and the National Science Foundation. I have also worked with many outstanding scientists, engineers, and undergraduate and graduate students over the years, all of whom have contributed to my understanding of natural systems. In this paper, I would like to share some of my observations and opinions about the natural processes I have studied. Many of my observations will not be surprising to field researchers who have studied those processes, but some may be of interest to all who have either investigated or modeled those processes.

## OBSERVATIONS ON WATERSHED PROCESSES

### General

There is a plethora of watershed processes that can be observed, studied, modeled, or incorrectly ignored. These processes include precipitation, evapotranspiration, infiltration, subsurface/groundwater flow, surface water flow, channel flow, erosion, transport of inorganic and organic particles and chemicals, water chemistry, mass wasting, and natural and human impacts. The reader might note that I have integrated a number of individual processes into a single process, such as water chemistry and human impacts. I have done so for brevity and as a way of organizing the rest of my comments. Note that I have organized the processes or groups of processes in a basic conceptualization of how water moves through a watershed. Not all the processes listed above will be reviewed as I will limit my remarks to those I have studied and about which I can offer some observations.

### Precipitation

There are three basic truths about precipitation: you never know how much you will receive, where it will fall, or how long it will last. We call these truths "temporal and spatial variability" to make them sound more scientific.

The two forms of precipitation we are usually concerned with are rainfall and snow. The first because it tends to cause quickly occurring floods, and the latter because it is the source of almost all our surface water supply. The first professional paper I presented was about rainfall precipitation (Ward and Gupta 1973). That paper analyzed rainfall data from various USDA-ARS watersheds in New Mexico and Arizona with respect to depth, duration, and temporal variation. Over the years, the analyses have continued as new data and new sites were added to the data base. More recently, Bolin et al. (1989) examined data from the Jornada Long-Term Ecological Research (LTER) site north of Las Cruces.

From these analyses, I have concluded that there is no relationship between the duration of a rainfall event and the corresponding depth of rainfall. It is only through radical massaging of the data that one can develop a design storm, which implies that for a selected probability of occurrence, such as 1%, there is a functional relationship between storm duration and rainfall depth. I believe that an appropriate rainfall event to use as a design storm is a thunderstorm event of one-hour duration and of a depth appropriate to some low frequency of occurrence, such as 1%. The event's time distribution should be such that most of the rainfall occurs early. A model of the temporal variation of rainfall can be written as:

$$V^{*}=\sqrt{T^{*}}$$

where $V^*$ is a nondimensional depth of rainfall ranging from 0 to 1, and $T^*$ is a nondimensional duration also ranging from 0 to 1. This equation implies that by half the duration ($T^* = 0.5$), 71% of the total rainfall ($V^* = 0.71$) will have occurred. This model of temporal variation is reasonable and based on a variety of storm depths from durations of two hours or less. This equation is what I use in developing design storms.

Snowfall and snowmelt are much more difficult to model as they require a thorough understanding of thermal properties of the snowpack over time. One interesting finding about snowmelt as revealed by a model study (Foltz 1987; and Foltz and Ward 1987) was that the total solar radiation at the top of the atmosphere worked just as well in modeling total snowmelt runoff as did the solar radiation adjusted to ground level by cloud cover and slope aspect corrections. This may have occurred because of the type of model used or the output modeled, but it may also be a short cut for further modeling efforts.

**Infiltration**

Much of my research has focussed on assessing infiltration and erosion characteristics with the aid of rainfall simulation (Sabol et al. 1982b; Sabol et al. 1982c; Ward 1983a; Sabol and Ward 1983; Ward and Seiger 1983; Bach et al. 1986; Ward 1986c; Ward and Bolin 1989a and 1989b; and Ward and Bolton 1991). My research associates and I have conducted rainfall simulation experiments at over twenty sites in New Mexico, Arizona, and Colorado for a total of over 1,000 experiments. A variety of vegetation-soil types were sampled for various reasons depending on the goals of a particular study. Recent activity has been in pinyon-juniper and desert rangelands.

A primary infiltration characteristic that has been sought is the steady-state loss rate which is taken to represent the hydraulic conductivity of the infiltrating zone. This characteristic is used by land managers in determining the health and hydrologic function of a watershed and by modelers in simulating the infiltration process. A desired outcome from infiltration studies would be the development of a simple, accurate equation or technique for estimating the hydraulic conductivity from site specific data. Although simple equations can be developed, the accuracy of such equations is not very good. I believe that the accuracy is affected strongly by the amount of natural variability or noise occurring when measuring infiltration of natural plots.

It is my observation, however, that a reasonable, conservative estimate of a steady-state loss rate for most natural vegetation-soil types is in the range of 25 to 50 mm per hour. The loss rate is much higher under a forest canopy, in the range of 75 to 100 mm per hour, and is about a factor of three lower in those areas denuded of vegetation.

We have also found a marked difference between the steady-state loss rates and whether the soil was initially dry, that is, in its typical field condition, or whether the soil had been prewetted by a previous experiment. This difference, which was larger for some vegetation-soil types and almost nonexistent for others, demonstrates that paired dry-wet experiments should always be conducted.

Another finding is that there is a marked difference in the loss rates of vegetation-soil types between seasons in rainfall dominated areas (i.e., not snowmelt). We believe that the surficial layers of soil become more porous (lower bulk density) over the winter and spring months because of physical and biological processes such as freeze-thaw and termite activity (Elkins et al. 1986). At the beginning of the monsoon season, the soils have a higher infiltration rate because of their higher porosity. By the end of the season, the soils have been compacted by rainfall and land-use activities and the loss rate has diminished. We have been able to create a similar response when we conduct the dry-wet experiments on a soil before the rainfall season begins. In this case, only the action of the rainfall and the subsequent overland flow is responsible for compacting the soil surface.

A spinoff from studying infiltration and erosion through construction and use of rainfall simulators is the knowledge gained about rainfall simulation and its appropriate application (Wilcox et al. 1986; Endebrock 1990; and Ward et al. 1991). A major problem facing hydrologists when they study watersheds, whether the watersheds are several hundred square kilometers or only one square meter, is that there is a tremendous degree of variability from one point to another with respect to hydrologic characteristics. Because loss rate, as measured through rainfall simulation, is calculated as the difference between rainfall rate applied to a target plot and runoff rate from the plot, the loss rate is an integration of all the point rates within the plot. The larger the plot, the more the point values are integrated. We have found that the loss rates over a large area can be estimated from small plot experiments (Ward 1986c; Ward and Bolin 1989a), a fact which was confirmed in other modeling efforts (Wicks et al. 1988). However, the effects of partial area contribution, that is, some areas within an experimental plot do not produce runoff from the applied rainfall, create a situation wherein increasing the applied rainfall rate appears to increase the loss rate. Therefore, it is necessary to apply a sufficiently high rainfall rate to produce runoff from all areas of a plot. My best estimate of that application rate for the vegetation-soil types we have studied is 75 mm per hour except for high-loss plots such as those in litter under forest canopy. Applied rainfall rates below 50 mm per hour will create a situation wherein partial area contribution will occur.

Although I cannot, I wish I could list a universal loss rate estimation equation. At this point in our knowledge of hydrologic processes, all I can recommend is that each watershed of interest be tested for infiltration rates before modeling commences.

**Surface Water Flow**

Surface water flow results from water not infiltrating and thus running across the soil surface. Channel flow is a specific case of surface water flow. The other specific case is overland flow whereby water flows across the vegetation-soil surface as either a broad sheet (rarely) or in tiny channels or rills (usually). Overland flow is affected by vegetation-soil surface characteristics on the bottom of the flow, and rainfall characteristics on the top of the flow. I have studied overland flow as a sideline to other experiments (Ward 1986c). Recently, Jorat (1991) used data collected from our small-plot experiments to explain some of the phenomena we have observed. One finding from his analyses was that the Manning's roughness coefficient, n, could be approximated by the total fraction of vegetation plus rock covering a plot. This implies that if a plot has 50% vegetation plus rock cover, then the Manning's n would be 0.50. Because overland flow helps control erosion and sediment transport, more research should be conducted in this area.

**Erosion and Sediment Transport**

At this point, I will discuss erosion and sediment transport as it relates to vegetation-soil surface interactions. Later I will discuss it again with respect to surface water (channel) flow. Rainfall simulation, if conducted correctly, can provide information on the erosion/transport characteristics of falling and running water when that water is applied to a vegetation-soil surface. For short plots, less than 3 meters in length, the erosion/transport measured is primarily from interrill processes of splash detachment and short distance, shallow overland flow transport. For plots greater than 3 meters in length, the erosion transport measured is a combination of rainfall splash detachment and shallow overland flow/rill flow detachment and transport. Measurements of erosion/transport are affected by the size of the plot and the applied rainfall. We have found that erosion/transport characteristics are typically higher for small plots compared to large plots (Ward 1986c; Ward and Bolin 1989a). This can be explained by the observation that material removed from a small plot has a much shorter distance to travel to the plot outlet (measurement point) than does material removed and transported across a larger plot. In fact, the point splash detachment of soils is much higher than the detachment inferred from plot studies (Ward et al. 1983; Ward 1983a).

The technique used to measure sediment concentrations in the runoff water from the plot can also affect the results. We have found that applying three different techniques for measuring suspended sediment concentrations produced three different values for the same runoff sample (Ward and Bolin 1989a and 1989b). Unfortunately, the techniques which produced the highest and lowest values were significantly different from each other. One technique which seems to produce a reliable result is filtration and drying of a subsample, a standard approach. Still, this technique appears to be a bit low if the subsample is not well mixed. The technique producing the highest values was drying the entire sample in an oven and then calculating the residue's weight. The problem we found with this technique is that dissolved solids were also part of the dried residue, thus increasing the apparent concentration of suspended materials.

We have observed that large plots have higher sediment yields than do small plots, as one expects based on size alone. However, our data also showed that the small plots exhibit higher per area sediment yields, again reflecting the mode of erosion and transport. When the sediment yield is expressed as a concentration of weight per unit area per unit of runoff, such as kilograms per hectare per mm of runoff, the differences between plot sizes or amount of runoff from a plot essentially disappears. For this reason, we have been reporting erosion/sediment data in units of yield per area and yield per area per depth of runoff. I believe that what we are observing is an applied energy threshold (rainfall rate and resultant runoff rate) which limits the amount or concentration of sediment entrained in the runoff (Bolin and Ward 1986).

Equations to estimate the detachment coefficients (model coefficients that is) associated with rainfall splash and overland flow on plots have been developed (such as Simons et al. 1977a; Simons et al. 1979a; Ward 1986a; and Riggins et al. 1989b), but the predictive capability of such equations is poor (Serrag 1987). Currently, we do not have a reasonably good technique for estimating detachment coefficients for modeling purposes. More research should be conducted on this topic.

**Channel Flow**

Channels can be classified in numerous ways. One way is by the presence of flowing water in the channel some of the time (ephemeral), most of the time (intermittent), or all of the time (perennial). Channels also can be classified as to their steepness: less than 1% channel slope, channel slopes much less than the angle of repose of the bed material (about 30° to 35° or 60% to 70%), slopes on the same order as the angle of repose, and slopes greater than the angle of repose. Steep channels are those with slopes greater than about 1%. By this slope classification, most channels in upland watersheds could be termed as steep. Therefore, flow and sediment transport characteristics of steep channels become of interest to those wishing to model channel processes (Ward 1981).

Li et al. (1979a and b), Ward and O'Brien (1980), and Ward (1986b) are examples of analyses which can be conducted on steep channel flow. An interesting characteristic of steep channel sediment transport is that the maximum concentration of transported material in the flow becomes a constant at high energy conditions, for example high slope or flow conditions. I found (Ward 1986b) that this concentration was related directly to the square of the channel slope and inversely related to the mean size of the sediment. The experimental data did not support the hypothesis that grain-size distribution had an effect on this maximum concentration. Subsequent data analyses implied that the observed slope effect may be an artifact of the experimental design and cannot be supported by a lack-of-fit test.

Transport rates for channels of lower energy conditions have been modeled for years using standard sediment transport formula developed for conditions that were not necessarily like those encountered in actual watersheds.

I had the opportunity to participate in preparation of an analysis of expert witness testimony for the reserved water rights case *In the Matter of the Application of the United States of America for Reserved Water Rights* (Water Division No. 1), (Water Court, Colorado) wherein the U.S. Justice Department argued on behalf of the U.S. Forest Service. A primary point of dispute was that flows in Colorado mountain streams should not be decreased by further diversions because the reduced flows would lead to channel sedimentation and an increased flood hazard.

Data were collected from several different streams by the U.S. Forest Service and by consultants for the State of Colorado. When all the data were plotted on a graph depicting sediment transport rate versus water discharge rate, the two sets of data overlapped and intermingled to such a degree that the two sets were indistinguishable. The interesting aspect of this comparison was that one of the litigants claimed the data proved that there was an excess of transport capacity and lack of sediment supply in the channels and, therefore, the flows could be safely reduced by further diversion. Conversely, the other litigant claimed that the graph showed that there was a distinctive hydraulic relationship between transport rate and water flow which meant that any reduced flows would cause sedimentation. As of this writing, the judge has not declared which interpretation he believes is correct.

It is my impression that traditional techniques for estimating sediment transport in mountain channels are inadequate. Fortunately, the U.S. Geological Survey is actively developing a new technique for estimating sediment transport in gravel and cobble bed streams which will address this problem. After working on this case, I have come away believing that the concepts I was taught are not necessarily correct in light of what I have seen in the data sets.

In arid and semi-arid areas, ephemeral channels perform a function in addition to transport of water and sediment; they form zones of high transmission or infiltration losses. These zones then become settings for plants and animals which may be quite different than those found in the surrounding non-channel areas. Ephemeral arroyo channels are a major path for surface water to enter the subsurface. Sabol et al. (1982a) and Van Vactor (1989) have measured the infiltration rates of arroyos and found that the rates are about an order of magnitude greater than rates on soils in non-channel areas. Van Vactor used this fact to demonstrate (using a distributed parameter, single-event rainfall runoff model) that channel flow would seldom, if ever, transverse the bajada at the Jornada LTER and reach the valley playa. Hydrologists should devote more effort to studying the importance of ephemeral channels in arid and semi-arid watersheds.

### Water Chemistry

Overland flow and channel flow have a common characteristic in that they both transport sediment (albeit at different rates) and associated nutrients and other chemicals. Inorganic chemicals in runoff from watersheds are typically anions and cations of bicarbonate, chloride, sulfate, sodium, potassium, calcium, and magnesium. Concentrations of these chemicals are controlled by groundwater flow to the channel system and dilution by snowmelt (Ward 1973). Watersheds exhibiting low groundwater transmission rates (thus allowing more time for the groundwater to be in contact with geologic materials) or low snowmelt (less dilution) tend to have higher concentrations of the major anions and cations. Nutrients such as nitrogen, phosphorous, and volatile suspended solids (organic carbon) are associated with surface soils and do not exhibit the same dilution phenomena as do the major cations and anions. We have been measuring nutrients in runoff from rainfall simulators as part of several different studies (Sabol et al. 1982c; Ward and Bolin 1989a and 1989b; Cole et al. 1990b; and Ward and Bolton 1991). Much of the work has been to fulfill objectives related to a long-term, state-wide modeling effort focussing on fisheries in New Mexico (Cole et al. 1990a). A summary of the work can be found in Bolton et al. (1991a) and Bolton et al. (1991b, these proceedings). In general, it was determined that for upland areas, total volatile suspended sediments (organic carbon) were strongly related to total suspended sediments (about 10% of the total was volatile), phosphorous was related to total suspended sediment, and nitrogen was not related to anything. These results now give us a technique for estimating loadings of the nutrients to channels.

Bolton (1991) took the analyses one step further by comparing the relationships observed in the upland simulator data to those relationships which could be developed at stream gaging sites on ephemeral and perennial channels. She found that for phosphorous and organic carbon, the simulator data tended to be somewhat higher at the same suspended sediment concentrations. This was not the case for nitrogen. Reasons given for these differences were that the phosphorous and organic carbon were probably diluted or scavenged, whereas the nitrogen could easily be enhanced by other chemical reactions in the channel system.

Water chemistry, then, is not a process in itself but an agglomeration of different processes ranging from surface erosion to groundwater flow. Water chemistry is further complicated, as in the case of nitrogen, when biotic activity comes into play. At present, empiricism and statistical modeling may be the best way to estimate chemical concentrations in runoff water.

### Mass Wasting

Another process, which is not as important in New Mexico as it is elsewhere in steep watersheds, is mass wasting, commonly referred to as landslides. Mass wasting ranges from the very slow creep of earth materials in a downslope direction under the influence of gravity to the extremely rapid and violent debris avalanches associated with the flushing of extremely steep chutes or channels. I have conducted numerous studies on landslides (e.g., Simons and Ward 1976; Ward 1976; Simons et al. 1978b; Ward et al. 1979; Ward et al. 1980; Ward et al. 1981a and 1981b; Ward and O'Brien 1981; Ward et al. 1982; and Ward 1985) as they relate to the overall mix of processes in watersheds and in the planning and management of watershed activities.

Landslides can destroy productivity at the site of the failure and add large quantities of sediment to existing channels downslope, or completely scour channels removing the sediments and vegetation which comprised the riparian system (Simons et al. 1977b). Recently, we had the opportunity to study the Aguirre Springs debris flow which occurred in August of 1991. This flow was initiated by a heavy rain on already wet soils. The resulting water flow eroded a steep channel near the top of the Organ Mountains, and the ensuing debris flow scoured the lower level channels and left extensive lateral deposits of large boulders and organic matter. Our site investigations indicated that this was not the first time that the scoured channel had experienced a debris flow, as evidenced by older lateral deposits. Measurements made of high-water marks (debris lines), cross sections and channel slopes suggest that the debris flow may have had a peak volumetric flow rate on the order of 300 to 400 cubic meters per second, occurring in a channel which typically had a capacity of less than one-hundredth that rate. Although rare, such an event can and does significantly alter the water and sediment carrying characteristics of the original channel and watershed.

**Natural Impacts**

The flood/landslide discussed above is just one natural impact which can alter a watershed and channel system. Floods alone can have a significant effect on the total amount of water and sediment leaving a watershed. Ward (1983b) and Ward and Baker (1984) present data which show that for a managed pine watershed in northern Arizona, most of the sediment yield over a twenty-year period of record was associated with one or two storms with low frequencies of occurrence (one storm was estimated to have a return period of one in 100 years). This supports the observation that it is the low frequency-high energy events doing the most work in ephemeral watersheds.

Another natural impact is that caused by wildfire. At one time, before fire suppression became standard operating procedure, wildfire cleared out deadwood and understory growth, thus reducing the fuel source for subsequent fires. Fire suppression, in contrast, increased the fuel source. Subsequently, fires burned hotter and did more damage to the vegetation and to soil productivity. Wildfire, like floods and landslides, are episodic events which occur infrequently, cause damage, and then allow the watershed and channel system to heal. Bolin and Ward (1987a) documented this healing process following a fire in northern New Mexico. Within about three years following the fire, water and sediment yields returned to prefire levels. Similar recoveries were observed in the data presented by Ward and Baker (1984) for a major flood event, and is also evident in the renewal of Yellowstone Park after the great fire and the slow return of the area devastated by the eruption of Mount St. Helens.

**Human Impacts**

Human impacts, unlike natural impacts, tend to be continuous and pervasive throughout the watershed. The two major impacts inflicted by man on watersheds are timber harvest operations and cattle grazing. Timber harvest operations require that roads be built in places that may be unsuitable. Over the years, we have studied the impact of roadways in forested watersheds (Simons et al. 1978a; Li et al. 1979c; Simons et al. 1980; Ward and Seiger 1985; Ward 1985; and Riggins et al. 1989a). It is estimated that between 70% and 90% of the suspended sediment found in channels of forested watersheds is derived from roadways.

Reduction in canopy cover from timber removal and disturbance of vegetative and litter cover by grazing and logging activities are two other severe impacts on a watershed. Ward et al. (1990) and Bolton et al. (1992b, these proceedings) clearly show the effects of cover removal on the hydrologic function of the vegetation-soil complex in the pinyon-juniper zone. Bach et al. (1984) and Bolin and Ward (1987b) had previously described the effects of cover in desert grasslands/shrublands. It is my observation that if ground cover is reduced below 50%, erosion and runoff will increase significantly. It is with these studies and observations in mind that I question the wisdom of the "new perspectives" approach to removing canopy cover (pinyon and juniper), which is really an old idea and practice, in an attempt to increase grass growth to encourage more grazing. Canopy removal will not in the long run add any more water or any more biomass than carefully controlled or restricted grazing practices. Ward and Baker (1984) make a similar statement about watershed treatments in Arizona which were conducted to improve water yield.

**CONCLUSIONS**

In this paper, I have attempted to summarize concisely some of the observations and findings my research associates and I have found or developed over the last twenty years of studying watershed processes. Watershed processes are complex, highly interrelated, and vary in space and time. Although we have learned a great deal about the processes, we have not yet achieved a level of confidence in our modeling to guarantee accurate predictions. Some of the errors we find are related to our inability to estimate accurately watershed and channel characteristics/parameters useful in modeling. Other errors are related to our failure to represent correctly the processes involved with our mathematical surrogates. Probably most of the errors we find in our watershed modeling is inherent in our attempts to try to make a complex system simple.

As scientists and engineers, we need to transmit our ideas and findings into concepts and rules which are useful to land managers. Although models are one way to achieve that goal, simple rules-of-thumb based on common sense and supported by good science will find greater use.

After twenty years of sampling, measuring, analyzing, and modeling, I have answered many of the questions I started with, but I now have more questions than when I began my career. In the next twenty years, I hope that my colleagues and I will be able to answer some of those questions.

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# A HISTORICAL LOOK AT WATERSHED IMPROVEMENT ON THE NATIONAL FORESTS IN NEW MEXICO

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Thank you for this opportunity to describe one aspect of the USDA Forest Service's role—that of water manager. This is not a "high-tech" paper—it is a chance to celebrate the Forest Service's history by enjoying some pictures of watershed improvement structural measures used over the years. Many people do not recognize the Forest Service's mission as a partner in water management. Our role as watershed managers goes back to the earliest debates in Congress concerning government's duty in managing forests.

Early conservationists, such as George Perkins Marsh, recognized the relationship between healthy forests and watersheds that responded orderly, that is, they yield the best quality water possible from wildlands in flows most useful for human and habitat needs.

This year we celebrate the centennial of the Forest Reserve Act. This act resulted after many years of debate in a Congress that was previously not inclined to favor legislation that imposed controls on land use. This was landmark legislation in our country's conservation history. Prior to the Forest Reserve Act, the country favored policies based on expectations of unlimited natural resources in a vast wilderness. With the debate and subsequent conservation legislation, we recognized the need to use wisely our resources and conserve their productive potential. Government had a role in this new attitude—land stewardship for this and future generations.

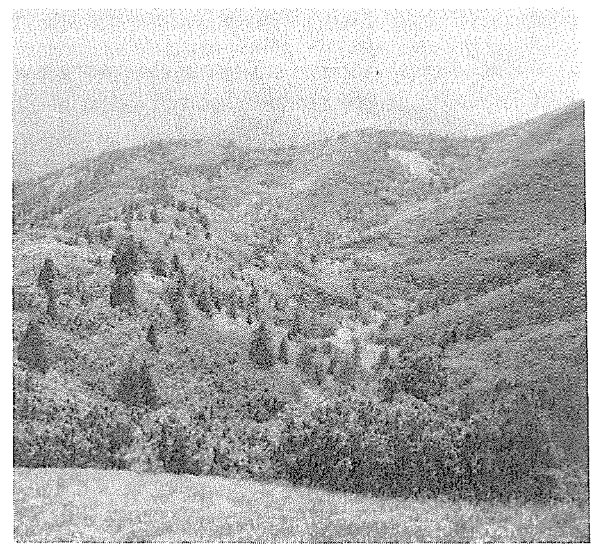

**Figure 1.** A watershed with good vegetative cover on a New Mexico National Forest.

Congress did not define the purposes of the forest reserves until the Organic Administration Act of 1897. Maintaining favorable conditions of water flow is one of three primary purposes for the lands that became national forests. The other primary purposes are the protection and improvement of the forests and the production of continuous supplies of timber. Thus, our role as watershed managers is clearly part of the enabling legislation and history.

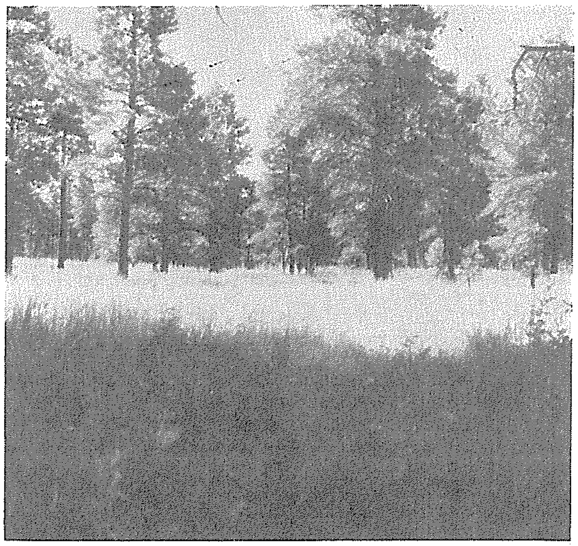

**Figure 2.** Good cover for watershed protection and multiple uses.

The Forest Service started taking an active part in southwestern resource conservation about 1908. By that time, many of the vegetation resources were heavily used. Watersheds were not in good condition. Vegetative use was uncontrolled, sheet erosion was common in the uplands, gully erosion was serious in the valley bottoms, and riparian vegetation was frequently abused. Flooding was a problem, perennial flows were reduced, and water quality was not up to its potential.

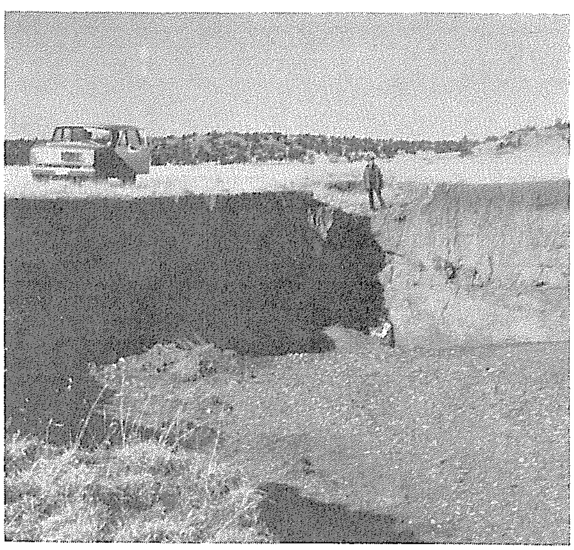

**Figure 3.** Gully erosion due to past land overuse.

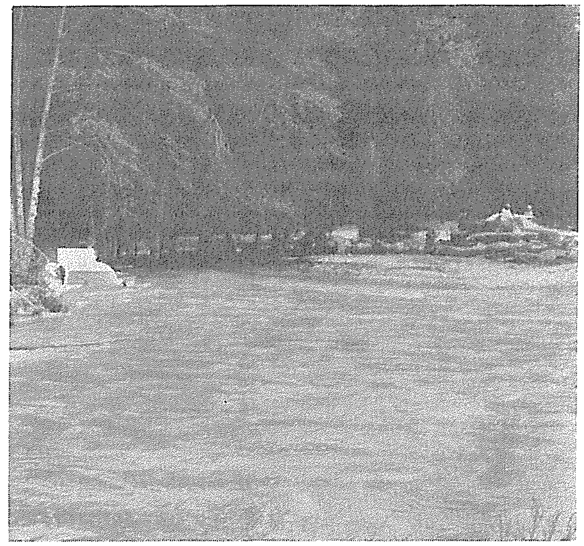

**Figure 4.** Flooding aggravated by unsatisfactory watershed condition.

World War I again placed heavy demands on these lands to provide timber and beef. However, the Great Depression brought renewed emphasis on the restoration of the national forest watershed in the form of the Civilian Conservation Corps. This program provided major restoration efforts, including structural measures that still stand and function today.

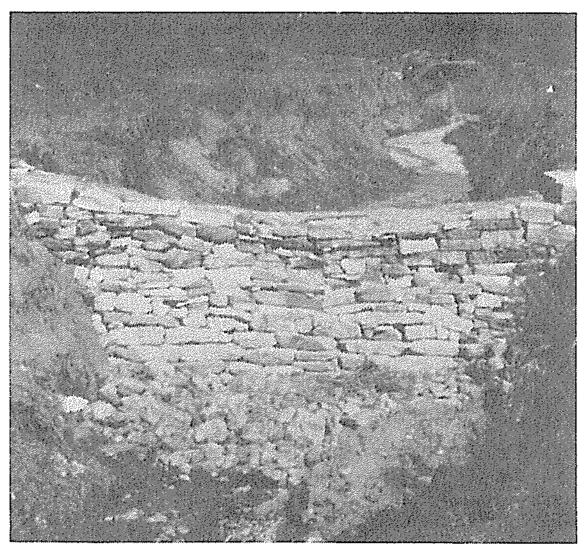

**Figure 5.** Watershed structure constructed by the Civilian Conservation Corps. Structure continues to function.

Several other laws, such as PL 534, the Flood Control Act, and PL 566, the Small Watershed Act, provided initiatives that helped our efforts to restore watersheds to function more orderly.

Through the years, there has been a trend from labor-intensive to mechanical methods for watershed treatment. Early in our history there was a heavy emphasis on channel treatments, subsequently on land treatments, then to a combination of channel and land treatments, and finally into ecosystem management. We started by trying to control flows and moved toward efforts designed to work with flows.

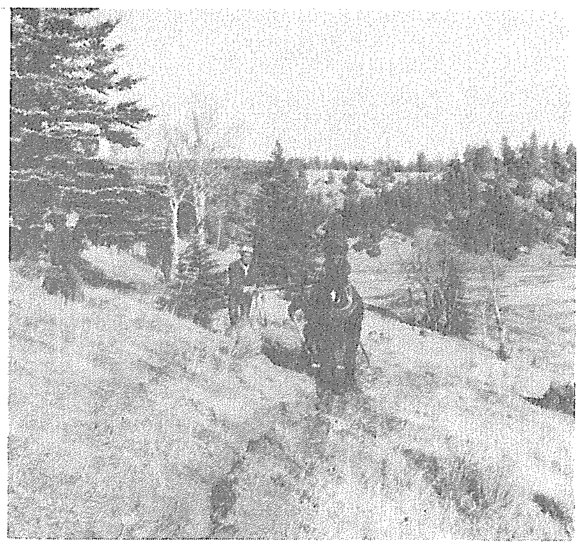

**Figure 6.** Land treatments such as this early terracing project enhanced watershed functioning.

Through experience we have learned quite a bit. We know that treating symptoms without curing the cause will lead to failure. On the other hand, projects that include treating symptoms after or in conjunction with solving the problems seems frequently to be successful. Working against the stream energy seems to result in long-term maintenance and frequent failure. Trying to save money on initial design is usually a fatal mistake. Not understanding risks or not developing understandable design criteria based on acceptable risk often results in constant maintenance. Finally, not considering all components of the ecosystem or not having an understanding of potential and desired future condition for the ecosystem leads to failure. It is often through our failures that we learn best how to proceed in the future.

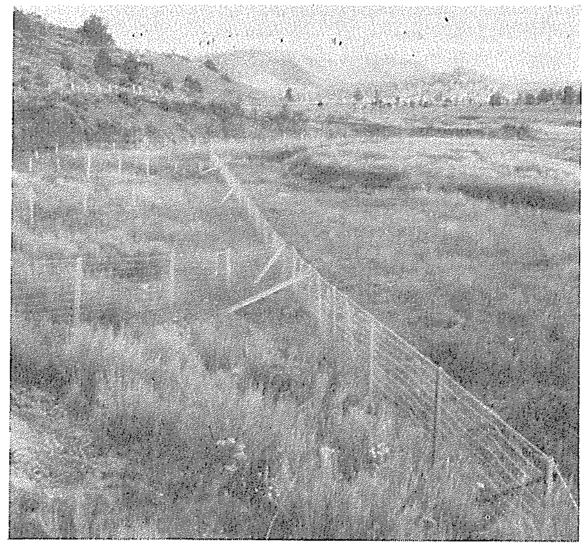

**Figure 7.** Working with the stream energy to stabilize bank cutting.

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# HYDROLOGIC RESPONSES TO FUELWOOD HARVEST AND SLASH DISPOSAL ON A PINYON-JUNIPER DOMINATED GRASSLAND SITE IN THE GILA NATIONAL FOREST

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## INTRODUCTION

Pinyon-juniper woodlands extend over an area of more than 19 million hectares in the western United States. In New Mexico alone, pinyon-juniper covers an area of 7 million hectares. Much of this land was once grass and shrubland which was later invaded and eventually dominated by pinyon-juniper as a consequence of man's activities, particularly overgrazing and fire suppression (Evans 1988). Pinyon-juniper woodland has its own place in the ecosystem where it is climax on hillslopes too rocky to have enough understory to carry a fire. Pinyon-juniper woodlands offer certain benefits to man and animals, including firewood, fence posts, poles, pinyon nuts, Christmas trees, outdoor recreation, livestock grazing, and an important habitat for elk and mule deer.

To sustain the supply of pinyon-juniper benefits, a scientifically proven management scheme is necessary. One way to promote these products is by maintaining the health of the land resource by preserving a balance of vegetation types. Also, a greater emphasis on the livestock and wildlife industries encouraging economic returns would essentially require type conversion from pinyon-juniper woodlands back to grasslands. This would not mean the total elimination of pinyon-juniper, but rather, the creation of a mosaic of vegetation that bears proportionate amounts of grassland and pinyon-juniper woodland to satisfy the legitimate needs of humans and animals.

When considering vegetational conversion, hydrological responses must be given particular attention. Replacing vegetation is a very sensitive operation from a hydrological standpoint (Wood 1988). The aim of vegetation conversion should always be soil and water conservation.

This study reflects an effort to reduce soil erosion and improve other hydrological attributes through the simple techniques of slash disposal associated with tree harvesting. Hydrologic responses to fuelwood harvest and slash disposal under natural conditions in a pinyon-juniper woodland will be studied. The project will quantify over time the effects of fuelwood harvesting and slash disposal on runoff, sediment concentration, sediment production, and bedload. Inferences drawn from this study will help determine the most reasonable management strategies to minimize accelerated soil erosion and increase phytomass production.

## STUDY AREA

### Location and Configuration

The study site is in the commercial fuelwood harvesting area of the pinyon-juniper woodland on Spring Mesa in the Black Range District of the Gila National Forest. Specifically, this area lies in Section 36, T9S-T10S, R12W, Catron County, New Mexico. The average elevation is 2245 meters. The experimental site extends over an area of about 20 hectares on three north to south ridges that join on the north end with Spring Mesa. In 1986, four replications of five runoff plots, each 22.1 meters long and 3.6 meters wide, were established to measure hydrological responses to fuelwood harvesting. The slope of runoff plots (5% - 8%) was quite uniform within the blocks but varied slightly among the blocks.

### Soil

Site soils have been described as the Lonti-Poley-Rough Broken Land Association. The study site is characterized generally by a thin surface layer of reddish-brown non-calcareous gravelly loam over reddish-brown gravelly clay or heavy gravelly clay loam to a depth of 30 cm to 90 centimeters (Javed 1991). These soils are Lithic Haplustalfs. The sparse understory cover and the high proportion of bare soil contribute to highly erodible soil conditions.

### Climate

Climatological data from the nearby Beaverhead Ranger Station show mean maximum and minimum temperatures of 19°C and -1.68°C. Mean annual precipitation according to records of the last 20 years is 319 mm with about 111 frost-free days from June 5 through September 24. Limited precipitation in the form of snow is experienced during December and January. Substantial precipitation is received as short-lived summer rains of mild to moderate intensity (Javed 1991).

On-site climatic data for the growing season during 1989 and 1990 were collected for rainfall, temperature, and relative humidity. The rainfall data indicated a mean annual rainfall of 325 mm for a total precipitation of 269 mm and 382 mm during 1989 and 1990, respectively. The mean annual maximum and minimum temperature for the growing seasons of 1989 and 1990 were 26°C and 10°C, respectively. The average monthly humidity percentage collected at the research site during the growing seasons of 1989 and 1990 was as low as 37% in the daytime and as high as 82% at night. The humidity was lowest during May and June. It started rising in July when summer rains began and reached a maximum in August. The humidity again showed a gradual decline in September.

### Vegetation and Distribution

The study area's vegetation consists of a moderately low tree density of the two-needle pinyon (*Pinus edulis*) and alligator juniper (*Juniperus deppeana*) (Javed 1991). Both pinyon pine and alligator juniper tend to be active reproductively. Scattered throughout, gray oak (*Quercus grisea*) is the only shrub species. The herbaceous growth comprises a variety of grass and forb species. Among grasses, the most plentiful species is blue grama (*Bouteloua gracilis*). Mountain muhly (*Muhlenbergia montana*), wolftail (*Lycurus phleoides*), and squirreltail (*Sitanion hystrix*) are other grasses commonly found in the area. Golden eye (*Viquiera dentata*), Bahia spp., and a few Chenopods are some eye-catching forbs in the area.

## MATERIALS AND METHODS

### Pre-Treatment Description

In 1986, twenty experimental plots were established in an area where commercial fuelwood harvesters remove pinyon and juniper. Five plots were located in each of four blocks. These experimental units were 25×12 meters and contained runoff plots which were 21.1×3.6 meters or 0.081 hectare. The plot size is the same length and twice as wide as plots used to develop the Universal Soil Loss Equation (Wischmeier 1966). The plots were arranged in a Randomized Complete Block Design. Prior to assigning the intended treatments, these plots were used to collect preliminary data on runoff, sediment yield, and phytomass production during the summers of 1987 and 1988. The objective was to determine variations among the plots under undisturbed natural conditions. The data showed no significant differences within the blocks but some slight differences among blocks.

The treatments in addition to the control were:

- clear cut in June 1989 with slash uniformly scattered and burned in October 1989
- clear cut in June 1989 with slash uniformly scattered
- clear cut in June 1989 with slash uniformly scattered and lopped at 60 centimeter height
- clear cut in June 1989 and slash removed

Each experimental unit included a runoff plot and an adjacent 4-meter-wide strip to allow destructive sampling.

## RESULTS AND DISCUSSION

### Runoff

Seven runoff storms were received in 1989 and nine in 1990, with most storms occurring during July, August and September. Only rainstorms having intensities higher than 25 mm $hr^{-1}$ produced runoff.

The treatment comparisons by year (Figure 1) revealed that the slash-removed treatment produced significantly higher runoff depth in 1989 compared with control, slash-scattered, slash-lopped, and slash-burned (essentially the same as slash-scattered in 1989) treatments. In 1990 a dramatic increase in cumulative runoff depth was observed for the slash-burned treatment when burning took place at the end of the previous year's growing season. The runoff resulting from the slash-burned treatment was almost 2.5 times more than the control treatment and was also significantly higher than other treatments.

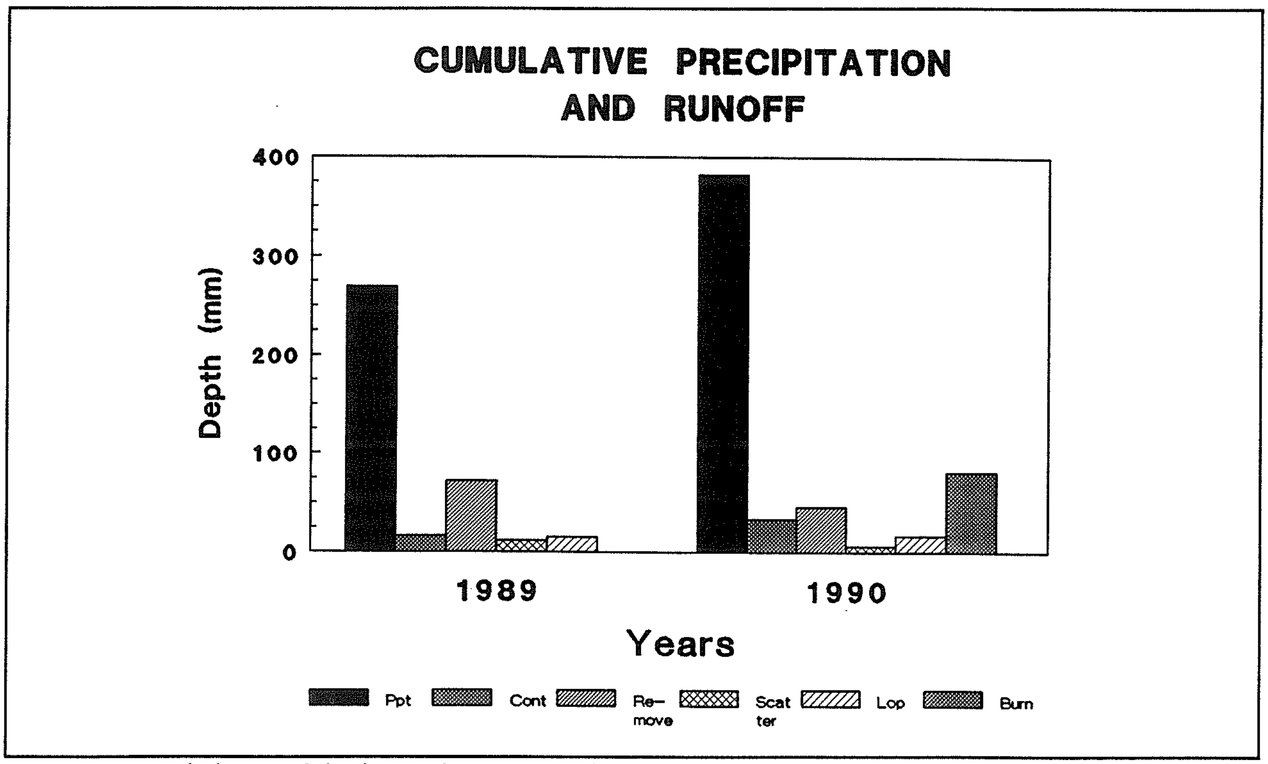


**Figure 1.** Cumulative precipitation and mean cumulative runoff for each treatment in 1989 and 1990.

The slash-removed treatment was next in runoff magnitude. The obvious reason for increased runoff from the slash-removed treatment in 1989 and slash-burned treatment in 1990 was the absence or small amount of vegetation cover due to complete removal and burning.

The mean runoff depth from the control treatment was higher in 1990 than that in 1989 (Figure 1). This is attributed to the high amount and frequency of precipitation in 1990. The slash-removed treatment responded very differently in 1990 and resulted in lower runoff depth despite a high amount of precipitation compared to 1989. A probable reason for lower runoff in 1990 is again the increased vegetal and litter cover which were negatively correlated with runoff as reported in the aforementioned studies. The slash-scattered treatment exhibited the lowest values in both years from the standpoint of runoff control.

Mean runoff depth was the highest for the slash-removed treatment followed by the control where the slash-lopped and slash-scattered treatments showed roughly the same responses during 1989.

The runoff magnitude was highest for the slash-burned treatment in the subsequent year followed by the slash-removed treatment on all dates. The slash-scattered treatment responded almost the same on all dates in both years and ranked lowest in producing runoff. The slash-lopped treatment was statistically and practically no different than slash-scattered treatment on any of the dates. The treatment by date interaction was also statistically significant in both years. This indicated inconsistency between the mean runoff response of different treatments over dates under the combined effect of precipitation amount and intensity.

## Sediment Concentration

Sediment concentration is a measure of water quality. It is a function of runoff and is an important determinant of suspended sediment production.

The overall mean treatment responses were significantly different when the data were combined for the whole growing season (Figure 2). The results were consistent with the runoff variable. In

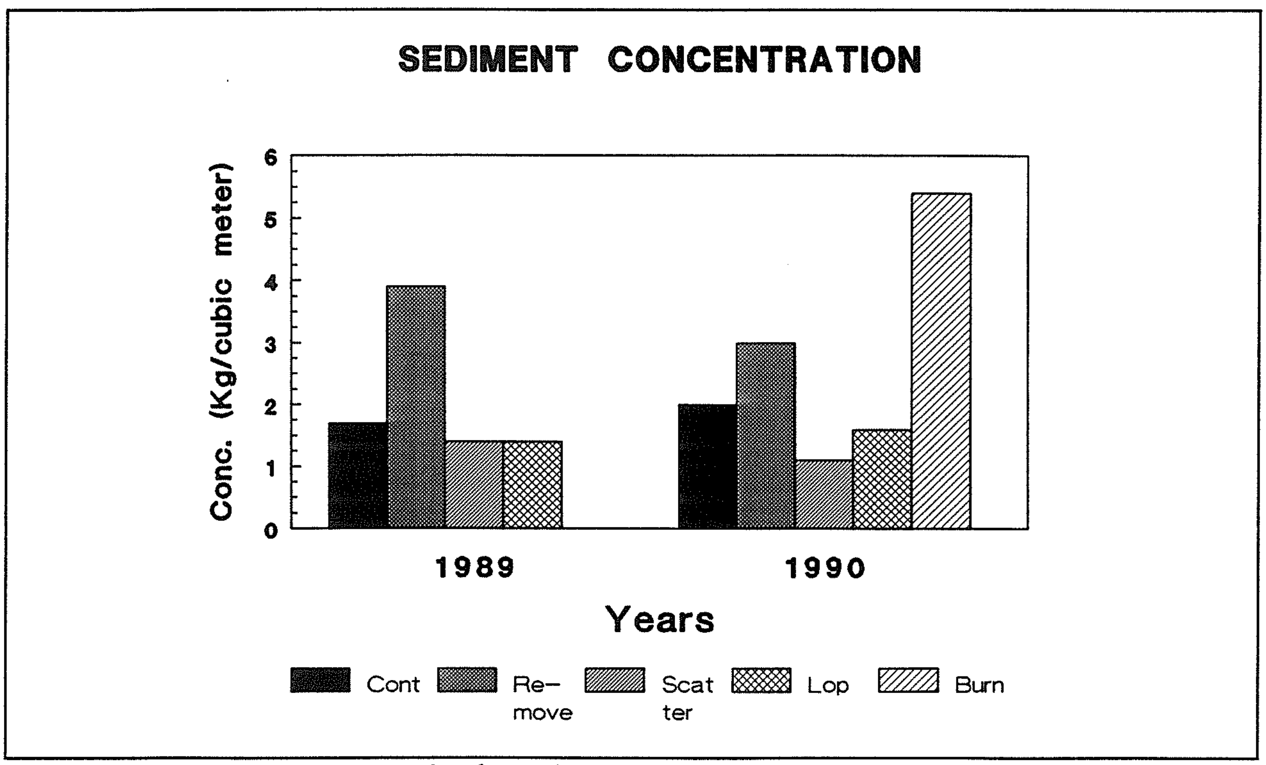


**Figure 2.** Mean sediment concentration for each treatment in 1989 and 1990.

1989 the slash-removed treatment was characterized by relatively higher sediment concentration and was found significantly different from the other treatments. The apparent reason for the high sediment concentration was the removal of vegetation cover that exposed the soil to direct rainfall.

The other reason could be greater soil disturbance due to the harvesting and logging operation. The slash-lopped, slash-scattered, and control treatments were not significantly different ($P < 0.10$) from one another. Unlike 1989, the slash-removed treatment in 1990 was also statistically similar to the slash-scattered and the mean sediment concentration was less than the preceding year despite higher precipitation. The major reason for reduced sediment concentration in 1990 was the relatively higher vegetal and litter cover that impeded soil erosion.

The sediment concentration yielded by the slash-burned treatment during 1990 was surprisingly high (Figure 2). Sediment concentration under the slash-burned treatment was significantly higher than all other treatments. In 1990 the control, slash-removed, slash-lopped, and slash-scattered treatments resulted in nearly the same mean sediment concentration and were statistically no different from one another ($P < 0.10$).

**Bedload**

Bedload refers to coarse sediments that are rolled along the soil surface by the driving force of runoff during stormflows. This is also a measure of soil erosion. The bedload data were collected and analyzed yearly for each growing season during 1989 and 1990 (Figure 3). Significant differences in mean bedload production were noticed between different treatments in 1989. The slash-removed treatment ranked the highest producing sediments 1.5 times more than the control and approximately 4 times more than the treatments with slash-lopped and slash-scattered treatments. The treatments having slash were also significantly lower from the control treatment in magnitude of bedload. In 1990 the slash-burned treatment produced 3 times more bedload than the control and 11 times more than the slash-lopped or slash-scattered treatment.

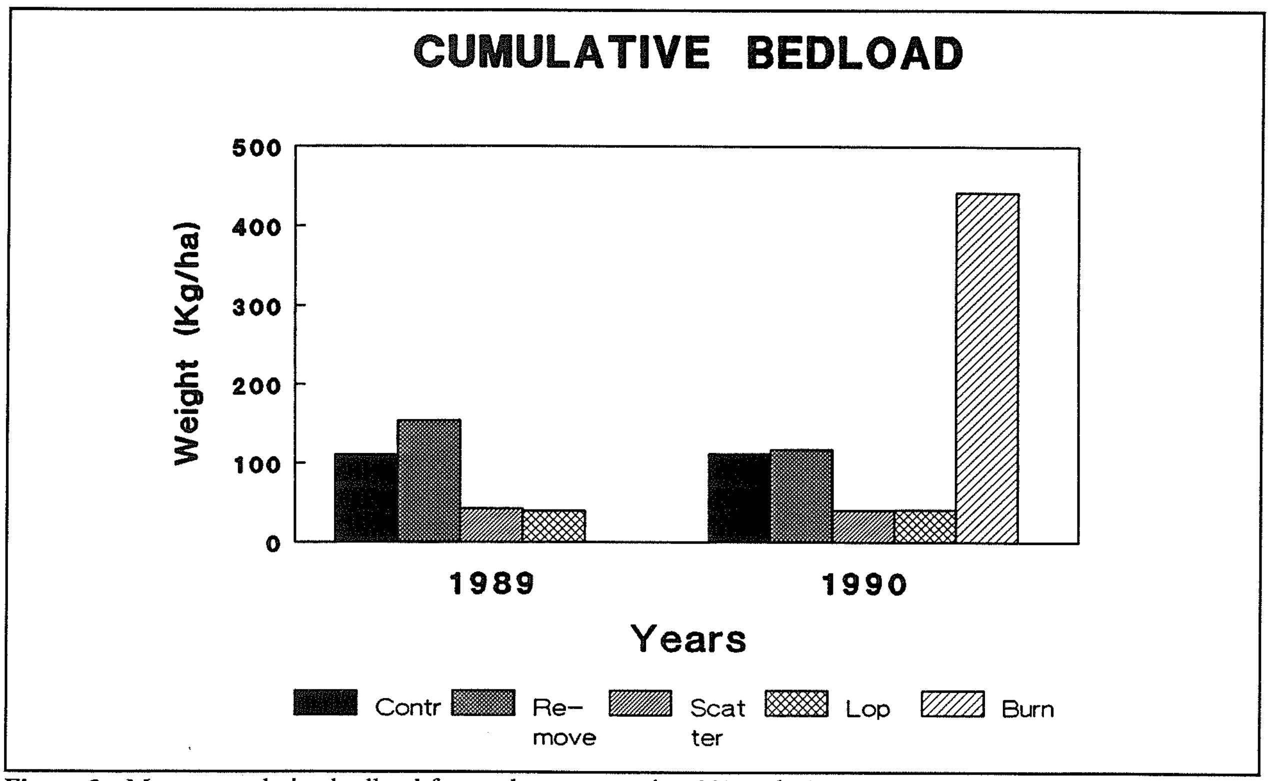


**Figure 3.** Mean cumulative bedload for each treatment in 1989 and 1990.

When the treatment effects were compared over time, their responses were apparently similar excluding the slash-burned treatment. During 1990 the bedload amounts did not differ statistically ($P < 0.10$) from 1989 except for slash-burned, in spite of the fact that precipitation was 113 mm more in 1990 than during 1989. This stability is attributed to higher phytomass production and more vegetal and litter cover that helped control excessive erosion. The slash-lopped and slash-scattered treatments were similar in both years and ranked the lowest in bedload production. The slash-burned treatment exhibited a geometric increase followed by the slash-removed treatment. This comparison suggests that slash-in-place treatments conserve soil better than the other slash disposal treatments.

## CONCLUSIONS AND RECOMMENDATIONS

Based on the results and discussion, the following inferences can be drawn from this study.

- Among the five treatments used to determine the hydrologic responses following tree harvesting, the slash-scattered treatment was found to be the most desirable. The slash-scattered treatment resulted in:
  - the least surface runoff and sediment loss;
  - relatively higher soil moisture;
  - best vegetational response from the standpoint of the highest amount of grass production (this will promote infiltration besides increasing the carrying capacity for grazing purposes); and
  - plentiful vegetal and litter cover to help increase infiltration, impede runoff, and control soil erosion.
- The slash-lopped treatment was found to be as desirable as the slash-scattered treatment but it is more time consuming and expensive.
- Complete removal of slash was harmful from a hydrologic standpoint. It resulted in higher runoff, higher sediment loss and low herbage yield.
- The slash-burned treatment was even more detrimental for all hydrologic variables listed against the slash-removal treatment. Complete removal and the slash-burned treatments are therefore, not recommended. In the long-run these differences would, however, diminish due to more soil stability and higher vegetation cover. Therefore, fire effects must be monitored in the long-run for soil moisture, sediment loss and vegetational responses.

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# HYDROLOGIC PROCESSES IN THE PINYON-JUNIPER VEGETATION ZONE OF ARIZONA AND NEW MEXICO

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## INTRODUCTION

The pinyon-juniper (PJ) vegetation type covers much of the semiarid Southwest and at least 17 million hectares of North America (West 1988). It forms the transition zone between the typically overgrazed lower elevation grasslands and the higher elevation pine and fir forests. Pinyon-juniper areas are subjected to a variety of stresses including roads to higher elevations for timber, fuelwood harvest, and livestock grazing. Because the PJ is subject to intense land-use pressures, it is important that land managers have as much information as possible about how the PJ will respond to these pressures.

One important aspect of these pressures is how they affect the movement of water and soil over the land surface. Ideal surface conditions would exist if all incident precipitation would infiltrate and the soil would not erode. In reality, water runs over the soil surface transporting soil particles, litter, and nutrients. This loss of material reduces potential site productivity and can damage downslope areas through gullying or excess loadings of materials to water bodies. To understand the PJ's hydrologic function, controlled experiments must be conducted which measure key variables affecting that function. Specifically, infiltration and erosion parameters which characterize the hydrologic function, and the site variables found in the PJ which influence the parameters, must be identified and quantified. With this information, scientists, managers, and engineers can make informed decisions as to the hydrologic effects of a given land-use practice.

It is a well established conceptual and empirical fact that a bare soil surface erodes more and has a higher volume of runoff than the same soil covered by a canopy, window screen, ground level vegetation, rock, other mulches, or similar types of protection. Gifford (1985) summarized the state of knowledge regarding vegetation effects on runoff and erosion. Among his conclusions and observations were:

- vegetative cover of between 50% to 60% tended to minimize erosion and maximize infiltration; any further increase in cover produced little improvement in either
- there is no consistent evidence to differentiate between the importance of plant species as to their effects on runoff and erosion
- specific infiltration (and erosion) parameters must be decided upon then related to cover to maintain a consistent data base (and provide usable relationships) (parenthetical expressions added by the authors)

Similar discussions of vegetative effects can be found in the multi-paper/chapter publications prepared by Branson et al. (1981), Haan et al. (1982), El-Swaify et al. (1985), Lal (1988), and ASAE (1988), or in most comprehensive hydrology or soil texts.

Beginning in 1985, the U.S. Department of Agriculture began a multiagency research project to develop a hydrologic/hydraulic process-based methodology to complement the often used and much maligned universal soil loss equation (USLE) (Wischmeier and Smith 1978). Gilley et al. (1988) provided a general description of the approaches and methodologies utilized in the USDA sponsored Water Erosion Prediction Project (WEPP). The development phase of WEPP ended in August of 1989 with publication of a manual (Lane and Nearing 1989) and distribution of a microcomputer-based MS DOS program (model). The WEPP has focused the attention of engineers, scientists, and model users on techniques for estimating model parameters and incorporating land management effects in the parameters. Of specific interest are Chapter 4 (Rawls et al. 1989b) on infiltration and Chapter 6 (Alberts et al. 1989) which includes soil erosion. These chapters describe the parameters used in the WEPP model and how they might be modified for cover conditions. Of particular interest are the hydraulic conductivity term in the Green and Ampt (1911) model for infiltration, and the raindrop impact soil detachment coefficient for interrill erosion (e.g., Foster 1982).

The Green and Ampt infiltration equation can be written as:

$$f = K\,(1 + a/F) \qquad (1)$$

where f = infiltration rate (l/T)
K = hydraulic conductivity (l/T)
a = the product of wetting front capillary potential and the difference between antecedent and final (after rainfall stops) volumetric water content (l)
and F = depth of water infiltrated (l)

The most often sought after and cited parameter in the Green and Ampt equation is the hydraulic conductivity. This is because it is easier to determine from field measurements than is the wetting front capillary potential, and because K, or a function of it, commonly occurs in other infiltration formulae (Rawls and Brakensiek 1985). The hydraulic conductivity, K, can be estimated from a variety of methods based upon soil properties or through data collected from rainfall simulation (e.g., Rawls and Brakensiek 1985; Ward and Bolin 1989a). For rainfall-runoff studies, K is usually presented in units of cm/hr, mm/hr, or in/hr. Typical values of K range from about zero up to about 100 mm/hr, although higher values have been reported. Rawls and Brakensiek (1985), Rawls et al. (1989a), and Rawls et al. (1989b) present techniques for estimating K with correction factors for cover and other effects. Rawls et al. (1989a) reported the results of analyzing data from Hutton (1984) from which they found that:

$$CF = Kc/Knc = (1 + 0.96\ Cc) \qquad (2)$$

where Kc = hydraulic conductivity under a canopy cover
Knc = hydraulic conductivity without canopy cover
and Cc = canopy cover as a fraction

Equation 2 was based on 13 data sets and had a correlation coefficient, r, of about 0.94, or a coefficient of determination, $r^2$, of 0.88. In the WEPP manual (Lane and Nearing 1989), the coefficient of 0.96 in Eq. 2 has been changed to 1.0 for both range and agricultural lands. Rawls et al. (1989b) also note that canopy above (vegetative) residue does not appear to have any effect on hydraulic conductivity. Therefore, grass canopy cover should not be used to modify hydraulic conductivity because there is usually residue beneath the grass. In general, hydraulic conductivity should approximately double as canopy cover approaches 100%, based on this analysis.

Density of vegetative and rock cover usually affects plot response to rainfall, but not necessarily as one might expect. This is important because many beliefs based upon conventional wisdom can be hypothesized, tested, and confirmed through scientific field tests. Studies of natural rainfall plots in arid regions have found that differences in runoff among plots may be difficult to detect. Cordery et al. (1983) report on runoff from small (25 square meters or about 270 square feet) natural rainfall plots in western New South Wales, Australia. Under some climatic conditions, systematic differences in runoff between plots were not evident despite differences in the plots' physical properties. Runoff from all the plots was lower during a wet period with lush vegetation than during a dry period with sparse vegetation. The authors attributed this difference to the increased interception losses caused by denser vegetation.

Many studies in arid regions that have used rainfall simulators have shown significant differences in plot responses based on vegetative and soil surface conditions. Lane et al. (1987) found rock and gravel cover and canopy cover to be negatively correlated with runoff depth. Kincaid et al. (1964) also found shrub cover, grass and litter cover, and gravel cover to be negatively related to runoff. In contrast, some studies (e.g., Blackburn 1975; Tromble et al. 1974) found rock cover and erosion pavement to be positively related to runoff.

These studies and others that used rainfall simulators in arid and semiarid regions with low vegetative cover have found that cover (shrub canopy cover in particular) is an important factor in reducing runoff and erosion. However, other studies of runoff from natural rainfall plots indicate that differences due to vegetation cover and rock cover are difficult to detect. A rainfall simulator study (Bolin and Ward 1987; Bolton et al. 1990) at the Jornada Long Term Ecological Research (LTER) site north of Las Cruces in south central New Mexico supported the results of the natural rainfall plot studies at the same site regarding sediment yields. In that study, average water and sediment yields were not significantly different between plots with and without shrubs. The natural rainfall data set contained information from low energy storms only. This may help explain why statistical differences were not found between natural rainfall plots with different vegetation and soil characteristics.

At lower energies in a sparsely vegetated area like the Jornada LTER site, the role of rainfall energy predominates in determining runoff and sediment yield. At higher energy levels, a threshold is reached in terms of additional sediment yield from energy increases alone. It was noted that when simulated rainfall was applied at almost twice the normal rate, some differences appeared which could be attributed to plot cover characteristics. These results are supportive of Gifford's (1985) suggestion that vegetal cover may be of minimal importance in determining infiltration and erosion rates on some semiarid rangelands. He indicates erosion rates may be a complex function of plant-soil-storm characteristics that are not well understood. Gifford also suggests that cover density above about 50% to 60% has little effect on increasing infiltration or reducing erosion. Ward et al. (1990) confirm this observation with data from Ward and Bolin (1989b). It is between the low cover situations like those found at the Jornada and the high cover situations as suggested by Gifford where cover improvements may increase infiltration and reduce soil erosion.

A related measure of surface conditions is "roughness" as measured with a point frame. This type of roughness is defined as the standard deviation of elevation measurements for the plot surface. Jorat (1991) found that point-frame roughness measured parallel to the direction of water flow can be correlated with flow resistance and total cover. This result may explain the findings of Sanchez and Wood (1987) relative to infiltration and sediment yield. The importance of surface roughness was recognized by a WEPP study in which numerous roughness measurements were gathered (Gilley et al. 1987).

Runoff, erosion, and sediment yield are all affected by cover conditions on the soil. The WEPP effort has provided guidance as to how those effects may be quantified for specific parameters related to infiltration and sediment yield. The question remains as to how adequately these quantification schemes can be used to predict runoff and sediment yield from areas not used in WEPP model development. This paper presents results of field-based rainfall simulator studies conducted to assess the hydrologic and hydraulic characteristics of pinyon-juniper (PJ) woodlands. The effects of cover on selected parameters are discussed with regard to the collected data and to the schemes developed in the WEPP effort.

## METHODS

### Location of Sample Sites

Three sites sampled in this study were located in New Mexico and three were in Arizona (Fig. 1). The sites were, in order of sampling, Beaverhead, New Mexico; Springerville, Arizona; Loco Knolls, Arizona; Heber, Arizona; White Oaks, New Mexico; and San Ysidro, New Mexico. Experiments were conducted in May and June at the Beaverhead, Loco Knolls, Springerville, and Heber sites in 1988 (Ward and Bolin 1989b) on plots with natural vegetation and plots that had all vegetation scraped off. The same rainfall simulator was used at a new Heber site in 1989 to examine the effects of the litter layers beneath trees in the PJ (Ward and Bolton 1991).

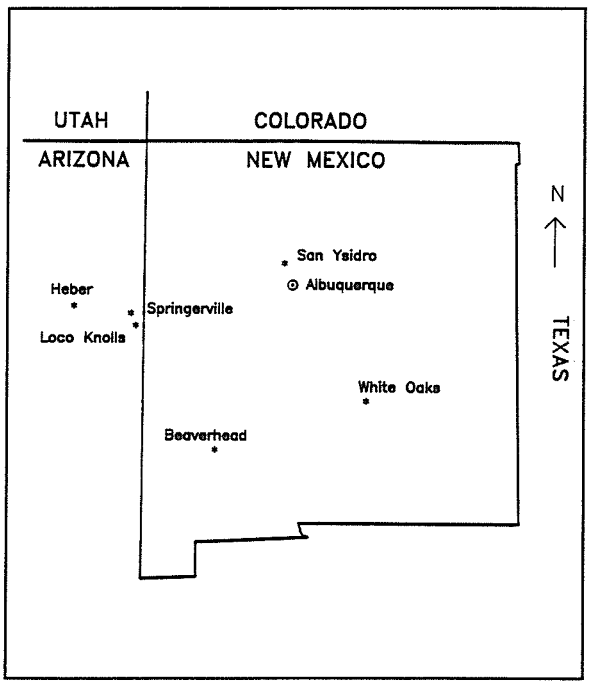


**Figure 1.** Location of sample sites.

A newly built, modified design, small-area simulator was used at White Oaks and San Ysidro. The experiments were conducted between May 14-15, 1990, at White Oaks and from June 25-28, 1990, at San Ysidro. These experiments, in addition to testing the new rainfall simulator, were designed to determine the effects of burning at White Oaks and the effect of soil type at San Ysidro (Ward and Bolton 1991).

Beaverhead, New Mexico - The Beaverhead site was located north and east of the USDA Forest Service's Beaverhead Work Center in the Gila National Forest west of Truth or Consequences, New Mexico. Eighteen plots were located in Section 36, T9S, R12W, near the junction of forest roads 584 and 953. The site is in a pinyon-juniper area and is adjacent to natural rainfall-runoff plots maintained by M. Karl Wood of the College of Agriculture and Home Economics, New Mexico State University. The simulator plots were located on the flanks of the ridges above the natural rainfall plots. The soils at the site have been described as Lithic Haplustalfs by Charles Souders (personal communication 1988), soil scientist, Gila National Forest, Silver City, New Mexico. Elevation at the site is about 2280 meters. Of the 18 plots, 6 were placed in "high" vegetative cover (based on visual estimates), 6 in "low" cover, and 6 were "scraped" bare (top layer of vegetation and rock removed). Three of the bare plots were protected by a layer of window screen at a height of about 4 inches above the soil surface. The screen was used to create the effect of raindrop impact protection afforded by vegetation and rock cover. Data on 36 plot-runs were collected at this site.

Springerville, Arizona - The Springerville site was located south of Springerville, Arizona, in Section 14, T8N, R29W, on the Apache-Sitgreaves National Forest. Eighteen plots were installed at the site, 6 under the canopy and 12 in the rangeland on the edge of the canopy. The plots were divided into the three groups as used at Beaverhead: high cover, low cover, and bare with and without screen. Site elevation is about 2240 meters. Data on 36 plot-runs were collected during the experiments.

Loco Knolls, Arizona - This site was located east and south of Springerville, Arizona, in Section 6, T8N, R31E. Six plots were located in the rocky rangeland soils on the edge of the canopy. Four of the plots had vegetative cover (two high and two low) and the remaining two were scraped bare. The low cover plots were barely distinguishable from the high cover plots because of the dense vegetation and rock cover at this site. The site is at an elevation of about 2380 meters. Twelve plot-runs were made at this site.

Heber, Arizona 1988 - This site was located within a pinyon-juniper area north and west of Heber, Arizona, in Section 33, T13N, R17E. The site is in the Apache-Sitgreaves National Forest at an elevation of about 2000 meters. Twelve plots were sampled; four high cover, four low cover, and four bare (two with screening and two without). Data on 24 plot-runs were collected during the experiments.

Heber, Arizona 1989 - A site near Heber was rained upon in 1988, but in 1989 the experiments were conducted at a new site closer to the large WEPP plots installed by the USDA Forest Service. Fourteen plots were rained upon at the new site in an area north and west of Heber, Arizona, in Section 27, T13N, R17E. The site is in the Apache-Sitgreaves National Forest at an elevation of about 2000 meters. Of the 14 plots, 4 had natural grass cover, 3 were in pinyon-pine litter, 3 were in juniper litter, and 4 plots were scraped bare of vegetation. Data on 28 plot-runs were collected during the experiments.

White Oaks, New Mexico - This site is near the town of White Oaks about 14 miles northeast of Carrizozo. The site is in the Lincoln National Forest, Section 22, T6S, R12E, at an elevation of about 2200 meters. Three plots were placed in areas that had been burned the previous year and three plots were placed in unburned areas. Data on 12 plot-runs were collected at this site. All plots were within the pinyon-juniper canopy.

San Ysidro, New Mexico - This site is about 10 miles south of San Ysidro and 9.4 miles west of the Zia Pueblo near natural rainfall-runoff plots maintained by Earl Aldon of the USDA Forest Service, Albuquerque (Scholl and Aldon 1988). The plots are located within the Jemez River basin at an elevation of about 1850 meters in Section 6, T14N, RlE. The plots are in an open rangeland with scattered PJ vegetation. Four plots were placed in Querencia soils and four plots in San Mateo soils. A total of 16 plot-runs were conducted at this site.

**Sample Techniques**

Plots were rained upon in an antecedent or "dry" condition and again 6 to 24 hours later in a "wet" condition. Simulations were continued until the runoff rate became steady. Water to be analyzed for suspended sediment concentrations was collected from barrels of accumulated runoff from each plot. Samples were collected in acid-washed bottles and frozen or kept on ice until analyzed. Runoff water from the experiments was analyzed by the New Mexico State University (NMSU) Soil and Water Testing Laboratory for concentrations of total suspended solids (APHA 1980).

Sediment retained on the surfaces of the collection device, which was not pumped into the collection bucket, was reported as deposited sediment. This material was dried and weighed, then computationally added to the suspended sediment to find total sediment yield. Sediment yields are reported as kg/ha and as kg/ha/mm of runoff. The kg/ha/mm of the runoff term is a concentration term which, if multiplied by 100, gives concentration in mg/l.

Infiltration rate can be computed a number of ways (Ward 1986; Ward and Bolin 1989a; Ward and Bolin 1989b). In this paper, infiltration is computed as the average of the final few (usually three) steady-state loss rates. According to Eq. 1, the steady-state infiltration rate should be equal to the hydraulic conductivity, K. After checking the statistical distributions of the data, infiltration rates and sediment values were log-transformed for analyses.

**RESULTS AND ANALYSES**

Tables 1 and 2 list the plot characteristics of the experimental plots at each site. Table 1 details the sites visited in 1988. Table 2 details the sites visited in 1989 and 1990.

**Rainfall Experiments 1988**

Table 3 lists the average steady infiltration rates for the different plot types. Previous analyses (e.g., Ward and Bolin 1989b) indicated that there were significant differences between dry run and wet run infiltration rates with wet run rates being significantly lower. For analyses, low cover plots were those with less than 50% organic cover as measured by the point frame and high cover plots had more than 50% cover.

For the dry runs, the bare-screen and the low cover plots had statistically the same infiltration rates. The high cover plots had significantly higher rates and the bare plots had significantly lower rates than the bare-screen and low cover plots. On

Table 1. Means and standard deviations (in parentheses) of plot characteristics for each site - 1988

| Site | # | Cover | Porosity % | Slope % | Canopy Cover % | Organic Cover % | Rock Cover % | Roughness | Amc Dry % | Amc Wet % |
|---|---|---|---|---|---|---|---|---|---|---|
| BH | 3 | B | 40.9 | 3.5 | * | * | * | * | 3.4 | 25.7 |
| | | | (2.1) | (0.7) | * | * | * | * | (1.7) | (1.4) |
| BH | 3 | BS | 43.1 | 3.3 | * | * | * | * | 2.1 | 20.3 |
| | | | (3.8) | (1.3) | * | * | * | * | (0.3) | (3.5) |
| BH | 6 | L | 42.0 | 2.5 | 9.3 | 41.1 | 37.8 | 0.33 | 2.5 | 21.4 |
| | | | (4.1) | (1.0) | (7.9) | (15.9) | (23.5) | (0.07) | (0.5) | (3.8) |
| BH | 6 | H | 39.3 | 3.4 | 19.6 | 57.6 | 20.9 | 0.41 | 3.2 | 20.2 |
| | | | (4.0) | (0.5) | (11.1) | (12.9) | (11.5) | (0.07) | (1.0) | (4.1) |
| HB | 2 | B | 24.0 | 3.3 | * | * | * | * | 0.7 | 15.0 |
| | | | (16.8) | (0.4) | * | * | * | * | (0.1) | (1.6) |
| HB | 2 | BS | 47.1 | 2.3 | * | * | * | * | 1.8 | 13.2 |
| | | | (30.1) | (0.4) | * | * | * | * | (1.0) | (2.6) |
| HB | 4 | L | 20.6 | 2.8 | 18.0 | 27.7 | 32.0 | 0.42 | 1.0 | 10.7 |
| | | | (6.1) | (1.0) | (12.6) | (22.0) | (14.1) | (0.06) | (0.3) | (2.6) |
| HB | 4 | H | 37.2 | 2.3 | 12.3 | 41.3 | 27.7 | 0.47 | 1.4 | 12.1 |
| | | | (21.8) | (1.0) | (4.7) | (28.5) | (14.5) | (0.13) | (0.8) | (4.1) |
| LK | 1 | B | 67.3 | 3.0 | * | * | * | * | 4.7 | 30.6 |
| | | | - | - | * | * | * | * | - | - |
| LK | 1 | BS | 67.3 | 3.0 | * | * | * | * | 4.7 | 30.6 |
| | | | - | - | * | * | * | * | - | - |
| LK | 2 | L | 52.2 | 3.5 | 36.7 | 52.7 | 14.7 | 0.51 | 4.1 | 31.2 |
| | | | (0.8) | (0.7) | (14.7) | (0.9) | (10.0) | (0.01) | (0.1) | (6.6) |
| LK | 2 | H | 52.2 | 3.0 | 39.3 | 55.3 | 21.3 | 0.57 | 4.1 | 31.2 |
| | | | (0.8) | (0.0) | (2.8) | (4.7) | (1.9) | (0.05) | (0.1) | (6.6) |
| SP | 3 | B | 58.8 | 4.8 | * | * | * | * | 3.6 | 23.4 |
| | | | (7.1) | (1.8) | * | * | * | * | (0.5) | (3.8) |
| SP | 3 | BS | 58.8 | 4.7 | * | * | * | * | 3.6 | 23.4 |
| | | | (7.1) | (0.6) | * | * | * | * | (0.5) | (3.8) |
| SP | 6 | L | 52.1 | 5.6 | 32.2 | 19.6 | 25.8 | 0.35 | 3.8 | 20.2 |
| | | | (10.4) | (2.3) | (11.8) | (6.5) | (17.6) | (0.07) | (1.3) | (0.5) |
| SP | 6 | H | 48.1 | 4.8 | 29.6 | 64.4 | 6.0 | 0.36 | 3.8 | 19.8 |
| | | | (10.2) | (1.8) | (24.0) | (24.0) | (6.5) | (0.08) | (1.3) | (1.0) |

Amc = antecedent soil moisture
BH = Beaverhead; HB = Heber 1988; LK = Loco Knolls;
SP = Springerville; WO = White Oaks; SY = San Ysidro

# - number of plots at each location
* - data not collected
Cover - assigned cover categories; B = bare; BS = bare-screened;
L = low cover; H = high cover

Note: Organic cover is basal vegetation, cryptogams and litter.
Rock cover is rock and gravel cover.
Roughness is the mean standard deviation in pin heights across and down the plot.

Table 2. Means and standard deviations (in parentheses) of plot characteristics for each site - 1989 and 1990

| Site | # | Cover | Porosity % | Slope % | Canopy Cover % | Organic Cover % | Rock Cover % | Roughness | Amc Dry % | Amc Wet % |
|---|---|---|---|---|---|---|---|---|---|---|
| HB | 4 | B | 33.9<br>(7.7) | 4.5<br>(2.7) | 0.0<br>(0.0) | 0.0<br>(0.0) | 0.0<br>(0.0) | 0.22<br>(0.06) | 2.0<br>(0.8) | 14.3<br>(8.1) |
| HB | 2 | L | 20.8<br>(8.0) | 4.8<br>(0.4) | 25.4<br>(1.9) | 26.6<br>(3.7) | 2.6<br>(1.9) | 0.44<br>(0.01) | 0.6<br>(0.2) | 8.6<br>(1.1) |
| HB | 2 | H | 40.6<br>(0.0) | 2.5<br>(0.0) | 39.4<br>(0.9) | 54.7<br>(17.0) | 0.6<br>(0.9) | 0.49<br>(0.03) | 2.6<br>(0.0) | 16.9<br>(1.1) |
| HB | 3 | J | 46.2<br>(11.5) | 5.7<br>(0.6) | 0.0<br>(0.0) | 100.0<br>(0.0) | 0.0<br>(0.0) | 0.63<br>(0.06) | 4.3<br>(2.6) | 21.2<br>(7.9) |
| HB | 3 | P | 58.5<br>(2.7) | 6.8<br>(3.2) | 1.3<br>(1.4) | 100.0<br>(0.0) | 0.0<br>(0.0) | 0.70<br>(0.09) | 6.4<br>(2.5) | 16.2<br>(8.1) |
| WO | 3 | F | 56.5<br>(12.4) | 2.5<br>(0.0) | 0.0<br>(0.0) | 0.0<br>(0.0) | 0.0<br>(0.0) | *<br>* | 10.4<br>(4.2) | 20.5<br>(1.7) |
| WO | 3 | N | 45.8<br>(2.7) | 2.7<br>(0.8) | 32.0<br>(10.1) | 54.7<br>(17.4) | 0.0<br>(0.0) | 0.38<br>(0.06) | 3.5<br>(0.1) | 16.7<br>(3.1) |
| SY | 4 | Q | 34.3<br>(5.2) | 4.8<br>(0.3) | *<br>* | 45.0<br>(4.1) | *<br>* | *<br>* | 1.4<br>(0.1) | 14.0<br>(1.1) |
| SK | 4 | M | 44.2<br>(4.8) | 2.4<br>(0.6) | *<br>* | 25.2<br>(13.0) | *<br>* | *<br>* | 1.9<br>(0.2) | 16.9<br>(2.4) |

Amc = antecedent soil moisture
BH = Beaverhead; HB = Heber 1989; WO = White Oaks; SY = San Ysidro

# - number of plots at each location
* - data not collected
Cover - assigned cover categories; B = bare; L = low cover;
H = high cover; F = burned plots; N = natural plots; P = pinyon litter;
J = juniper litter; Q = Querencia soils; M = San Mateo soils.

Note: Organic cover is basal vegetation, cryptogams and litter.
Rock cover is rock and gravel cover.
Roughness is the mean standard deviation in pin heights across and down the plot.

Table 3. Average infiltration rates (mm/hr) for the four plot types and two moisture conditions. Standard deviations are in parentheses. Values in a given row followed by different letters are significantly different at $p < 0.05$.

| Cover Condition | Bare | Bare-screen | Low | High |
|---|---|---|---|---|
| Number of Plots | 9 | 9 | 20 | 16 |
| Dry Run | 23.4a<br>(7.2) | 39.1b<br>(17.0) | 48.6b<br>(16.8) | 63.9c<br>(18.6) |
| Wet Run | 14.5a<br>(7.0) | 22.3a<br>(13.8) | 25.1a<br>(12.5) | 39.7b<br>(17.1) |

the wet runs, the high cover plots had significantly higher infiltration rates than the other plots. In general, the bare-screen, low and high cover plots had average infiltration rates of about 1.6, 1.9, and 2.7 times, respectively, the average bare plot rate.

Because the published methods did not predict infiltration rates very well (Ward et al. 1990), stepwise regression was used to identify significant relationships between steady infiltration rate and plot characteristics. Residual analysis indicated the presence of one outlier, which was then deleted. A dummy variable of either -1, 0, or +1, respectively, was used for the three cover conditions of bare, low, and high cover. The screened plots were not used in the analysis because they represented an abnormal condition. The other significant variables were found to be soil moisture and canopy. Soil textures did not enter the relationship at a significant level which may be caused by the low variability in the soil types among the sites relative to the other characteristics. The canopy factor relationship in Eq. 2 could not be duplicated with this data set. However, an increase in $r^2$ was found when only shrub canopy, rather than total canopy including grass, was used and when it was corrected for litter beneath the canopy. The best relationship for predicting infiltration rate, f, was:

$$f = 41.2 \exp[0.472(fcov) - 0.031(sm) + 0.022(canopy)] \quad (3)$$

where f = steady infiltration rate in mm/hr
fcov = the dummy variable (-l, 0, or +1)
sm = soil moisture by weight in percent
and canopy = shrub canopy with no litter beneath it in percent

Equation 3 results in a correlation coefficient of 0.76 between the measured and predicted infiltration rates.

Three other data sets collected with the same rainfall simulator were used to check the validity of Eq. 3. The Jornada data set is from a creosote desert area. The 1989 simulator data (Ward and Bolton 1991) were collected from the same plots as the 1988 samples (Ward and Bolin 1989b), except that there were no bare plots. The Heber 1989 data set is from a PJ area close to one of the 1988 sites. Figure 2 shows the relationship between measured and predicted values of the infiltration rates for the various data sets. Factor lines of 2 times and 0.5 times have been added to the figure to illustrate the variability in the predictions. For the 68 validation data points, the correlation coefficient between predicted and measured values was $r = 0.51$ ($p < 0.0001$).

Overall, 89% of the predicted infiltration rates for the test plots were within a factor of 2 of the measured rates. At individual sites, 92.3% of the Heber 1989 predicted values, 91.7% of the Jornada values, and 85% of the 1989 simulator values were within a factor of 2 of the measured infiltration rates.

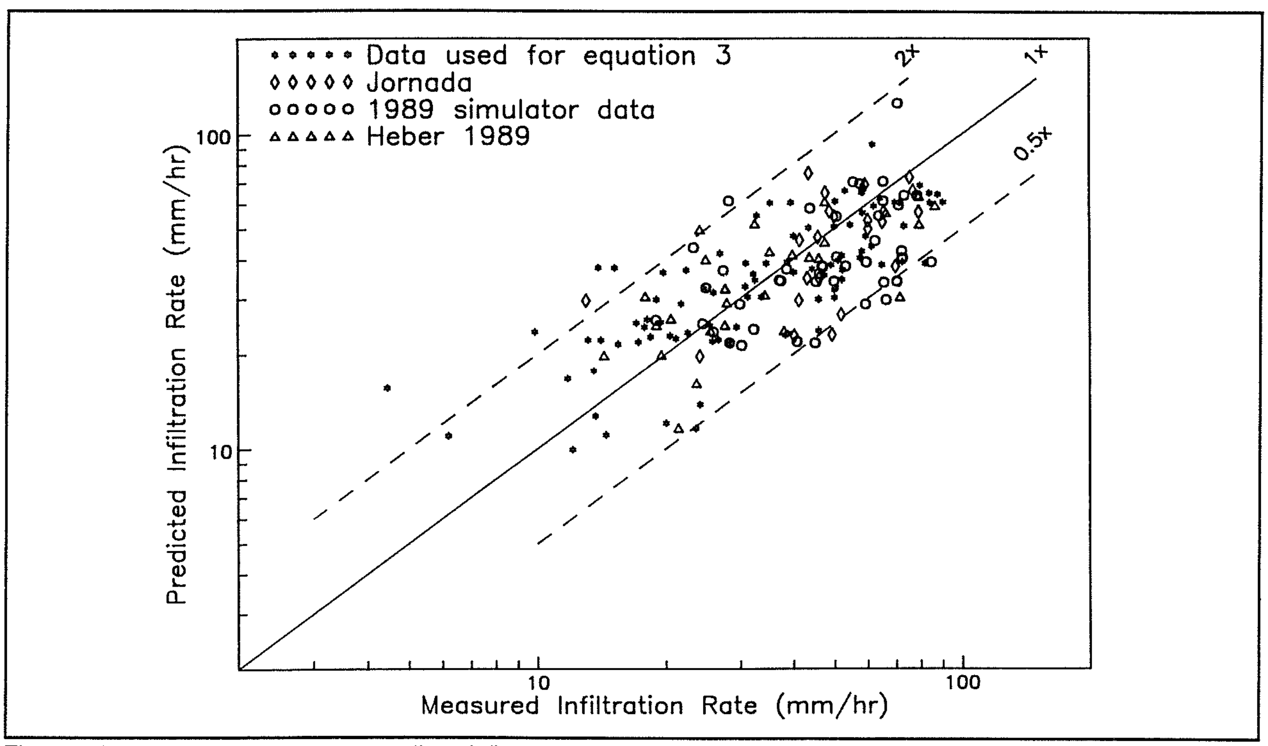


**Figure 2.** Comparison of measured and predicted infiltration rates.

**Rainfall Experiments 1989 and 1990**

Table 4 lists the summarized results of the rainfall experiments at the five sites. Plots at each site were assigned to different cover categories. At Heber there were five plot cover categories: high, low, pinyon-pine litter, juniper litter, or scraped bare of vegetative cover. At White Oaks, plots either had all vegetation burned off or had natural vegetation. At San Ysidro, plots were not separated by vegetation characteristics, but rather as being situated either in Querencia or San Mateo soils.

Table 4. Means and standard deviations (in parentheses) of rainfall and runoff characteristics for each site.

| Site | # | Cover | Intensity (mm/hr) | | Runoff/Rainfall (percent) | | Steady Infiltration Rate (mm/hr) | |
|---|---|---|---|---|---|---|---|---|
| | | | Dry | Wet | Dry | Wet | Dry | Wet |
| HB | 4 | B | 88.0 (3.2) | 87.9 (2.9) | 47.5 (7.1) | 69.5 (7.4) | 27.6 (7.9) | 19.7 (4.0) |
| HB | 2 | L | 89.0 (3.2) | 91.3 (2.8) | 32.5 (2.9) | 51.4 (4.2) | 44.9 (1.6) | 31.0 (4.7) |
| HB | 2 | H | 90.0 (1.9) | 90.7 (2.5) | 29.6 (3.7) | 57.6 (0.5) | 43.8 (5.5) | 22.8 (3.0) |
| HB | 3 | J | 87.1 (1.6) | 89.4 (2.1) | 5.1 (4.5) | 36.2 (13.8) | 72.9 (9.2) | 31.1 (15.0) |
| HB | 3 | P | 92.2 (2.7) | 91.0 (1.4) | 22.6 (25.4) | 36.8 (17.7) | 66.2 (29.3) | 43.6 (24.8) |
| WO | 3 | F | 87.5 (2.8) | 90.0 (1.2) | 54.9 (20.6) | 74.8 (14.4) | 34.0 (25.9) | 19.7 (15.7) |
| WO | 3 | N | 91.4 (6.6) | 92.7 (2.2) | 45.5 (5.3) | 64.1 (6.3) | 33.3 (4.0) | 17.6 (4.4) |
| SY | 4 | Q | 82.6 (2.3) | 83.0 (2.4) | 27.6 (4.8) | 49.9 (4.5) | 48.3 (6.2) | 28.7 (1.8) |
| SY | 4 | M | 83.1 (3.4) | 82.8 (4.1) | 60.5 (9.8) | 79.4 (6.9) | 23.0 (8.9) | 10.5 (5.6) |

HB = Heber; WO = White Oaks; SY = San Ysidro
# - number of plots at each location

Cover - assigned cover categories: B = bare; L = low cover; H = high cover;
J = juniper litter; P = pinyon litter; F = burned; N = natural;
Q = Querencia soils; M = San Mateo soils.

**Runoff to Rainfall Ratios 1989 and 1990**

Comparisons were made at each site among the different cover types. At sites with only two cover levels, t-tests were used and homogeneity of variances were checked. Heber had five levels of cover so a least squares means test was used to test for differences among cover types.

The burned plots at White Oaks had higher mean runoff to rainfall ratios but the differences were not statistically significant for the dry or wet runs. At San Ysidro the San Mateo soils had significantly higher runoff to rainfall ratios than the Querencia soils for dry and wet runs. The Heber dry runs showed considerable overlap in runoff to rainfall ratios among the five cover types. Juniper and pinyon litter plots and the high cover plots had statistically the same runoff to rainfall ratios. The pinyon litter, high and low cover plots were not significantly different and the high, low, and bare plots were not different. At Heber, for the wet runs, the litter plots and the high and low cover plots had statistically the same runoff to rainfall ratios and the low, high and bare plots were not statistically different.

**Infiltration Characteristics 1989 and 1990**

Small plot data indicate that the estimated average value of hydraulic conductivity (steady-state infiltration or loss rate) decreases between dry and wet runs. Paired difference t-tests were performed on the infiltration rate values between the soil moisture conditions. There were significant differences in infiltration rates at all sites between dry and wet runs.

At Heber, the pinyon-pine and juniper litter plots had significantly higher infiltration rates on the dry runs than the bare plots. There were no significant differences among the other cover categories. For the wet runs, only the pinyon-pine litter plots had significantly higher infiltration rates than the bare plots and there were no statistical differences among the other cover types.

At the other sites, for the dry runs, only San Ysidro had significant differences between plot types. At that site, the differences are not cover related but rather caused by differences in soil types. For the wet runs, the Querencia soils at San Ysidro again had significantly higher infiltration rates than the San Mateo soils. There were no significant differences in infiltration rates at White Oaks between the burned and unburned plots.

**Sediment Production 1988**

Tables 5 and 6 report average sediment production for the plots in terms in kg/ha and kg/ha/mm of runoff, respectively. The cover effect is evident in the total yields expressed as kg/ha where the average yields for the bare-screen, low and high cover plots were 0.6, 0.3, 0.2 times, respectively, the average yield for the bare plots. However, when the total yields are expressed in units of kg/ha/mm of runoff, the ratios of the average values for the bare-screen, low and high cover plots are 0.6, 0.5, and 0.6 times, respectively, the average value from the bare plots.

Table 5. Average sediment losses (kg/ha) for the four plot types and two moisture conditions. Standard deviations are in parentheses. Values in a given row followed by different letters are significantly different at $p < 0.05$.

| Cover Condition | | Bare | Bare-Screen | Low | High |
|---|---|---|---|---|---|
| Number of Plots | | 9 | 9 | 20 | 16 |
| Suspended Sediment Yield | Dry Run | 759.1a<br>(483.5) | 505.5a<br>(694.2) | 134.5b<br>(121.2) | 58.4c<br>(62.3) |
| | Wet Run | 447.0a<br>(243.0) | 263.5a<br>(175.9) | 122.7b<br>(95.3) | 104.8b<br>(138.5) |
| Deposited Sediment Yield | Dry Run | 1452.0a<br>(1084.5) | 901.9ab<br>(1020.7) | 533.1b<br>(348.0) | 309.6c<br>(249.8) |
| | Wet Run | 1793.0a<br>(1129.4) | 835.1b<br>(614.9) | 698.9bc<br>(571.7) | 422.1c<br>(259.9) |
| Total Sediment Yield | Dry Run | 2211.1a<br>(1198.7) | 1407.4a<br>(1706.8) | 667.6b<br>(417.3) | 368.0c<br>(290.4) |
| | Wet Run | 2240.0a<br>(1238.6) | 1098.6b<br>(611.0) | 821.6bc<br>(632.1) | 526.9c<br>(352.6) |

Table 6. Average sediment losses (kg/ha/mm of runoff) for the four plot types and two moisture conditions. Standard deviations are in parentheses. Values in a given row followed by different letters are significantly different at $p < 0.05$.

| Cover Condition | | Bare | Bare-Screen | Low | High |
|---|---|---|---|---|---|
| Number of Plots | | 9 | 9 | 20 | 16 |
| Suspended Sediment Yield | Dry Run | 26.5a | 18.9a | 8.4b | 6.5b |
| | | (14.4) | (19.1) | (6.2) | (4.6) |
| | Wet Run | 18.7a | 11.4a | 6.3b | 5.3b |
| | | (10.4) | (5.2) | (4.5) | (4.1) |
| Deposited Sediment Yield | Dry Run | 50.9a | 40.6a | 39.9a | 62.6a |
| | | (33.3) | (42.5) | (24.6) | (57.6) |
| | Wet Run | 76.5a | 39.2b | 36.3b | 25.8b |
| | | (51.9) | (30.2) | (26.2) | (13.6) |
| Total Sediment Yield | Dry Run | 77.4a | 59.5a | 48.3a | 69.1a |
| | | (33.4) | (39.7) | (27.3) | (57.5) |
| | Wet Run | 95.2a | 50.7ab | 42.7b | 31.1b |
| | | (57.1) | (30.1) | (28.6) | (15.8) |

## Sediment Production 1989 and 1990

Table 7 is a summary of the sediment yields collected with the small simulator in 1989 and 1990. Values were log-transformed for analysis because the log-transformed values were found to be normally distributed and thus met the assumptions of the statistical tests.

At all sites, except Heber, cover conditions were compared with a t-test for differences in total sediment yield from the cover types. Because there are more than two cover types at Heber, a t-test could not be used and a least squares means test was used to test for differences in total sediment yield from the five cover types. Few significant differences were found in total yield between the dry and wet runs, so the analyses were not split by moisture condition.

At Heber, the total sediment concentrations and yields were significantly lower from pinyon-pine and juniper litter plots compared to the other

Table 7. Means and standard deviations (in parentheses) of the components of sediment yield for each site

| Site | # | Cover | Runoff (mm) | | Suspended Yield (kg/ha) | | Suspended Conc. (kg/ha/mm) | | Deposit (kg/ha) | | Deposit (kg/ha/mm) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| HB | 4 | B | 88.0 | 87.9 | 998.7 | 939.7 | 45.9 | 35.3 | 3812.1 | 4846.4 | 176.0 | 215.9 |
| | | | (3.2) | (2.9) | (793.8) | (1172.1) | (36.0) | (37.3) | (2025.2) | (2304.5) | (95.6) | (71.9) |
| HB | 2 | L | 11.2 | 14.1 | 89.5 | 53.9 | 7.9 | 3.8 | 743.7 | 564.6 | 66.0 | 40.3 |
| | | | (0.2) | (0.5) | (11.0) | (2.2) | (0.8) | (0.3) | (142.6) | (214.8) | (11.4) | (16.4) |
| HB | 2 | H | 13.0 | 14.8 | 189.8 | 212.2 | 15.7 | 14.7 | 928.7 | 812.6 | 65.0 | 54.1 |
| | | | (5.3) | (1.3) | (15.0) | (77.0) | (5.3) | (6.6) | (767.8) | (395.4) | (32.7) | (21.9) |
| HB | 3 | J | 4.0 | 18.7 | 5.8 | 50.9 | 3.4 | 2.5 | 45.3 | 358.6 | 13.7 | 18.2 |
| | | | (4.5) | (7.5) | (6.2) | (71.1) | (3.6) | (3.2) | (40.3) | (370.3) | (16.7) | (16.2) |
| HB | 3 | P | 9.9 | 15.7 | 48.2 | 36.3 | 3.4 | 2.6 | 46.5 | 122.6 | 9.1 | 9.8 |
| | | | (11.7) | (8.2) | (69.7) | (30.6) | (2.0) | (1.7) | (25.8) | (70.7) | (7.6) | (6.3) |
| WO | 3 | F | 20.4 | 25.0 | 1168.2 | 993.3 | 59.5 | 39.3 | 7689.5 | 8113.4 | 404.7 | 312.9 |
| | | | (4.6) | (4.0) | (857.6) | (406.5) | (43.4) | (14.5) | (3949.5) | (5824.3) | (274.8) | (183.2) |
| WO | 3 | N | 20.6 | 17.8 | 534.1 | 354.9 | 26.3 | 20.1 | 2238.5 | 957.0 | 108.8 | 54.0 |
| | | | (10.6) | (2.1) | (279.0) | (34.7) | (11.5) | (2.9) | (1707.9) | (683.3) | (97.1) | (40.9) |
| SY | 4 | Q | 13.3 | 21.7 | 220.5 | 319.3 | 17.2 | 14.9 | 2838.8 | 2300.5 | 210.2 | 109.5 |
| | | | (2.8) | (2.5) | (30.0) | (81.5) | (4.4) | (4.2) | (2135.6) | (1262.2) | (144.7) | (64.5) |
| SY | 4 | M | 21.2 | 34.6 | 684.8 | 1015.4 | 33.2 | 28.4 | 2224.6 | 3055.8 | 103.2 | 93.8 |
| | | | (4.9) | (8.4) | (157.5) | (443.7) | (8.4) | (6.6) | (1362.8) | (1032.7) | (56.2) | (47.9) |

Total yields are found by adding suspended and deposit values.

HB = Heber; WO = White Oaks; SY = San Ysidro
\# - number of plots at each location
Cover - assigned cover categories: B = bare; L = low cover; H = high cover;
J = juniper litter; P = pinyon litter; F = burned; N = natural;
Q = Querencia soils; M = San Mateo soils

cover types. Sediment yields and concentrations were not significantly different from the low and high cover plots. The bare plots had significantly higher total sediment yields and concentrations than the other plots. At White Oaks, the burned-plots had significantly higher total sediment yields and concentrations than the unburned plots. There were no significant differences in sediment yields or concentrations from the two soil types at San Ysidro.

## DISCUSSION

The study results reiterate the importance of cover and soil moisture with respect to infiltration rates and erosion. In the stepwise regression for infiltration, the cover variable was the first variable entered for Equation 3 and soil moisture was the second variable entered. An increase in cover increases infiltration rates and decreases soil erodibility. An increase in soil moisture decreases infiltration rates and increases soil erodibility. Soil porosity and soil texture, prominent variables in many models for estimating infiltration parameters, did not enter the stepwise regression as significant ($p < 0.05$) variables. This may be due to the soil similarity among sites in 1988. There were clear differences in hydrologic response at San Ysidro where plots were purposely located in two distinct soil types. Cover was not that different between sites at San Ysidro indicating that soil type can be an influential variable separate from cover. The studies at Heber in 1989 indicate that most runoff and erosion problems in the PJ are from interspace areas. The litter layers beneath the trees significantly reduce runoff and accompanying soil loss. This effect is probably even more pronounced than indicated by these data since the rainfall simulator rained directly over the litter layer and real rainfall has to penetrate the tree canopy. Earlier analyses (Ward and Bolin 1989b) indicated that soil surface roughness was an important variable for predicting infiltration rate. However, roughness is a difficult variable to estimate quickly in the field and therefore is of limited utility in predictive equations.

Within the limits of comparably measured data, published models for estimating infiltration and erosion parameters were tested with the field data set and found lacking. Equations were developed which better predicted the observed values, and then were tested on additional data sets. It is important to validate published models, such as those presented here or in the WEPP manual, in order to test their applicability. The results and predictive equations presented in this paper should better help define field conditions which effect runoff and erosion in pinyon-juniper woodlands.

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*New Mexico native **Eluid Martinez** was appointed state engineer last December. He has worked for the State Engineer Office for almost 22 years. He served on the Santa Fe School Board from 1979-1985 and was board president during the last two years of his tenure. Mr. Martinez is an accomplished artist and recently created the official poster commemorating the New Mexico Columbus Quincentennial.*

# CURRENT ISSUES IN NEW MEXICO WATER RESOURCES

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In 1963, I attended my first water conference as a NMSU student in the College of Engineering. Today I return as a speaker to provide you with the philosophy and direction the State Engineer Office (SEO) is taking and will take in the future. In my opinion, New Mexico's water laws developed in the early 1900s for the purpose of exploiting the state's water resources. By Indian and Hispanic custom, there was no such thing as legal title to water. Water was held in common for the benefit of the public. But New Mexico and the West began to develop, and as money came in from the East, bankers insisted on collateral for any money they made available. The result was a mechanism put in place across the West to acquire title to water. The prior appropriation doctrine permitting system was developed as a way to obtain some definitive paper title to water which could be taken to the bank to serve as collateral. Water began, to paraphrase Steve Reynolds, to flow uphill to money.

We had an era from the early 1900s until fairly recently where water development and exploitation was the norm—big dams, big irrigation projects, and so forth. During this period in New Mexico, state engineers and other water administrators across the West were primarily concerned with the development of water resources and the protection of rights authorized under the permitting system or by the courts. The administrators served as protectors of those rights, protectors of prior rights, and as advocates for water development.

We have come to the end of the development era. We are now faced with the reallocation of existing uses. There is no magical new source of water, and we must deal with public welfare questions and environmental concerns. Not only New Mexico's State Engineer Office, but water resource agencies across the West, as well as federal agencies, are having to shift their objectives. They must be more involved with environmental problems. The Bureau of Reclamation, for example, is developing a statement of new direction. At the SEO, we are not so much involved with water developmental issues, but with how to best utilize our resources.

The New Mexico SEO is unique in the West. Because of Steve Reynolds' 35-year tenure as state engineer, there was not much change during that period as to how New Mexico directed its efforts regarding administration or development of water rights. The administration of water resources in other western states, whether good or bad, evolved into separate agencies with no one agency having an overall authority, responsibility, or final word on how water should be developed in that state. In the past, some efforts were made in New Mexico to take the state engineer's power and authority and piecemeal it out. Those efforts were not very successful primarily because of Steve Reynolds' stature. Thus, it is the state engineer's sole responsibility to administer the state's water resources.

The state engineer permits new water uses, allows transfers of uses, and so forth. This is a little different from other states. Some states require an application to go through the court system to secure water rights. In New Mexico, if you want a water right permit, you go to the state engineer and he makes the decision to grant or deny that request. His decision is appealable to district court. For all practical proposes, unless the state engineer makes a decision that does not provide somebody their legal remedy, or if a procedural mistake occurred, historically the courts have not overturned his technical decisions. Therefore, the state engineer has great power in the way water is administered in New Mexico.

Some argue that the state engineer is as powerful as the governor because of his authority to administer water and the effects of that authority on the state's future growth. Steve Reynolds often said it was not that he was powerful, it was the position that was powerful. I have come to realize that this is very true. It is the person who fills those shoes at a particular point in time that has the authority under law to make certain decisions. When that individual moves on, another person fills those shoes. Similarly, when I was president of the Santa Fe School Board, I had a bit more clout than if I were merely a board member. That is basically the state engineer's position. If you have a person in that position who has integrity and intelligence, and the best interest of the state, the state can go forward. If you do not have that combination, you could have some problems in the water rights administration of the state.

The SEO consists of a legal division, an administrative services division and a technical division, which is divided into sections. This method of operation has existed for at least 21 years—as long as I have been with the SEO—and the organizational structure probably predates my tenure. The SEOs structure is currently being changed.

The technical division has four sections—a section primarily involved in the adjudication of water rights throughout the state; a hydrology section involved in surface and groundwater analysis of new water rights applications or the transfer of surface or groundwater rights; a water planning section; and a dam section responsible for dam inspections, dam safety, assisting the ditch program, and rehabilitating ditches. The SEO also has the water rights administration division responsible for administering water rights, providing permits, and processing applications.

The Interstate Stream Commission (ISC) is comprised of nine members, eight appointed from different areas of the state by the governor, and the state engineer who serves as secretary of the commission. During the last 35 years, the state engineer served not only as the secretary of the commission but also directed the ISC staff consisting of 10 to 13 individuals. For all practical purpose, the state engineer was the voice of the commission. The ISC is responsible for water matters related to neighboring states across the West. Because of the state engineer's power on the ISC, it has been said the state engineer was the commission. Decisions made by the state engineer were the decisions of the commission.

Today the state engineer also serves on six compact commissions. In the past, he served on seven commissions. The Pecos River Commission was the only commission on which he did not serve. Therefore, New Mexico's state engineer used to serve on seven compact commissions, directed and was the voice of the ISC, and administered the water resources within the state of New Mexico. There are those who will argue that it is best to have one individual responsible for all directions New Mexico takes concerning its water resources. Only history will tell us if they are right.

I assumed the position as state engineer with the understanding that I do not want to be in that position for 35 years. I have been with state government for nearly 28 years and I could have retired two years ago. That puts me in a very interesting position because I am able to retire, and much of what I do or say is because of that flexibility.

When I took the position I realized where the agency was and where it should be in four years. With that in mind, I have begun to change how the agency is operated internally by gathering around me the best people I can find within the agency and hiring others from outside the agency. Some NMSU professors, for example, are working under contract with the SEO and have been given a lot of authority to make decisions. In the past, the state engineer made the ultimate decisions. There were many people who put in substantial time with the SEO and left the agency feeling that they never really made much of an impact because they did not make decisions on their own. I am changing that. I don't work at night, and I don't work on weekends, even with all the responsibilities I have. I am delegating authority to others. The primary reason for delegating authority is so that the agency does not vest all its knowledge in one, two or three individuals. If those individuals walk out the door, you really have some problems. I am trying to spread responsibility across all supervisory levels, and staff members are taking it to task and doing a good job. Staff members who had never been out of New Mexico are being sent across the West to expose them to western water resource development. They also are being sent across New Mexico to meet with water user groups. They are testifying before the legislature and you would be surprised what people will do when given an opportunity.

This conference's topic concerns how universities and state and federal agencies cooperate. The SEO has historically funded a water-use program with the U.S. Geological Survey (USGS) for a half million dollars per year. Our efforts with the USGS have primarily dealt with data acquisition. We have always worked with the U.S. Army Corps of Engineers and with the Bureau of Reclamation.

However, I have not had the opportunity to sit across from individuals representing these agencies and say, "What do you think would be in the best interest of water resources development for this state? Give me your perspective." When I first became state engineer I found that many people did not know how to relate to me but they did remember how they had related with my predecessor. I am beginning to open lines of communication and have no problem sitting down and talking with staff from the U.S. Fish and Wildlife Service, or with the State Land Office Commissioner, although I realize that some people might not like that fact. I also have no problem sitting down with the Indian leaders across New Mexico and discussing their concerns even though some water users might not like that. These relationships should have been cultivated long ago. These discussions have opened my eyes to what I perceive to be in the best interest of New Mexico in terms of water rights administration and I am trying to pass that same feeling onto my staff. Staff now come to me and express concerns about the environment and I foster that communication. Although I don't necessarily agree with them in every decision, I hope they feel they can come to me with their concerns.

In 1976, a water resource assessment was completed for New Mexico. The SEO has made attempts to update that assessment. We now project the completion of a state water plan within 24 months. The plan will address concerns such as instream flows, water conservation, and issues of public welfare. These issues are very emotional and should be addressed in the context of a state water plan rather than through individual legislation. If you do not have a well laid foundation, you might as well forget trying to get an instream flow bill or conservation bill passed through the legislature.

New Mexico is the only western state that does not have some kind of instream flow law. Growing up in northern New Mexico, I lived next to a river where I would fish every weekend. My kids have grown up in New Mexico and I hope their kids do also. I want to preserve the environment and the qualities of New Mexico. I am not serving as the state engineer having relocated from another state, working for two or three years, and then going to work elsewhere. My roots are here and this is where I am going to stay.

The question is how to achieve what is best for New Mexico. In some areas, certain water user groups in the state—and this is not only common to water user groups—take the position that they want all the pie or none of it. They are not willing to sit down and talk. As long as people take that kind of position, you will never reach common ground. When I became state engineer and appeared before the first legislative session, a Representative introduced an instream flow bill. I think there may have been the perception that since we have a new state engineer, we might get something by him that appeared impossible under Mr. Stephen E. Reynolds. What they did not realize was that there was another water user group very concerned about instream flow. Regardless of who the new state engineer was, they were not going to allow certain things to occur. I very hurriedly looked at the legislation and said that I was not prepared to address instream flow 30 days after becoming state engineer. Instream flow is a very critical issue to New Mexico. Although I am using instream flow as an example, there are other important issues. Taking the safe course, I took the position Mr. Reynolds usually took—creating instream flow laws in New Mexico is against the state's constitution. That is a very simple statement, but you would be surprised how effective. Because I said it was unconstitutional, the bill was tabled. To the community concerned with instream flow, I have indicated that I need some time. We must look at instream flow in the context of the state water plan. I think we can then come up with something that is in the best interest of all New Mexicans and get that through the legislature.

Some might say that my operating style might cause me a lot of headaches. Maybe allowing other folks to have a say will ultimately get you into a worse situation. My gut feeling is that this is not true. One could argue that if I made every decision, I would know what each decision was, and I would have to deal with my own decisions. The problem with not delegating decision making within an agency is that you do not allow staff members to grow professionally. You must give them a little push and see if they sink or swim.

Currently, there are some difficult decisions before the state engineer. We have an application from a gold mining company for water rights in the Cerrillos Mountains. This is a situation potentially falling under the public welfare criteria where the state engineer might be called upon to determine whether it is in the best interest or in the public welfare of the state of New Mexico to allow a mining operation to be built versus—what the environmental community in Santa Fe is calling—the destruction of the environment and the potential for groundwater contamination.

In Taos a developer wants to build a $45,000,000 development with an 18-hole golf course. There are folks in Taos that want the development because they feel it will provide income and jobs. There are others in Taos who do not want the development because they are concerned that it will change the character of Taos and northern New Mexico.

The U.S. Fish and Wildlife Service has applied to build an experimental fish hatchery in Mora, completely funded by federal monies. Some in the Mora Valley think it is going to bring tourism into the area and provide some jobs. Others say Mora does not want the jobs or the tourism. They feel it will ruin their countryside and their quality of life.

These issues will force the state engineer to deal with the public welfare criteria. When I took office fully realizing that I was going to have to deal with the public welfare issue, I called in my legal staff and asked for a review of options. One option is to continue to deal with public welfare on an application-by-application basis. Another option is to do what other western states have done—set up criteria through the rule-making authority or develop regulations indicating what is considered in the public welfare, with a final clause that says you will consider everything else that has not been considered in the regulations. Another option is to look seriously at this issue during the planning process. The 21 regions in New Mexico now developing water plans should indicate what they perceive to be in the best interest of the public welfare in terms of water resources development. Those 21 regional water plans could then be used to develop the state water plan. Through a series of public hearings and input from all interested water groups, one could produce a state water plan that is perceived to be in the best interest of New Mexico. The plan would not only assist me, but also will help future state engineers who will have to deal with this issue.

I have decided to take my staff's advice and deal with the issue on a case-by-case basis for the next two years, assuming I am the state engineer for the next two years. We will address the public welfare issue in the state water plan. Farmers, ranchers, environmentalists, mining interests, cities, and so forth will have input through the state water plan hearing process. Hopefully, the state water plan will serve as the foundation for where this state is going in its use of its water resources. It will not be an easy task. Ultimately, the state engineer will have to make the final recommendations. We must wait to see whether the legislature and the public accept the recommendations.

Since December the state engineer has conducted public meetings in Alamogordo, Carlsbad, Roswell, Ft. Sumner, and Silver City, and has met with the 22 Indian tribes. We had a state fair exhibit for the first time and the SEO has contracted with an individual to develop a water conservation course for public elementary schools. A publicity program on water conservation soon will be aired on radio and television. These activities are an attempt to educate people of the State Engineer Office's responsibilities.

When I appear before many groups and tell them that I am the state engineer, most people think that I either drive the state's locomotive or I build highways. Recently I visited the Navajo Nation. I went into one of their leader's offices and sat down with the leader and said, "I'm Mr. Martinez, the state engineer." The individual looked at me and said, "Well, we don't have any problems right now with our roads." I said to myself right then, "there is a perception problem." I am going to try and change that perception under my tenure. Future decisions having to do with water and water administration in the state are going to take on a broader focus, are going to have more input from universities, from other state agencies, and so forth. Hopefully we will do what is in the best interest of the state.

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# TRAINING NEEDS OF THE NEW MEXICO ENVIRONMENT DEPARTMENT

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Thank you for the opportunity to share with you my thoughts on the ways in which various agencies can help the New Mexico Environment Department and other environmental related agencies meet our future hiring needs. Since the theme of the conference is *Working For the Future*, it is important to note that the only way we will be able to work in the future is if we have adequately trained staff. Beyond that, we need more than "book learning" about environmental issues. We need a real-world sense of those issues — a sense of practical application of what the textbooks can so eloquently present in theory.

Let me give you a practical application of my comments, as well. Yes, we need scientists; yes, we need biologists. We need chemists; we need health physicists. We even need engineers and we need them trained in the state-of-the-art technology that changes the way we do things on an almost daily basis. But we also need some of these environmental technicians to have a background in economics. I'm not saying that all our personnel should be economists; but certainly, they should be exposed to economics courses in their training. Much of what we do today is influenced by economics—whether the action is one of prevention or remediation.

Cross-disciplinary programs would also be helpful. Many years ago, when I first started with the department's predecessor, the Environmental Improvement Division, the only groups that really challenged our actions were industry. However, we now find many permittees, such as local governments, have developed good expertise in the environmental area. Oftentimes, the concerns expressed by permittees center around economics. We must be prepared to defend our actions and demonstrate that they are indeed justified.

It would be helpful for environmental scientists and engineers to have some exposure or training in Indian law. Recent amendments to several federal statutes (Clean Water Act; Safe Drinking Water Act; Comprehensive Environmental Response, Compensation, and Liability Act) have authorized the U.S. Environmental Protection Agency (EPA) to treat Indian tribes as states for several sections of these laws. Setting surface water quality standards is the area that seems to have drawn the greatest interest in New Mexico. Several tribes in New Mexico have proposed their own surface water quality standards. These proposed standards are generally more stringent than those adopted by the New Mexico Water Quality Control Commission. Staff familiar with the basics of tribal law and tribal sovereignty would greatly benefit our department.

We also need environmentally trained personnel graduating from New Mexico universities to have a trait I'm not sure you can teach: common sense. We need people who are not so specialized in their chosen field that they can't see the big picture. All aspects and approaches to solving problems must be considered and evaluated.

How can you help us? I believe cooperative relationships between the universities and our department are crucial. We need an ongoing dialogue. As environmental protection technology advances, we need to ensure that schools are not left behind. We need universities to recognize that environmental careers will be a growth area of employment and they should tailor their programs appropriately. We need top-level university support to make these recommendations happen. Real-world experience and training in the environmental field such as that provided by government intern programs are invaluable to our department.

Field trips to observe wastewater treatment plants, water supply systems, landfills, remediation projects, or even unremediated sites could help students visualize what they are taught in the classroom. I also would encourage you to attend board and commission meetings that promulgate the state's environmental regulations; that is, the Environmental Improvement Board and the New Mexico Water Quality Control Commission. Students should be encouraged to not only attend the meetings, but to participate in discussions. Perhaps students could present their research findings to these decision-making groups. Students should also attend and participate in legislative committee meetings.

Finally, as many of you already know, EPA is making environmental education a priority, from grade school through higher education. We must ensure that New Mexico schools follow that directive. Only by nurturing the desire and interest of our kids in environmental issues throughout school will we ever have the trained workforce we need in the future.

*James Markwiese is pursuing a doctorate in biology at UNM under the direction of Dr. Clifford Dahm. This paper is a result of previous cyanide bioremediation work performed under the direction of Dr. Carlton White at UNM. James received his B.S. in zoology and in environmental biology at Eastern Illinois University. He plans to continue studies in the application of biotechnology to hazardous waste management.*

# ASSESSMENT OF IN SITU BIOREMEDIATION OF CYANIDE AND NITRATE AT A HEAP LEACH MINING OPERATION IN NEW MEXICO

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## INTRODUCTION

The Ortiz Mountains in southern Santa Fe County are the location of one of the oldest gold-producing areas in the United States. Mining began there with the discovery of gold in 1828 and has continued sporadically ever since. Gold Fields Mining Corporation took a long-term lease on property in the district in 1973 and began milling the ore in 1980.

From 1980 to 1987, the Ortiz Mine utilized the heap leach process (Hickson 1982) for gold recovery. The gold bearing ore was crushed and placed on an impervious leach pad. A cyanide solution was sprayed on and percolated through the heap for 90 days. Nitric acid was used to partially neutralize the solution after the gold was removed from the heap pile and to remove scaling from activated carbon later in the mining process. The pile was then rinsed with fresh water. The rinsed residue was hauled from the impervious pad to an unlined arroyo for disposal.

Despite washing and natural removal mechanisms, the residue pile at the Ortiz Mine has been identified as the source of cyanides and nitrates found in groundwater more than 1100 feet downgradient from the residue pile. Some of the nitrate nitrogen in the residue pile may be a result of nitric acid used in the gold recovery process. However, nitrate contamination may also be a consequence of microbially mediated cyanide degradation. In some groundwater sampling wells, total cyanide and nitrate values exceed Environmental Protection Agency (EPA) and New Mexico standards for groundwater. Groundwater contamination is caused by cyanides and nitrates leaching from the residue pile.

These contaminants are regulated at the state and federal level because of the potential health threats associated with their ingestion from drinking water. Cyanide is a well known toxin which inhibits aerobic respiration. Nitrate itself is relatively innocuous until it is converted to nitrite in the intestinal tract. The nitrite is then absorbed into the bloodstream and interferes with hemoglobin's ability to carry oxygen. A comparison of the EPA groundwater and state drinking water regulations to contaminant levels found at the Ortiz site is shown in Table 1.

Table 1. Regulatory Levels of Cyanide and Nitrate

| | EPA Groundwater/State Drinking Water Regulations | Contamination Levels Found at the Ortiz Site | |
|---|---|---|---|
| | | Groundwater | Residue Pile |
| Cyanide Guideline | 0.2 ppm | <0.01-0.76 | <0.3-12.4 |
| Nitrate Standard | 10 ppm | <0.1-41.3 | 0.3-72.0 |

A potential method for reducing cyanide and nitrate concentrations at the Ortiz site involves the microbial remediation of these contaminants. In 1991, Pegasus Gold Corporation contracted Dr. Carleton White, James Markwiese and Lisa Valle from the University of New Mexico's Department of Biology to explore this possibility. Their objective was to assess the potential for bioremediation of cyanide and nitrate contamination at the Ortiz site. Meeting the objective required a literature survey related to microbial cyanide degradation; enumerating total indigenous heterotrophic microorganisms in the pile; enumerating cyanide degraders in the residue pile/groundwater-soil system downslope of the residue pile; and evaluating amendments that promote cyanide degradation and nitrate uptake by the indigenous microbial communities.

## LITERATURE SEARCH

In an extensive literature search, over 80 articles on microbial degradation of cyanide were identified. In these articles, more than 20 species (and numerous unidentified microorganisms) are reported to degrade cyanide compounds. Microorganisms including fungi, bacteria, and actinomycetes are able to obtain the energy and raw materials for growth by metabolizing cyanide. Researchers (Allen and Strobel 1966; Bunch and Knowles 1980; Castric and Strobel 1969; Raef et al. 1977; Rodgers 1982; Skowronski and Strobel 1969; Strobel 1967) using $^{14}CN$ and/or $C^{15}N$, have shown that the general pathway (without intermediates) for microbial cyanide decomposition is:

$$CN + O_2 + \text{Microorganisms} \rightarrow CO_2 + NH_3 \text{ (or } NH_4^+ \text{ or } NO_3^-) + \text{Microbial Biomass}$$

Nitrate is not degraded by microorganisms; it is taken up as a nutrient unless anaerobic conditions prevail in which case denitrification may occur. There exists extensive literature on microbial nitrate uptake and therefore less emphasis was placed on this aspect of the literature search. The general reaction for the aerobic uptake of nitrate is:

$$NO_3 + \text{Organic Carbon} + \text{Microorganisms} \rightarrow CO_2 + H_2O + \text{Microbial Biomass}$$

The literature also reports that microbes in natural and contaminated settings are likely to be limited in growth by the availability of organic carbon. To build proteins for the synthesis of new cells, all organisms use amino acids as basic building blocks. The ratio of carbon to nitrogen is roughly 10:1 in an amino acid. The carbon and nitrogen ratio obtained from the metabolism of cyanide is 1:1, 9 carbons less than the typical amino acid. By adding carbon to this type of system, the growth of microorganisms should be greatly enhanced. A proliferation of microbes capable of degrading a contaminant should result in an accelerated rate of contaminant removal.

## ENUMERATION OF HETEROTROPHIC BACTERIA

Literature search results showed that many microorganisms are capable of degrading cyanide. The next step was to identify whether microbes were present at the Ortiz site. This involved sampling the residue pile in various locations.

The sampling involved drilling with a hollow-stem auger to a depth of 100 feet or until native soil was reached. Since all of the residue pile had contact with the atmosphere during the mining, milling, and extraction process, potential contamination by exposure to the atmosphere was not a concern. Care was taken to minimize cross-sample contamination. Samples were transported in a cooler on ice to the Biology Annex at the University of New Mexico. All analyses were carried out using standard methods employed at the Department of Biology, UNM.

Microbiological procedures generally followed those in *Methods of Soil Analyses, Part 2, Chemical and Microbiological Properties*, in the section by Wollum (1982). The entire sample was weighed and oven dried to determine total sample dry weight. The remainder of each soil sample was separated into greater than and less than 2 mm fractions. Approximately one tenth of the <2 mm fraction was weighed and dried to determine moisture content. Only the organisms associated with the <2 mm fraction were used in plating experiments. Plating results were extrapolated to the whole sample for number of organisms per gram of residue material.

Enumerating heterotrophic bacteria was done on three types of media (see Appendix for formulas). Preliminary plating was performed with minimal dilution of the sample because few organisms were expected. Nearly all plates had too many colonies; thus, later platings used standard conditions (soil methods). Ten grams of moist residue pile material were added to 95 ml of sterilized water, yielding a solution with 0.1 gram residue material/ml. Triplicate plates were made by spreading 0.1 ml of this solution on each agar type (0.1 ml of this plus the original solution gives 0.01 gram of residue material spread on each plate or a hundred-fold dilution). Additional 10- and 100-fold dilutions of the residue material were plated in triplicate for each agar type. These procedures gave 100-, 1000- and 10,000-fold dilutions of the original residue pile solution. Viable colonies were counted after incubating for 72 hours at room temperature on plates that contained between 30 and 300 colonies.

There were no clear preferences for any of the three agar types used in this study. The results from the plating indicate that the residue pile has unusually high numbers of viable heterotrophic organisms, given that the pile was mined rock. After incubating at room temperature for 72 hours, microorganism numbers ranged from $10^3$ to $10^6$ per gram of residue material.

Given the high winds and large amount of dust (soil) in the air typical for this region, inoculation of the pile probably occurred by air-borne microorganisms during leaching and before burial under other residue material. Some microorganisms have adapted to the pile conditions and are able to utilize cyanide, which is the major source of available carbon in the pile.

## ENUMERATION OF CYANIDE DEGRADING MICROORGANISMS

### Residue Pile

Growth of microorganisms provided with cyanide as their sole source of carbon and nitrogen for new biomass would confirm that they are capable of degrading cyanide. Plates were made with a mineral-salts media that had no other source of nitrogen or carbon (formula given in Appendix). Thus, any microorganisms growing in the agar will derive their energy (carbon) and nitrogen from the cyanide. Sample preparation was as described earlier, with subsamples of the <2 mm fraction prepared and spread to yield 100-, 1000- and 10,000-fold dilutions. Plates were incubated at room temperature and viable colonies counted starting after 6 days of incubation.

Unexpectedly high numbers of cyanide degrading microorganisms were obtained from the residue pile, ranging from $10^3$ to $10^5$ microbes per gram of residue material. The incubation period for these plates was extended to allow maximum development of the organisms into colonies. Some plates reached near maximum numbers after 6 days, while other plates took as long as 13 days.

### Well Water Samples

Triplicate spreads of 0.1 ml of each water sample were made on KCN plates as described above. Dilutions of 10- and 100-fold were prepared and triplicate spreads with 0.1 ml of each dilution were made. Plates were incubated at room temperature and viable colonies were counted after 13 days of incubation.

After 13 days, all water samples had viable cyanide degrading organisms ranging from 10 to 430 microbes per ml of water. These results are particularly encouraging since most wells show declining cyanide and nitrate levels. The presence of cyanide degrading organisms lends support to the hypotheses that the decline is at least in part due to in situ biological activity.

The fact that the residue pile and well-water samples all have microorganisms capable of degrading cyanide may be explained by several factors. First, the pH of the residue pile and groundwater systems (about 7.5-8.1) are near optimum for the majority of cyanide degrading microorganisms reported in the literature. Second, the only carbon source readily available in the residue pile should be cyanide, which would select for organisms capable of growth on that substrate.

## AMENDMENTS TO PROMOTE CYANIDE DEGRADATION AND NITRATE UPTAKE

Based on earlier studies and the current status of the residue pile and groundwater system, aerobic pathways appear the most feasible for bioremediation. In reviewing microbial and cyanide metabolism, Knowles and Bunch (1986) referred to a number of fungi (mainly snow moulds) and bacteria (Pseudomonas species) capable of growth with the apparent sole source of carbon and nitrogen being cyanide. As noted previously, these microorganisms may often be carbon limited. An experiment using cyanide degrading bacteria (Pseudomonas fluorescens) and glucose as a source of carbon and energy with KCN or $NH_4Cl$ as a nitrogen source, (Harris and Knowles 1983) showed that microbial growth was terminated due to glucose depletion from the medium. For the following experiments then, a base medium was prepared with all nutrients necessary for growth other than carbon and nitrogen. To this medium, cyanide and/or glucose was added as a source of carbon and energy for the microorganisms. Nitrogen was added as cyanide and nitrate because nitrate contamination is also a significant problem in this system. Nitrate served as a potential source of nitrogen (to be immobilized into amino acids) for the microorganisms.

Sample sets were prepared with three different levels of cyanide (2.6, 13, and 26 mg/l CN) and three levels of nitrate (6, 30, and 60 mg/l $NO_3$-N) (complete matrix shown in Appendix). These concentrations bracket those found in well water at the site (Newcomer 1991). The sets of the 3×3 matrix solutions were treated with glucose to produce a set with a 5:1 and a set with a 10:1 total carbon:nitrogen ratio in the solutions. Two other sets of solutions had no carbon amendments. One-gram subsamples of the <2 mm fraction sample with the highest number of cyanide degraders were added to each bottle of the glucose amended sets and to one of the unamended sets. Another portion of this sample was sterilized for 15 minutes prior to adding 1 gram to each bottle of the remaining unamended set of solutions.

All samples were placed on a shaker stand during incubation at room temperature. A 2 ml portion was taken from each bottle of all sets 0, 4, 10, 17 and 38 days after introducing the sample. This portion was diluted to within working range for the nitrate analysis and for the cyanide analysis. Nitrate was determined with a Technicon Auto-Analyzer using a cadmium reduction method. Cyanide was determined by automated analysis with a cytochrome T method (ASTM Designation: D 2036-75). As of September 6, 1991, a total of 180 analyses on the batch culture had been performed for cyanide and nitrate. After 38 days of incubation, the highest carbon amendments resulted in significantly reduced concentrations of nitrate and cyanide in the culture.

All statistical analyses were performed on StatView SE using analysis of variance and significance set at the 95% confidence interval.

## CONCLUSIONS

The presence of microorganisms capable of growth on cyanide in the residue pile and groundwater, coupled with the significant reduction of cyanide and nitrate using carbon amendments, indicates that in situ bioremediation would be feasible at the Ortiz site. We recommend supplying additional energy to the indigenous microbial community by injecting glucose dissolved in contaminated groundwater into the pile. Pumping the groundwater and injecting glucose into the pile will keep the contaminants in a semi-closed system allowing bioremediation to occur with subsequent reduction in evaporative water loss.

At this time, it is unknown whether the nitrate problem at the Ortiz site resulted from nitric acid used during the mining process or was a consequence of microbial cyanide degradation. Determining microbial activity rates, the byproducts and end products of degradation, and the effects of additional energy supplies (organic carbon compounds) on these processes and pathways are goals for future research.

### ACKNOWLEDGMENTS

We would like to thank Dr. Cliff Dahm (Department of Biology, UNM) for his advice on various aspects of the project, Lisa Valle (Department of Biology, UNM) for her tremendous contributions to the project from its initiation to completion, Mary Barroco (Pegasus Gold Corporation) for her assistance on the site and for information about the site and Pat Leonard (Department of Biology, UNM) for her assistance in various microbiological aspects of this project. This work was supported by a grant to the University of New Mexico from Pegasus Gold Corporation.

**APPENDIX**

**Microbiological Media**

- Total Heterotrophes Agars:
  Nutrient Agar (Difco #DF 0001-01-8)
  23 g agar in 1 liter $H_2O$
  TSA Agar (Difco #DF 0369-01-4)
  40 g agar in 1 liter $H_2O$
  Dilute NA Agar 2.3 g NA agar + 13.5 g granulated agar
  *Bring agar to a boil, autoclave for 15 minutes at 18-20 pressure

  Sample Plating (1 g residue material = 0.5 ml volume)
  10 g residue material + 95 ml $H_2O$ =
  0.1 g residue material/ml (STOCK)
  Plate 0.1 ml = 0.01 dilution
  1 ml STOCK in 9 ml $H_2O$ = 0.01 g rm/ml
  Plate 0.1 ml = 0.001 dilution
  0.1 ml STOCK in 9.9 ml $H_2O$ = 0.001g rm/ml
  Plate 0.1 ml = 0.0001 dilution

- Cyanide Agar:
  Agar consisted of primary mineral salts without nitrogen. Formula contained the following amounts per 800 ml of agar solution.

| Ingredient (common hydrated form) | Amount (in grams) |
|---|---|
| $KH_2PO_4$ | 0.4 |
| $Na_2HPO_4$ | 0.6 |
| $MgSO_4$ | 0.2 |
| $CaCl_2$ | 0.01 |
| $MnSO_4$ | 0.02 |
| $FeSO_4$ | 0.015 |
| Agar | 15.0 |

The above mixture was mixed and autoclaved. A separate solution of 23 g KOH with 3.256 g KCN per liter was mixed and autoclaved. Then 200 ml of the cyanide solution was added with 800 ml of the mineral salts agar immediately before pouring. This gave a 1.0 mM KCN solution in the agar. The KOH was used to insure that the pH was above 10.

- Cyanide/Nitrate Utilization: Amendments with glucose

This study examined the influence of carbon amendments on microbial degradation of CN and uptake of $NO_3$. The following four treatments were used: No amendment, Low amendment (carbon:nitrogen ratio 5:1), High amendment (carbon:nitrogen ratio 10:1), and a sterile control (same as no amendment but with autoclaved residue material). Each treatment consisted of nine separate containers having variable amounts of CN, $NO_3$ and glucose (the latter in amendment studies only). The containers each had a total volume of 101 ml and were placed on a shaker stand for the duration of the study. Transfer of gasses in containers was facilitated by screw caps left open one quarter turn.

Each treatment was prepared in a 3×3 matrix with low, medium and high concentrations of cyanide and nitrate.

Experimental Matrix: Bottle # for each set

| Nitrate Level (mg/l) | CN Level (mg/l) Low 2.6 | Medium 13 | High 26 |
|---|---|---|---|
| 6.0 | 1 | 2 | 3 |
| 30 | 4 | 5 | 6 |
| 60 | 7 | 8 | 9 |

Imposed on this 3×3 matrix were the appropriate amounts of glucose to give a 5:1 or 10:1 total C:N ratio, including the carbon and nitrogen in cyanide and the nitrogen in nitrate. The final concentrations of glucose in each bottle are given below:

| Treatment A (C:N 5:1) Bottle | ppm | Treatment B (C:N 10:1) Bottle | ppm |
|---|---|---|---|
| 1 | 89.5 | 1 | 182.0 |
| 2 | 147.5 | 2 | 310.0 |
| 3 | 220.0 | 3 | 470.0 |
| 4 | 389.5 | 4 | 782.0 |
| 5 | 447.5 | 5 | 910.0 |
| 6 | 520.0 | 6 | 1070.0 |
| 7 | 764.5 | 7 | 1532.0 |
| 8 | 822.5 | 8 | 1660.0 |
| 9 | 895.0 | 9 | 1820.0 |

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# SORPTION OF ORGANICS TO SURFACE-ALTERED ZEOLITES

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## INTRODUCTION

Over 41 naturally occurring zeolites have been discovered (Newsam 1986). This mineral group is characterized by high cation exchange capacities (CECs) and a cage-like structure allowing for a molecular sieving effect. The CEC is separated into external and internal sites. Small cations including many metals can enter into the internal structure of the mineral, which allows for enhanced sorption of these compounds. In contrast, the internal sites are typically unavailable to large organic cations such as quaternary amines. Untreated zeolites have low organic carbon contents (<1%) and although they are capable of sorbing metals, they do not favor sorption of organic compounds prior to modification.

Previous work (Huddleston 1990) showed that zeolite modified with hexadecyltrimethylammonium (HDTMA) had an enhanced ability to sorb non-polar chlorinated solvents from aqueous solution. In addition, Huddleston (1990) also showed that the ion exchange process through which HDTMA is bonded to the zeolite is essentially permanent. The modified surface greatly increases the organic carbon content, which has been seen to enhance the sorption of non-polar organic compounds (Chiou 1989). In effect, the modification process creates an organic coating over the surface of the zeolite, which allows partitioning of the organic molecules into the organic coating. Thus, it seems likely that the same material could remove the gasoline components benzene, toluene, and xylene (BTX) from contaminated waters.

The objectives of this research project were to:

- characterize sorption of BTX to HDTMA-altered zeolite
- determine the magnitude of competition effects among multiple sorbates in solution
- compare the experimental results with literature values for sorption of BTX on other materials

## METHODS AND MATERIALS

The zeolite used for these experiments was supplied by the Zeotech Division of Leonard Minerals from their mine in Tilden, Texas. The mineralogical composition of the material, determined by X-Ray Diffraction (XRD), was approximately 60% clinoptilolite, 20% smectite, 15% amorphous material, and 5% carbonates. The external CEC of the Tilden sample, determined by Huddleston (1990) using the procedure of Ming and Dixon (1987), was approximately 30 milliequivalents/100 g.

The modifying agent, HDTMA, was chosen for its demonstrated success in similar experiments with clay minerals and its commercial availability. The surface of the zeolite was modified with HDTMA using the procedure outlined in Huddleston (1990). It was previously determined that once modified, the surface of the zeolite is stable (Huddleston 1990).

The sorption experiments were performed as batch isotherms, using a 0.005 M $CaCl_2$ solution as the aqueous phase. Solutions containing concentrations of 10, 50, 100, 150 and 250 mg/l of each chemical were injected into 15-ml crimp-top vials containing 2.5 g of the surface-modified zeolite. In the case of p-xylene, the maximum aqueous concentration obtained was 198 mg/l which is the aqueous solubility of the chemical. The zeolite-solution mixtures were placed on a shaker for 24 hours in order to reach equilibrium. After equilibration, approximately 2 ml from each vial was withdrawn using a Hamilton gas-tight syringe and placed in gas chromatography (GC) crimp-top vials. Appropriate blanks prepared both with and without zeolite were prepared in a similar manner. The samples were analyzed with a Hewlett Packard 5890A GC using an FID detector. From this data, the amount of chemical sorbed and the equilibrium concentration of the solution were obtained.

The sorption of each compound was first determined individually, with no other sorbates present. This procedure was used to maximize the sorption of the chemical to the HDTMA-modified surface. After quantifying individual sorption, pairs of sorbates were used to determine if there was any competition among chemicals for sorption sites.

## RESULTS AND DISCUSSION

Figure 1 illustrates the increased sorption capability of HDTMA-treated zeolite for benzene compared to the untreated or natural zeolite. As seen in this plot, the sorption of benzene is increased over 20-fold by the surface alteration. Using the same data as an example, Figure 2 illustrates that the sorption of organic chemicals onto altered surfaces can be quantified as a linear process. The sorption affinity is characterized by the distribution coefficient, $K_d$ (L/kg), which is the slope of the line obtained from a plot of the chemical sorbed (mg/kg) versus the compound concentration in solution at equilibrium (mg/l). The greater the slope of the line, the greater the chemical's sorption.

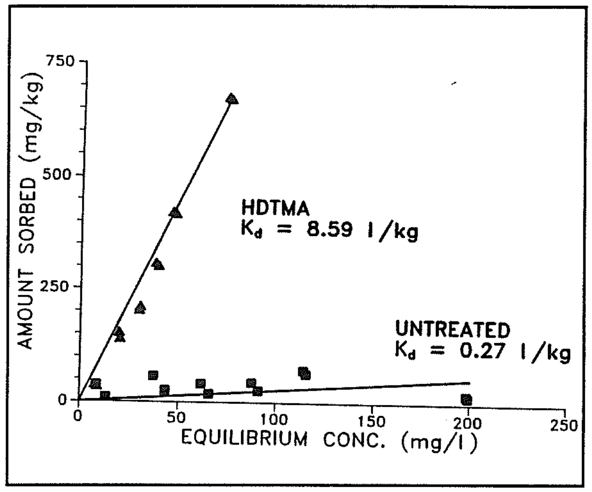


**Figure 1.** Sorption of benzene to treated versus untreated zeolite.

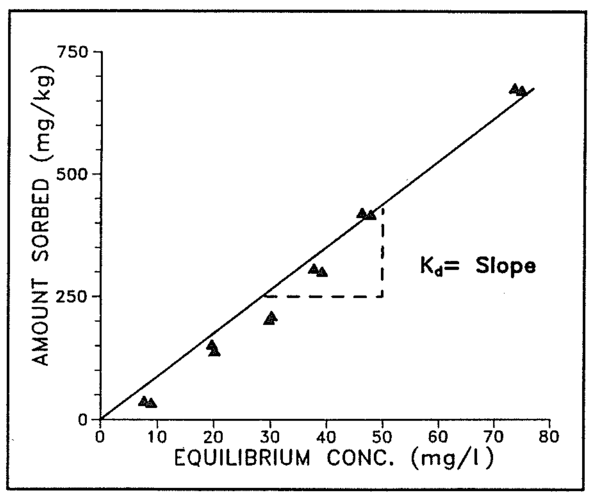


**Figure 2.** Determination of distribution coefficient (Kd) from sorption isotherm.

Figure 3 shows the results obtained for three separate benzene experiments; sorption of benzene alone, sorption of benzene while in solution with equal concentrations of toluene, and sorption of benzene with an equal concentration of p-xylene. Figure 3 clearly indicates that neither the presence of toluene nor the presence of p-xylene has any marked influence on the sorption of benzene. Indeed, the converse relation also holds true for these chemicals; the presence of benzene has little or no effect on the sorption of either toluene or p-xylene (data not presented). This lack of competition for sorption sites is indicated by the experimental $K_d$ values obtained for each experiment. As shown in Table 1, the $K_d$ values of the multiple sorbates do not differ greatly from the $K_d$ values obtained from the individual isotherm experiments. Thus, in this case, the sorption of any particular organic in aqueous solution is not influenced by the presence of other components.

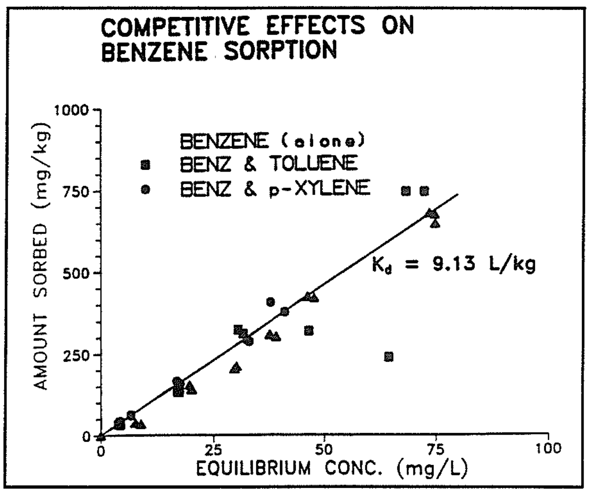


**Figure 3.** Sorption of benzene to HDTMA-zeolite individually and with multiple sorbates.

Table 1. Summary of competition experiments

| Chemical | $K_d$ (l/kg) |
|---|---|
| Benzene (alone) | 8.59 |
| Benzene with Toluene | 8.44 |
| Benzene with p-Xylene | 9.40 |
| Toluene (alone) | 19.2 |
| Toluene with Benzene | 19.1 |
| p-Xylene (alone) | 70.4 |
| p-Xylene with Benzene | 56.6 |

To validate the methodology and the experimental results, a comparison of experimental $K_d$ values for these chemicals with values obtained in the literature was necessary. However, literature values for these chemicals are scarce, so the relationship between the distribution coefficient and the organic carbon distribution coefficient ($K_{oc}$) was used to provide this comparison. The relationship between the two is as follows (Dragun 1988):

$$K_{oc} = \frac{K_d}{f_{oc}}$$

where: $f_{oc}$ = mass fraction organic carbon

The literature values for $K_{oc}$ were calculated by means of the octanol-water coefficient ($K_{ow}$), shown as equation 6.20 in Dragun (1988). Table 2 shows the comparison of log $K_{oc}$ values obtained from literature $K_{ow}$ values and those calculated from the experiment based on an organic carbon content of 6.4% for HDTMA-modified zeolite (Huddleston 1990). Evaluation of Table 2 demonstrates that the experimental data agrees well with literature values, which infers that the observed sorption is an ideal partitioning process. The lack of competition among sorbates also supports this conclusion (Chiou 1989).

Table 2. Comparison of experimental $K_{oc}$ values with literature values.

| | Lit. log $K_{oc}$ | Exp. log $K_{oc}$ |
|---|---|---|
| Benzene | 2.02 | 2.14 |
| Toluene | 2.43 | 2.48 |
| p-Xylene | 2.76 | 3.00 |

As previously seen, from a theoretical standpoint the sorption of organics to surface-altered zeolites shows great promise for the research and academic community. But of what value does this information provide to the consulting or perhaps regulatory community? Figures 4 and 5 illustrate practical uses for these surface-modified minerals. One possible use would be to incorporate modified zeolites into pump-and-treat systems as shown in Figure 4 for remediation of contaminated groundwater. The zeolites could be used as packed col-

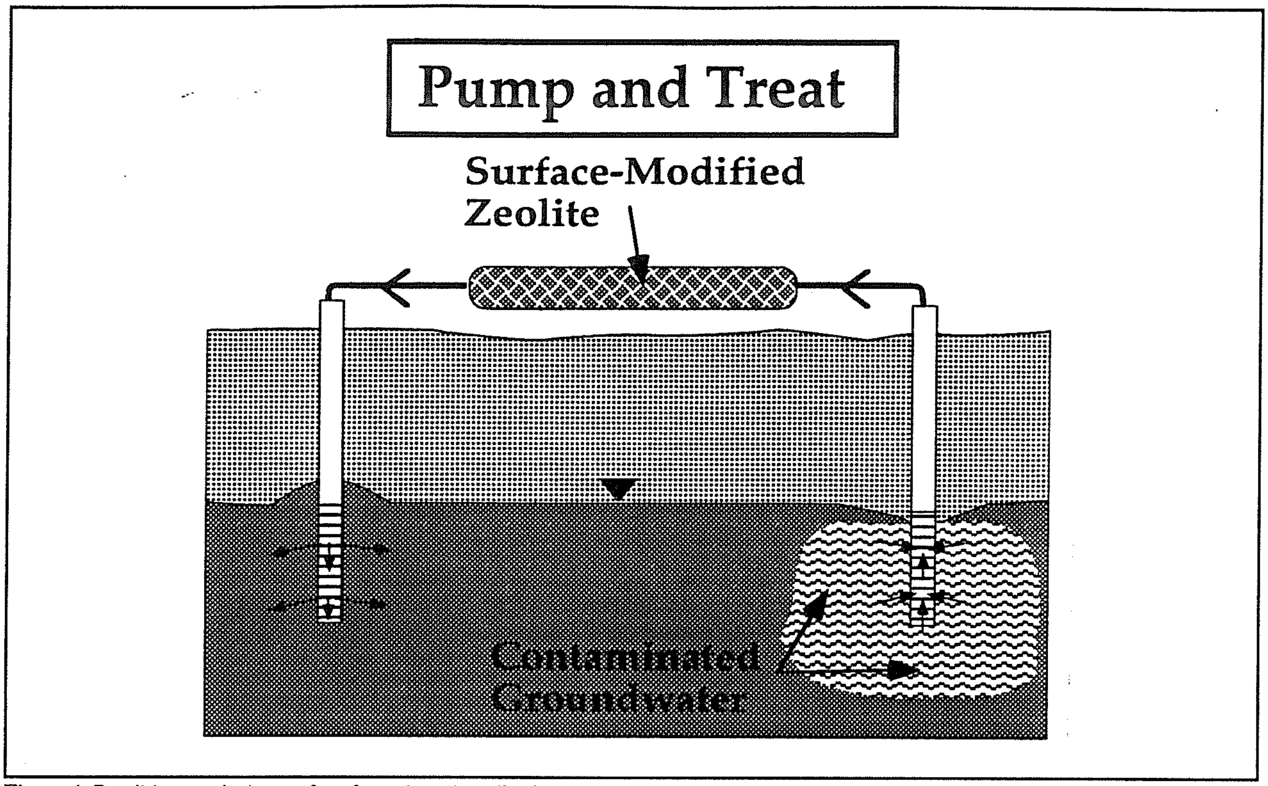


**Figure 4**. Possible practical use of surface-altered zeolite in a pump and treat groundwater system.

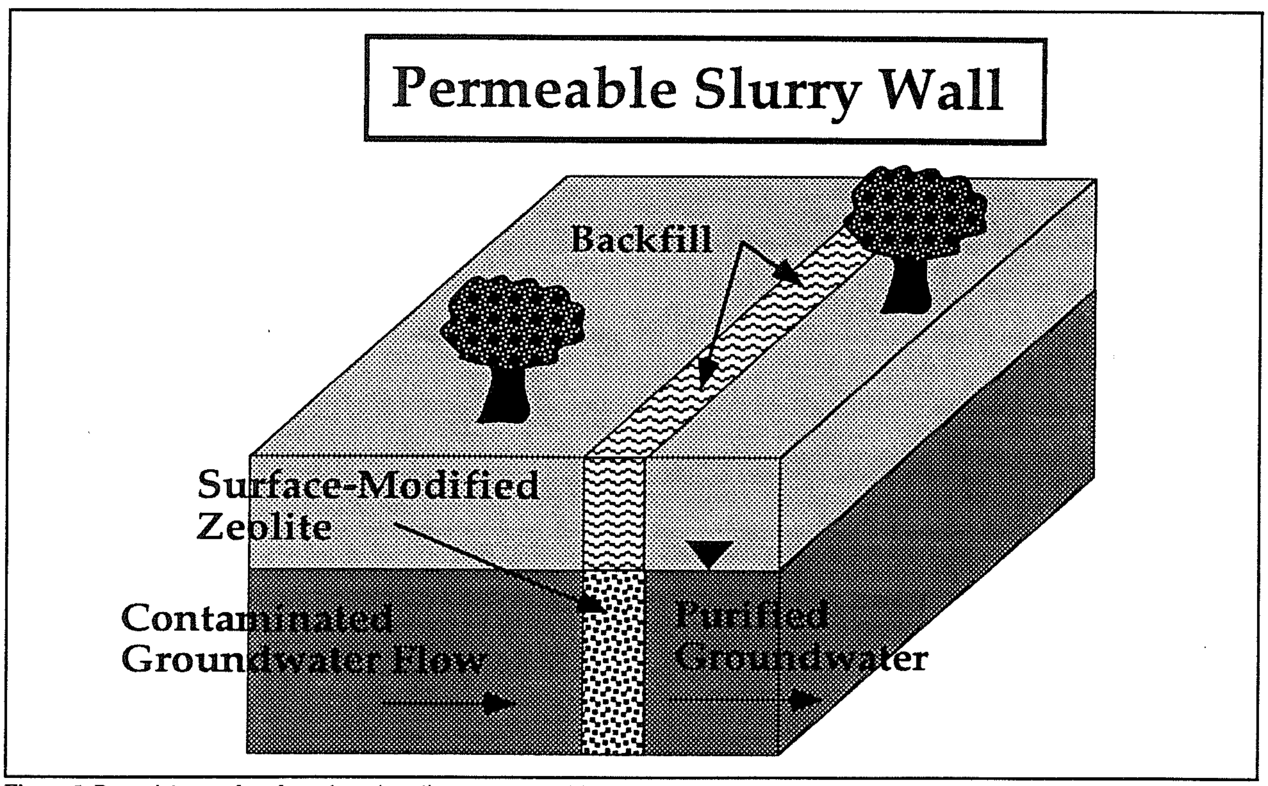


**Figure 5**. Potential use of surface-altered zeolite as a permeable slurry wall.

umns through which the contaminated water flows before being re-injected into the aquifer. Another use for the zeolites is as part of a land application spray system that introduces contaminated water to a bed of surface-modified zeolite for the purpose of providing purified recharge to the aquifer. Yet another application might be in the form of a permeable slurry wall as shown in Figure 5. Contaminated groundwater could be diverted to the slurry wall whereby the organic compounds (or metals) would be sorbed to the surface. This process would also allow the contaminants to be concentrated in a smaller area, perhaps enhancing the use of additional remediation techniques, such as bioremediation. Of course in all these applications, the zeolite surface would have to be regenerated, much like activated carbon or other ion-exchange materials are now. Further study of these materials will be necessary in order for these applications to be implemented. However, the availability of zeolites and the demand for additional environmental remediation techniques make zeolites a viable option for the future.

ACKNOWLEDGEMENTS

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# ENHANCEMENT OF SOLAR PHOTOCATALYTIC DETOXIFICATION BY ADSORPTION OF PORPHYRINS ONTO $TiO_2$

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## INTRODUCTION

Toxic waste disposal is a major problem of international importance. There is a clear and present need to develop chemical processes that can be used to detoxify various classes of toxic chemical wastes. For example, polyhalogenated hydrocarbons, benzene, and sulfur compounds present a major challenge. In particular, polychlorinated biphenyls (PCBs) are known to be highly toxic carcinogens and mutagens even at low concentrations.[1-3]

Titanium dioxide ($TiO_2$) is capable of using UV light for the photocatalytic detoxification of aqueous organic waste contaminants, including solvents, PCBs, dioxins, pesticides, and dyes.[4-6] For many reasons, it would be advantageous to use direct solar energy to drive a $TiO_2$ photocatalytic waste detoxification process. In general, the toxic compound is oxidized to harmless compounds like dilute acids, water, and $CO_2$ and no hazardous products are formed. Unfortunately, the energy used by $TiO_2$, ($\lambda < 400$ nm), only comprises about 4% of the solar spectrum (Fig. 1).[7]

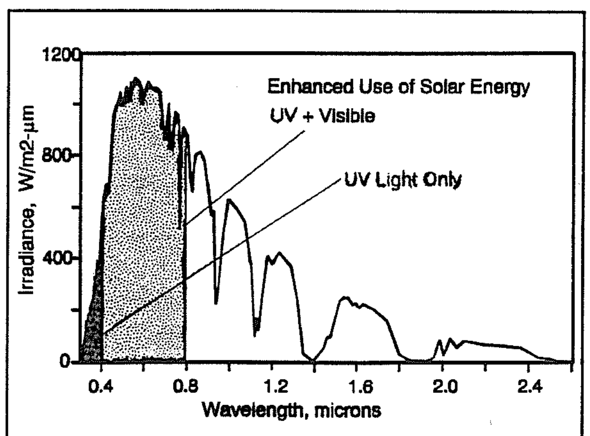


**Figure 1.** Direct normal solar spectrum (Air Mass 1.5).[7] Shaded region (light and dark) shows portion of solar spectrum used by photosensitized $TiO_2$ catalysts. Only the ultraviolet (light shaded region) is used by bare $TiO_2$.

One way to enhance the efficiency of solar detoxification technologies is to utilize a larger portion of the solar spectrum to initiate detoxification chemistry. This can be accomplished by adsorption of appropriate dye molecules onto $TiO_2$.

The dye absorbs visible light, not utilized by bare $TiO_2$, initiating photochemical redox reactions by electron transfer with the $TiO_2$ surface and thereby improving the utilization of the available solar energy to drive the detoxification process.[8-10]

Metal porphyrins and metal phthalocyanines are chemically robust dyes with strong absorption bands throughout the visible portion of the electromagnetic spectrum. Moreover, porphyrins with carboxylic acid peripheral substituents are known to adsorb readily onto the $TiO_2$ surface.[8,9] Consequently, we have investigated the ability of Ni(II) uroporphyrin (NiUroP), Sn(IV)$Cl_2$ uroporphyrin (SnUroP) and Sn(IV)$Cl_2$ tetrakis (*p*-carboxyphenyl) porphyrin (SnTCPP) to enhance destruction of a model organic compound, salicylic acid, through the photosensitization of suspended $TiO_2$ particles. The structures of these metalloporphyrins are shown in Figure 2.

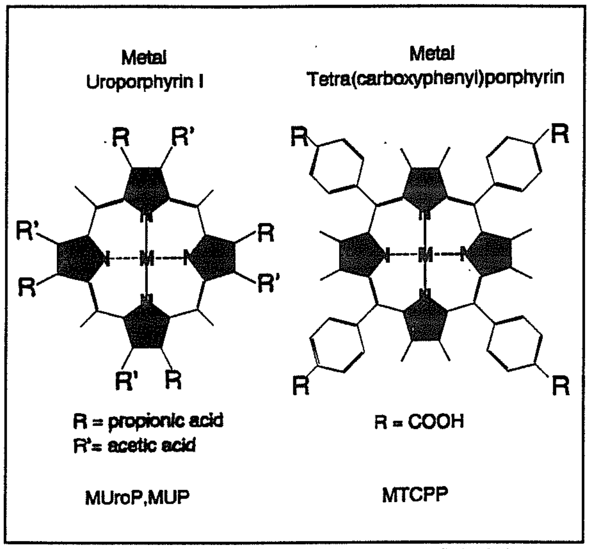


**Figure 2.** Porphyrins used as photosensitizers (M = Sn).

The main objective of this work is to demonstrate that attachment of suitable and stable porphyrins to the $TiO_2$ semiconductor surface provides more efficient electron transfer between the photosensitizer and $TiO_2$, and thereby enhances solar photocatalytic detoxification. A second objective is to develop an understanding of the mechanism of porphyrin dye-enhanced solar detoxification. A third goal of this work is to stabilize the photodegradable photosensitizers on the $TiO_2$ surface to obtain the optimal photosensitization over a long period of time.

## MATERIALS AND METHODS

The $TiO_2$ powder used in this study was obtained from Degussa (P-25) or from Tioxide. P-25 $TiO_2$ contains a mixture of 80% anatase (band gap, 3.2 eV) and 20% rutile (band gap, 3.0 eV), whereas Tioxide $TiO_2$ contains almost entirely the anatase form. The surface area of the Tioxide $TiO_2$ (268 $m^2/g$) is also about five times as great as for P-25. Both semiconductor materials have large particle size distributions. The uroporphyrins were obtained from Porphyrin Products and SnTCPP was obtained from Mid Century Chemical. All porphyrins were used without further purification. Reagent grade salicylic acid was purchased from Fisher Scientific. The water used was deionized with a conductivity of ~1 $\mu$mho.

The photosensitized samples were prepared by adding solid $TiO_2$ and salicylic acid (SA) to a tin-porphyrin (SnP) solution for a final composition of ~15 $\mu$M SnP, 0.1% $TiO_2$, and 30 ppm SA (pH 6.0). The mixture gives a cloudy, white dispersion in the absence of porphyrin, but, in the presence of porphyrin, gives either a cloudy, pink (high pH) or a cloudy, green (low pH) mixture. Without stirring, much of the $TiO_2$ settles out. Components were added in different orders and in varying compositions to determine the effect of competitive adsorption onto the $TiO_2$ surface. The amount of porphyrin adsorbed onto the $TiO_2$ surface was measured by following the decrease in the Soret band absorption (~400 nm) of the porphyrin in supernatant solution while the pH of the solution was adjusted to the operating pH (4.5, 5.0, or 6.0).

A UV filter was placed between a mercury vapor lamp and the sample mixture to use only the visible portion of the lamp spectrum, $\lambda > 390$ nm unless indicated otherwise. Samples were collected at regular intervals up to 240 minutes for immediate analysis using a HP8452A UV-visible absorption spectro-photometer. All samples were either centrifuged for 20 minutes at 3400 rpm or centrifuged and filtered through 200-nm filters before recording the UV-visible spectrum of the transparent supernatant solution.

Before performing the experiments under visible light, some of the $TiO_2$ samples were washed with water (pH 6.0) several times in an effort to remove the colloidal $TiO_2$ stabilized by the presence of porphyrin. The colloidal dispersion of small $TiO_2$ particles depends on pH and is influenced by the presence or absence of porphyrin (see below). When these fine particles appear in solution, a broad, flat UV absorption band is observed in the range from 200-340 nm (Fig. 3) and the concentration of the particles is quantified by the absorbance at 296 nm, also a peak position of salicylic acid when present. In some cases the porphyrin-stabilized dispersion of $TiO_2$ was removed by repeated washing of $TiO_2$ with water at pH 6.0.

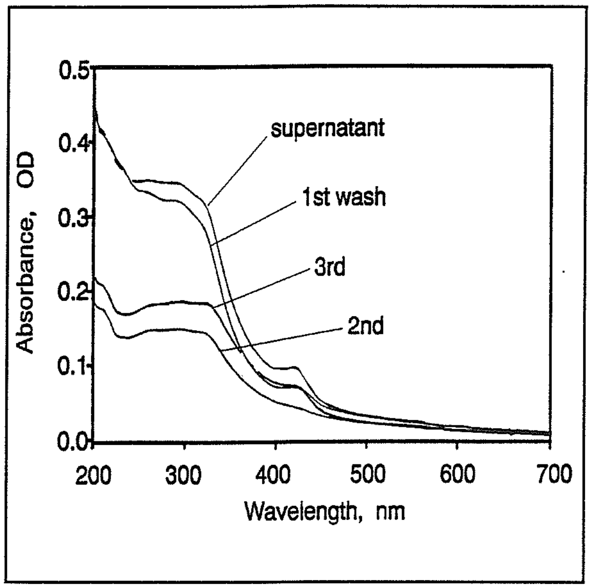


**Figure 3.** Successive washings of $TiO_2$ photosensitized by adsorption of SnUroP at pH 6.

## RESULTS AND DISCUSSION

### Photocatalytic Activity of Tin(IV) Porphyrins

In the absence of $TiO_2$, both Sn porphyrins in solution show photoactivity for the conversion, but not destruction of salicylic acid. Photocatalytic conversion of salicylic acid is indicated by the increase in absorbance near 260 nm between the SA absorption peaks at 230 and 296 nm, the increase in absorbance in the wings on the red side of the 296-nm absorption band, and other changes in the SA absorption spectrum. The conversion product is thought to be a slightly modified aromatic ring compound that is yet to be identified. SnUroP photodecomposes considerably during 90 minutes irradiation with visible light. The initial pink color changes to green; from the absorption spectrum of the green pigment, the reduction product is mostly the Sn-urochlorin[11] in which the β-carbons of one pyrrole ring of the porphyrin are reduced and urophlorins[11] may also be formed. SnTCPP does not photodecompose in the absence of $TiO_2$.

### Photosensitization of $TiO_2$

Combining either of these two porphyrins with $TiO_2$ yields a colored $TiO_2$ powder due to the absorption of visible light by the adsorbed Sn porphyrin onto the suspended $TiO_2$ particles. Binding to the surface occurs at lower pH for SnTCPP (pH 4.5) than for SnUroP(pH 6.0). The attachment of SnUrop to the semiconductor surface enhances the destruction rate of SA as described below. Determination of the degree of enhancement is complicated by the generation of a salicylic acid intermediate product (see below) and by the dispersion of small $TiO_2$ particles in the pH range above 5. The complication in the analysis arises because both processes result in an increase in the absorbance in the UV portion of the absorption spectrum, interfering with the SA band at 296 nm used to monitor its destruction. The UV absorption that is caused by fine $TiO_2$ dispersions is shown in Figure 3.

### Porphyrin-mediated Colloidal Dispersion of $TiO_2$

In the absence of porphyrin, dispersion of fine $TiO_2$ particles occurs at high (>9) and low (<3) pH, but not in the pH range from 4 to 8. This is illustrated in Figure 4, where the absorbance due to the conduction band of the fine particles at 296 nm is plotted versus pH. The conduction band absorption is relatively flat at wavelengths less than 300 nm, so the absorption at 296 nm was used to quantify the concentration of dispersed $TiO_2$ (Figs. 3-4). High positive (low pH) or negative (high pH) charge on the surface apparently breaks up aggregates of small $TiO_2$ particles resulting in the observed colloidal dispersion in the pH regions far from 6, the point of zero charge for $TiO_2$.[12]

A similar process is observed in the presence of porphyrin. An increase of UV absorbance resulting from dispersion of fine $TiO_2$ particles is demonstrated by water washing of the porphyrin-treated $TiO_2$ samples shown in Figure 3. UV-visible absorption spectra of washings from samples of compositions, SnUroP/$TiO_2$/SA (added in the order indicated) and SA/$TiO_2$/SnUroP, before illumination show a significant broad absorption band from 200 nm to 340 nm, which is attributed to the conduction band absorption of the porphyrin-stabilized colloid of fine $TiO_2$ particles. This characteristically broad UV absorption band is also observed in the washings from the $TiO_2$/ SnUroP preparations shown in Figure 3. In contrast, the supernatant from $TiO_2$/SA did not exhibit this broad absorption band at pH 6.

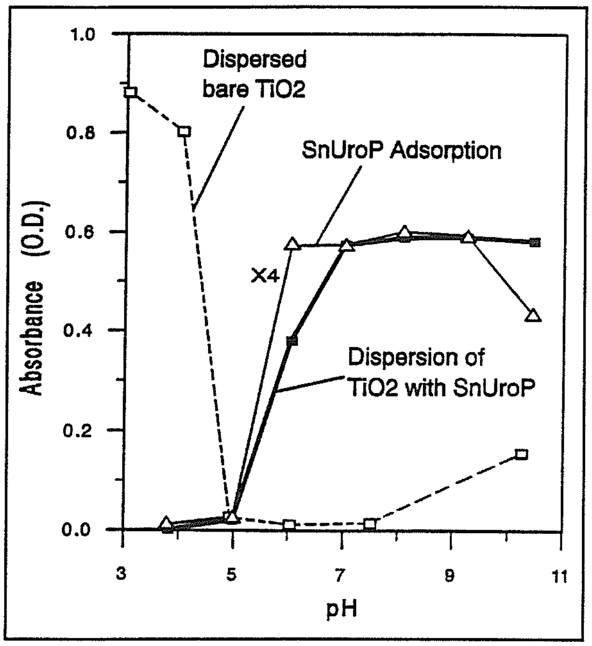


**Figure 4.** pH dependence of the dispersion of small $TiO_2$ particles for bare $TiO_2$ and for $TiO_2$ photosensitized with SnUroP (measured by the conduction band absorbance at 296 nm), and the adsorption of SnUroP onto $TiO_2$ (measured by the Soret band absorbance at 402 nm of the SnUroP remaining in solution).

The presence of SnUroP shifts the pH range in which colloidal dispersion occurs as illustrated in Figure 4. Dispersion occurs above pH 5, but not below. As the pH is lowered, the first of the eight acid substituents of uroporphyrin are protonated at about pH 6.6.[13] This is also the pH range in which SnUroP starts to be adsorbed onto the surface (Fig. 4). Although the aggregation of uroporphyrins typically is observed below pH 7 for four- and five-coordinate metal complexes, aggregation does not occur for six coordinate metals like Sn.[13] This suggests that either Sn uroporphyrin interacts dynamically with the surface in the pH range from 5 to 8 and the interaction results in the dispersion of $TiO_2$ or adsorption of SnUroP onto the surface in this range acts to maintain a high negative charge on the porphyrin modified surface. In the latter case, for example, a SnUroP$^{-x}$ molecule (with $0 \leq x \leq 8$ acid groups deprotonated) might bind to a $-OH_2^+$ group on the surface changing the charge at that location from +1 to 1-x, that is, the charge of the -OH$_2$-SnUroP$^{-x+1}$ surface group. Thus, for more than one deprotonated group on the porphyrin, binding results in replacing the positively charged group with a negatively charged one.

Below pH 5, negatively charged carboxylate groups of the porphyrin molecule will be attracted to regions of positive charge on the $TiO_2$ surface. However, binding of porphyrin will now neutralize the charged regions, preventing the electrostatic repulsion that might break up aggregates of small $TiO_2$ particles. This is because the porphyrin substituents are nearly all protonated (and 1-x is close to 0). The large aromatic ring of the porphyrin also acts to modify the surface properties of the $TiO_2$ particles in a way that may promote aggregation of these particles. For example, when fully coated with neutral porphyrins, the surface is hydrophobic.

SnTCPP does not appear to influence as strongly as SnUroP influences the colloidal dispersion process, although enhanced dispersion may occur in the region between pH 5 and pH 9, the region where bare $TiO_2$ is not dispersed. Finally, the presence of salicylic acid does not influence the dispersion of fine $TiO_2$ particles, nor does its presence effect the pH dependence of the porphyrin-induced dispersion process. Its presence, however, may influence the degree of dispersion.

**Porphyrin Modification by Adsorption onto $TiO_2$**

As a first step in developing a stable photosensitized $TiO_2$ catalyst, we compared the effects that the adsorption of the two Sn porphyrins onto the $TiO_2$ surface has on the porphyrin's structure. Adsorption of SnUroP was, by itself, enough to convert the porphyrin to a reduced porphyrin species, probably Sn urochlorin.[11] The conversion can be observed by lowering the pH of a mixture of $TiO_2$ and an aqueous solution of SnUroP until the porphyrin is adsorbed (pH 6), then raising the pH until the modified porphyrin is removed from the surface. The UV-visible spectra, obtained before and after the adsorption of porphyrin, clearly show the formation of the Sn urochlorin. In contrast with SnUroP, adsorbing SnTCPP onto the $TiO_2$ surface in the same way, by lowering the pH to 4.5, does not result in conversion of the porphyrin to a reduced product.

In the absence of salicylic acid, we followed the porphyrin-mediated $TiO_2$ dispersion process at pH 6.0 as a function of irradiation time. The absorption due to the conduction band of colloidally dispersed $TiO_2$ rapidly disappears over the first 30 minutes of irradiation. This decrease in the amount of dispersed $TiO_2$ is most likely a result of the rapid destruction of the porphyrin, since $TiO_2$ dispersion does not occur at pH 6 unless porphyrin is present. Destruction of the porphyrin is confirmed visually by the bleaching of the photosensitized $TiO_2$.

**Enhanced Photocatalytic Detoxification**

Our primary goal is to enhance $TiO_2$ redox reactions that destroy toxins, by using the visible light absorbed by a photosensitizer. At wavelengths longer than 390 nm, weak absorption by the band edge in $TiO_2$ still gives formation of electron-hole pairs in the semiconductor. These holes (and electrons) normally initiate the destructive redox chemistry. For the photosensitized $TiO_2$, absorption of light throughout the visible spectrum by the porphyrin results in the formation of the excited triplet state. The redox potentials of the porphyrin are altered in the excited state, and these new redox species of the excited state are then available to either interact with electrons and/or holes of $TiO_2$, or to add species with different redox properties that can modify rates of destructive reaction pathways, or to participate directly in detoxification redox reactions with SA.

Visible-light assisted reactions occurring in a solution containing SA and the porphyrin-sensitized $TiO_2$ were monitored as a function of irradiation time to determine if the destruction of SA was enhanced by the presence of the metalloporphyrin dye. UV-visible spectra of samples taken at various irradiation times for un-sensitized (bare $TiO_2$) and dye-sensitized systems are shown in Figures 5 and 6, respectively. Both the $SA/TiO_2$ and $SA/TiO_2$/SnUroP mixtures were initially at pH 5 and used $TiO_2$ from Tioxide.

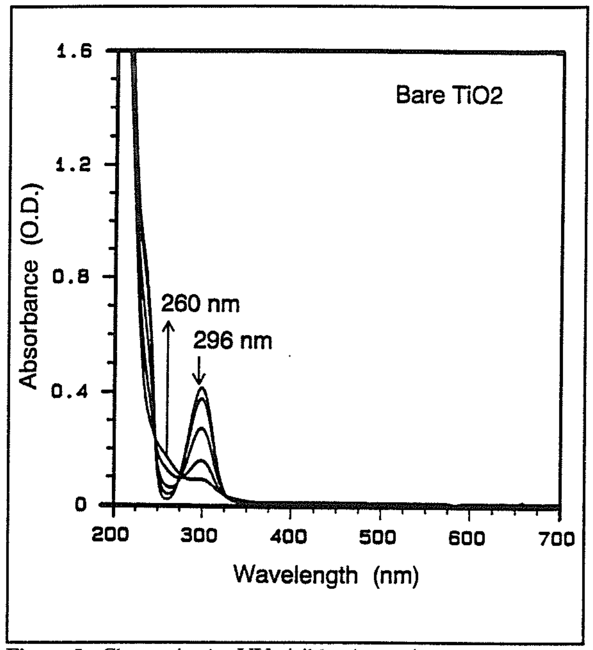


**Figure 5.** Change in the UV-visible absorption spectrum upon irradiation of an aqueous mixture of suspended $TiO_2$ and salicylic acid at pH 5 ($SA/TiO_2$). Spectra are taken at 0, 5, 20, 40, and 60 minutes.

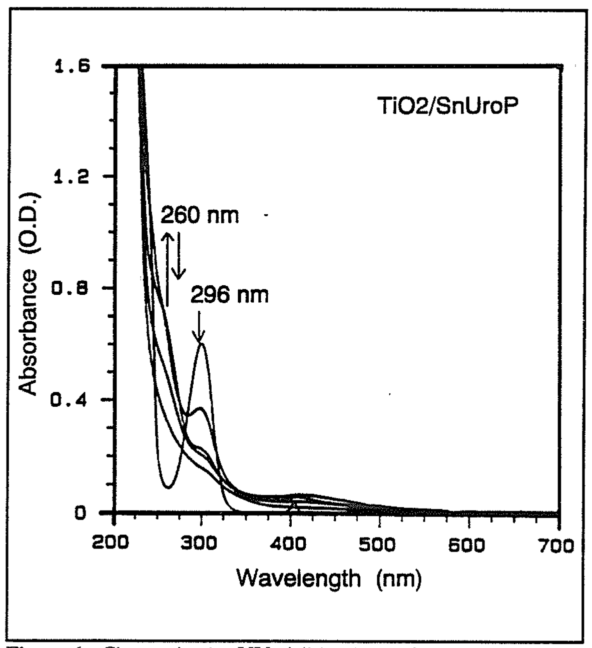


**Figure 6.** Change in the UV-visible absorption spectrum upon irradiation of an aqueous mixture of tin-uroporphyrin-modified suspended $TiO_2$ and salicylic acid at pH 5 ($SA/TiO_2$/ SnUroP). Spectra are taken at 0, 5, 20, 40, and 60 minutes.

For the SA/$TiO_2$ mixture, enough absorption into the edge of the conduction band occurs to generate electron-hole pairs so the destruction of the SA occurs, but at a much slower rate compared with UV irradiation of the solution. Also, the rise in absorbance to the red of the 296-nm SA peak and in the valley (at about 260 nm) between the 296-nm and 230-nm peaks shows evidence of the formation of a SA degradation product. Note that clear isosbestic points are located on both sides of the 296-nm band, indicating the formation of primarily one SA degradation product that absorbs in the UV. If no intermediate were formed, the absorption spectrum of salicylic acid would maintain the same shape, while decreasing in intensity as it is destroyed.

In the presence of adsorbed SnUroP, the destruction of SA by $TiO_2$ results in a more complicated spectral profile as shown in Figure 6. A much larger rise in the UV absorbance below 350 nm is observed and is best understood to result from the formation of a much greater concentration of the intermediate SA product. We speculate that the intermediate is similar, if not the same, as the intermediate formed at a much lower level in the absence of the porphyrin. As evidence, notice the rapid filling-in of the valley at 260 nm and the increase in the absorbance just to the red of the 296-nm SA band. The dispersion phenomenon already described may also play a role in increasing the UV absorbance, but should not be significant in the data obtained at pH 5 and shown in Figures 5 and 6.

Using the spectra illustrated in Figures 5 and 6, we can estimate and compare the rates of SA destruction. The absorbance at the peak of the SA band at 296 nm, a measure of the conversion and destruction of SA, is plotted as a function of irradiation time in Figure 7 for photosensitized $TiO_2$ ($TiO_2$/SnUroP) and the bare $TiO_2$. One problem with this measure of destruction rate is that the absorbance of the SA peak at zero time for bare $TiO_2$ is only 69% of the SA absorbance of the photosensitized $TiO_2$ solution. This is in spite of the fact that the concentration of SA added is the same for both cases. Most likely, a larger fraction of the SA has adsorbed onto the bare $TiO_2$ surface as opposed to the competitive adsorption between SA and SnUroP on the sensitized $TiO_2$ surface. Almost half the SA is bound in the case of bare $TiO_2$. Upon illumination SA is destroyed on the surface, allowing more SA to adsorb from solution and, thus, contributing to the decrease in absorbance at 296 nm. The decrease in absorbance at 296 is indicative of an exponential rate of destruction of SA.

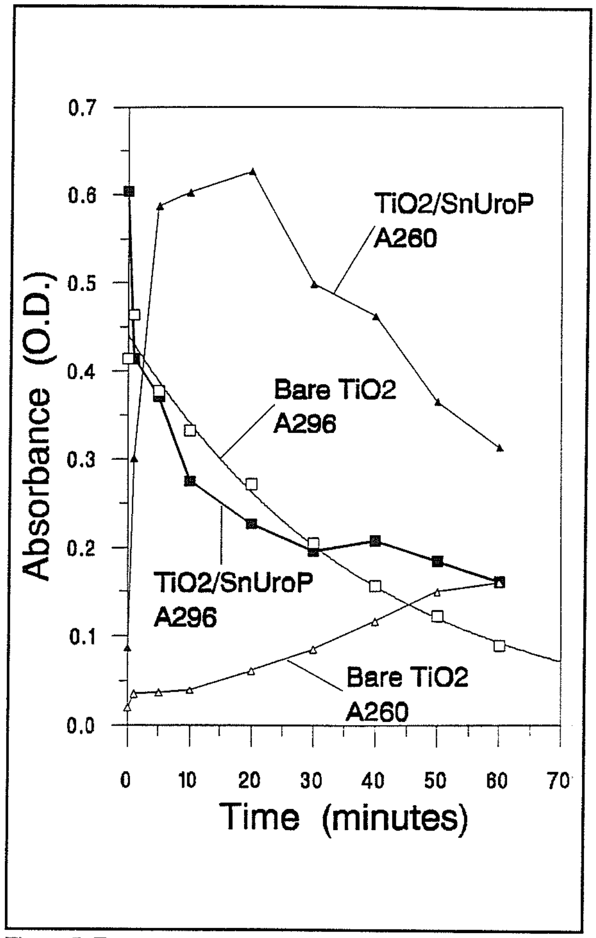


Figure 7. Enhancement of salicylic acid detoxification using Sn uroporphyrin as a photosensitizer. Salicylic acid absorbance at 296 and 260 nm (1-cm cell) is plotted against irradiation time. The curve through the data points for bare $TiO_2$ at 296 nm is an exponential fit.

An enhanced rate of salicylic acid destruction is observed in the presence of adsorbed SnUroP on the $TiO_2$ surface when compared with bare $TiO_2$. The enhancement in the detoxification rate is most apparent in the slope of the curve for the photosensitized $TiO_2$ within 30 minutes of illumination. The pseudo-exponential rate in the first 20 minutes is about 2.5 times faster than the exponential destruction rate for bare $TiO_2$. The SA peak at 230 nm evolves in a similar way with illumination time.

The absorbance at 260 nm (A260) is predominantly a result of the formation of the initial SA degradation product (Fig. 7). In the absence of

SnUroP, the absorbance shows a steady, slow increase over the first 60 minutes. In contrast, when SnUroP is present, A260 increases rapidly to a maximum in the first 30 minutes and then decreases. Thus, A260 indicates a strong initial increase in the rate of formation of the initial SA product and then its further destruction at a rate consistent with bare $TiO_2$.

Removal of the fine $TiO_2$ particles through several washings decreased the catalytic efficiency for the cases of SA/$TiO_2$/SnUroP, SnUroP/$TiO_2$/SA and $TiO_2$/SA at pH 6.0 (data not shown). The decrease in the efficiency of photodestruction of salicylic acid is expected, since washing removes $TiO_2$ photocatalyst from the system. More importantly, the improved efficiency of the composition SA/$TiO_2$/SnUroP (SA added before porphyrin) over SnUroP/$TiO_2$/SA (SA added after porphyrin) confirms that competitive adsorption between porphyrin and salicylic acid occurs as noted above and suggests that salicylic acid must be adsorbed onto the $TiO_2$ surface for subsequent destruction. The optimal surface coverage of the porphyrin as well as its stability on the $TiO_2$ surface has yet to be fully determined.

**Effect of Molecular Oxygen**

When the experiments of Figure 7 are repeated in the absence of $O_2$ under a nitrogen atmosphere, almost no change in the salicylic acid spectrum is observed. This suggests that $O_2$ is required for both destruction of salicylic acid and formation of the SA intermediate species. SnUroP is known to photosensitize the formation of singlet $O_2$ with high quantum yield (~0.6),[14, 15] and singlet oxygen could be involved in formation of the SA intermediate. However, for the bare $TiO_2$ surface also, oxygen is required for the destruction of salicylic acid, and this requirement is maintained in the presence of the photosensitizer.

**Mechanisms of Photosensitization of $TiO_2$**

Several possible mechanisms could lead to enhancing photocatalytic activity. First, the absorption of visible light by the porphyrin could lead to a redox cycle that generates reactive porphyrin species (e.g., the anion and/or cation) that directly attack salicylic acid. Evidence for such a process is found in the rapid conversion of SA to some species regardless of whether $TiO_2$ is present. Then the enhancement would be explained if the SA product is more labile than SA.

A second mechanism of photosensitization involves the removal of conduction band electrons by reducing the porphyrin triplet state at +1.1 V versus NHE. Removal of electrons from $TiO_2$ would prevent rapid electron-hole recombination, leaving the strongly oxidizing hole for reaction with adsorbed SA. This is equivalent to the enhancement observed when metal ions and other additives are used to extract conduction band electrons from $TiO_2$.[16] This mechanism would be consistent with the production of reduced porphyrins. Reduction of Sn porphyrins is known to result in a long-lived radical anion (at -0.66 V for SnUroP) that eventually decomposes unless it is re-oxidized soon to the neutral porphyrin. Indeed, inclusion of methylviologen, an electron acceptor (-0.45 V) does seem to protect the porphyrin from degradation beyond the Sn chlorine. The potential of the Sn porphyrin anion is sufficient for $H_2$ generation. Alternatively, reduction of the porphyrin triplet by solution species would result in the anion, which could inject electrons into the conduction band.

Enhancement mechanisms involving porphyrin oxidation chemistry via the oxidation of either the triplet state at -0.13 V or the neutral porphyrin at >1.64 V by valence band holes also cannot be ruled out. Most likely either oxidative or reductive reactions of the porphyrin initiate the destruction of the porphyrin. Determining the mechanism of porphyrin degradation on $TiO_2$ will allow us to design more stable photosensitizers.

**SUMMARY**

The properties of two tin porphyrins were investigated regarding their ability to enhance the destruction rate of salicylic acid by $TiO_2$. Adsorption onto $TiO_2$ occurs below the point of zero charge of the $TiO_2$ surface, and for SnUroP results in reduction of the porphyrin macrocycle. Interaction of the porphyrins with the surface modifies the colloidal properties of $TiO_2$. Sn-porphyrin-modified $TiO_2$ shows enhanced ability to photocatalytically destroy salicylic acid. The mechanism of enhancement remains to be determined.

SnUroP is rapidly destroyed during the detoxification reaction. SnTCPP shows greater stability on the $TiO_2$ surface, but is apparently also

ultimately destroyed. We are attempting to stabilize the adsorbed porphyrins by adding suitable peripheral substituents onto the porphyrin macrocycle to either change their interactions with the surface or modify their electronic properties.

ACKNOWLEDGEMENT

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# SOIL LOSS — KEY TO UNDERSTANDING SITE PRODUCTIVITY

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## INTRODUCTION

The concept of site productivity has changed significantly over the past two decades. Foresters previously characterized site productivity in terms of "site index." Site index is based on height of dominant or dominant and codominant trees in even-aged stands at some index age, usually 25, 50, or 100 years (Wenger 1984). The recent emphasis on managing whole ecosystems has made it increasingly difficult to use a single index for describing the productivity of an ecosystem, however, because productivity should reflect a host of complex interacting functions and processes (Steele and Pfister 1991). Therefore, ecosystem productivity must be expressed as the integrated product of all the processes acting dynamically over time. Presently, our best concept of ecosystem productivity is based on the capacity of soil to support plant growth as reflected by some index of biomass production (Powers 1991).

Although ecosystems are made up of a wide range of component parts and interrelated processes, soil and vegetation are the fundamental building blocks of all terrestrial ecosystems and thereby can serve as useful surrogates for studying and discussing ecosystem processes and their responses to perturbation. Soil is important because it not only provides a physical medium for plant growth, but also supplies most of the essential plant nutrients and, along with climate, relief, and biology, establishes the limits of biomass production. Vegetation is an important component of ecosystem productivity because it provides a mechanism for converting solar energy and carbon dioxide into biomass, and also provides a protective cover against surface erosion.

Ecosystem processes and subsequent productivity are affected by a wide range of natural and human perturbations (Powers 1991). Many of these human perturbations affect both vegetation and soils (the key surrogates for site productivity). For example, soil is disturbed during such management activities as grazing, prescribed fire, and timber harvesting. Therefore, there is an urgent need to better understand the influence of different management practices on soil disturbance. This knowledge will provide a better basis for developing guidelines for making future management decisions.

The objectives of this paper are to review the influences of management practices on site productivity, to discuss the importance and influence of soil erosion on productivity, and to describe some of the Forest Service research being used to address these issues in the Southwest.

## MANAGEMENT INFLUENCE ON SITE PRODUCTIVITY

The three ecosystem properties most likely affected by human activities are losses of soil organic matter, porosity, and depth.

The soil normally contains 80% to 90% of the total ecosystem nitrogen and even more of the phosphorus (Powers 1991). The remaining nitrogen and phosphorus is in the aboveground biomass. Loss of organic matter from the vegetative and soil components of an ecosystem can produce nutrient and moisture stress and ultimately a reduction in site productivity (DeBano 1991), particularly on infertile and droughty sites (Powers 1991). Using information from Wells and Jorgensen (1979), Powers (1991) concludes that loss of organic matter and nutrients by conventional timber harvesting (leaving slash lobbed and scattered) is unlikely to have a major influence on productivity of most sites. However, shorter harvest rotations, whole-tree logging, and broadcast burning of slash and forest litter may detrimentally affect productivity over time. Management practices that expose the soil also increase the risk of erosional losses and could reduce site productivity.

Soil compaction and the associated increases in soil density by animals and machinery can limit plant growth (Powers 1991). Soils, according to Sands (1983), will also compact under their own weight if appreciable amounts of organic matter are lost (Powers 1991). Losses in productivity are generally proportional to increases in soil bulk density (Froehlich and McNabb 1984). Soil compaction reduces porosity and infiltration capacity of the soil, which leads to potential increases in surface runoff and erosion. Therefore, the type of equipment, animal use, distribution of animal and equipment traffic, and susceptibility of a given soil to compaction must be considered when making any management decisions.

Soil depth is important because organic matter (where many nutrients are concentrated) is not distributed evenly in the soil. Because organic matter generally is concentrated at the surface and declines rapidly with depth (Powers 1989), small losses in surface soil can have a major effect on productivity. Displacing logging debris and layers of topsoil during site preparation (piling and windrowing slash) can produce nutrient deficiencies that result in loss of productivity (Powers 1991). These practices also expose the mineral soil, subjecting it to increased raindrop impact and surface sealing, which increases the potential erosion losses.

## IMPORTANCE OF SOIL EROSION

Surface erosion rates are largely influenced by the amount of vegetative cover and surface litter available to protect the soil surface (Megahan 1991). Road construction and wildfire are often responsible for the greatest reduction in vegetation and, therefore, can result in the greatest increase in erosion (Megahan 1991).

The impact of erosion on site productivity depends on the depth of soil loss, the areal extent, the erosion rate, and the redistribution of eroded material (Megahan 1991). Surface erosion often has a relatively short-term effect (often a matter of a few years) on a site. It normally involves loss of a small depth of soil, but this loss can be widespread in a given area. In a few years, with reestablishment of vegetation, erosion rates are quickly reduced. In contrast, gully or rill erosion occurs on relatively small areas but involves greater loss in soil depths, and often occurs on highly productive sites such as swales or along channel bottoms. This concentrated gully erosion can have a long-term effect on site productivity. Although erosion generally reduces productivity from the area that is eroded, productivity of downslope areas of deposition floodplains can increase.

Management practices that accelerate soil erosion can have a major impact on site productivity by reducing nutrient supply and water-holding capacity of the soil, and damaging the vegetation (Megahan 1991). Examples of damage to vegetation include loss of mechanical support of the vegetation, removal of propagules (seeds, small plants, roots), and actual burial of the vegetation. However, even erosion rates under the most severe conditions can often be quickly mitigated with the rapid reestablishment of vegetation (Megahan 1991).

## CURRENT RESEARCH

A wide variety of natural ecosystems in the southwestern United States are being subjected to increasing use by a rapidly expanding human population. To better understand these impacts, the U.S. Forest Service is conducting a series of basic and applied studies aimed at predicting the effect of different management activities on runoff, erosion, sediment movement, nutrient cycling, and soil productivity (DeBano 1989). These studies are formulated within the context of the cumulative effects of integrated land management activities on watershed condition and ecosystem productivity. Cumulative land-use effects are defined as changes to the environment caused by interactions of natural ecosystem processes with the effects of land-use activities distributed through time or space, or both (Sidle et al. 1988). The concept "cumulative effects" is the concern that, although each individual land-use activity can remain within the bounds of acceptable environmental damage, the cumulative effects can become unacceptable, particularly when several activities occur collectively. Although we are studying many facets of the overall cumulative effects, only two important areas of investigation dealing with water and wind erosion are reported below.

### Water Erosion

When erosion studies were first initiated, water erosion was considered to be one of the most important processes affecting the productivity of southwestern ecosystems. To study water erosion, we used a rotating-boom rainfall simulator equipped with V-Jet nozzles (Swanson 1965). This simulator, which is capable of producing rainfall rates of 60 and 120 mm/hr, is situated between two, 3-m × 10-m plots (Simanton et al. 1989). Both naturally vegetated and mechanically bared plots are subjected to simulated rainfall (Baker et al. 1991). Runoff and sediment production from bared plots yield an estimate of soil erodibility which is independent of plant cover. Measurements from adjacent naturally vegetated plots indicate how different vegetative covers (e.g., pinyon-juniper woodlands, annual grasslands, forests) affect runoff and sediment production.

The initial results of rainfall simulator trials on several forest and range sites in California indicated that the soil loss from bare soils varied widely from 0 to over 14,000 kg/ha (Fig. 1). The inherent erodibility of these soils was probably related to several soil chemical and physical properties. Soil physical properties such as aggregate stability are known to affect the susceptibility of soils to raindrop impact and detachability which affects infiltration and, finally, the rate and amount of runoff and erosion (Trott 1982).

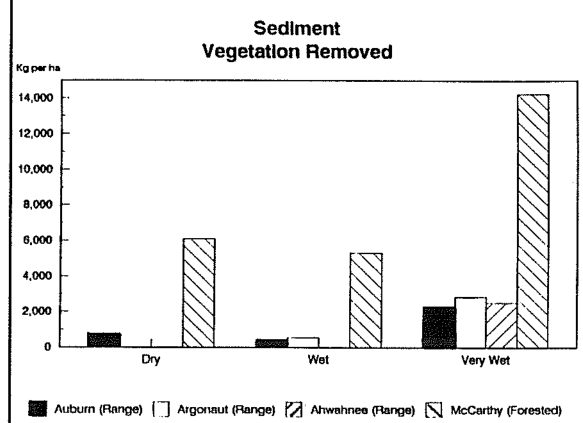


**Figure 1.** Sediment yields from four California soils in two vegetation types with cover removed. Simulations were made under three soil moisture conditions—dry, wet, and very wet.

Vegetative cover was also found to have a pronounced effect on runoff and sediment yields (Fig. 2). Sediment yields of the same range soils presented in Figure 1 were reduced to 150 kg/ha or less when vegetation was undisturbed. Vegetation is known to have several desirable effects including reduction of raindrop impact, thereby limiting soil detachment and splash (Trott 1982). Both vegetative cover and organic material improve the water storage capacity of the soil surface, thereby delaying and reducing runoff. Plant cover itself also obstructs overland flow, reducing flow velocity and sediment transport capacity. Soil crusting is also less likely to occur under vegetation.

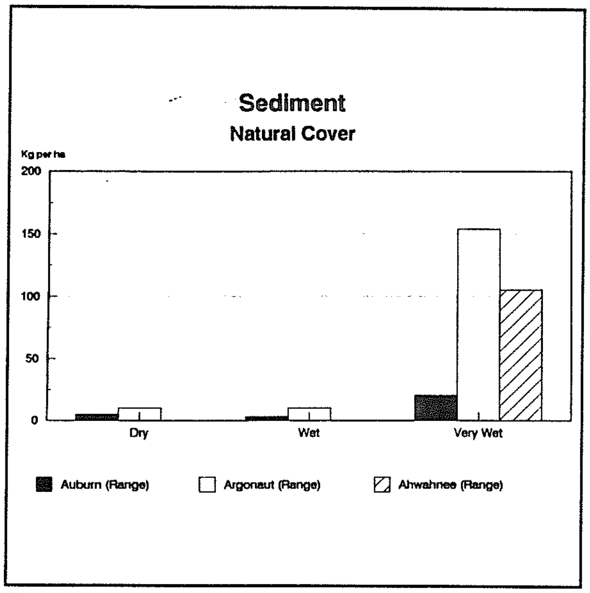


**Figure 2.** Sediment yields from three California range soils with vegetation undisturbed. Simulations were made under three soil moisture conditions—dry, wet, and very wet.

## Wind Erosion

Studies using a rainfall simulator on pinyon-juniper woodlands revealed only small amounts of sediment movement. This finding, in conjunction with the observation of substantial soil deposition under and around the bases of trees and shrubs, suggested that wind erosion may be an important erosional process in pinyon-juniper woodlands. Ash and soil movement by wind were also observed, particularly following prescribed burning of fuelwood slash.

A study was initiated by the Forest Service to quantify the effects of slash and subsequent wind erosion on the transport of nutrients and sediment in pinyon-juniper woodlands (Baker 1991). A 10-ha opening was created in a pinyon-juniper stand during a firewood harvest (Fig. 3). The residual slash was lopped and scattered, and allowed to cure for two years. In the fall of 1990, the cured slash was mechanically crushed except for a 1-ha block, located near the center of this opening, that was burned in the spring of 1991.

Wind erosion samplers (Fryrear 1986), for sampling suspended particles in the air, were located along the windward edge of the opening (the prevailing wind is from the southwest), in the crushed slash area, and in the slash area that was burned (Fig. 3). These erosion samplers were located at heights of 1 m, 0.2 m, 0.1 m, and 0.05 m above the soil surface. Mean sediment amounts (kg/m$^2$) collected in the samplers during the summer season (May 15 through October) are given in Table 1. These measurements reflect the amount of windborne sediment caught in the vertical profile at each area sampled, not the total amounts that were removed from the site.

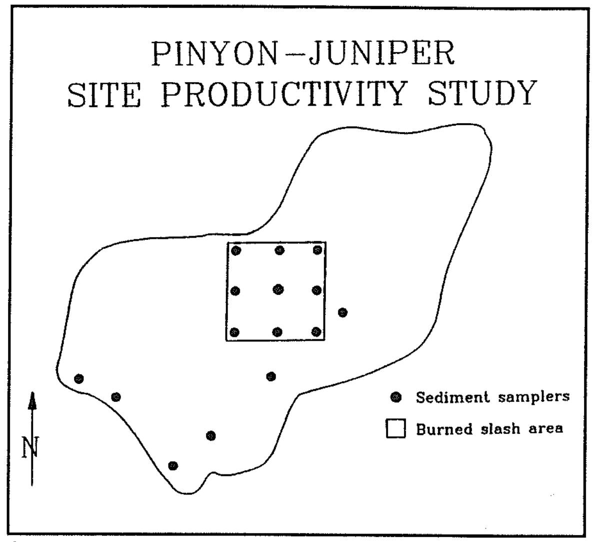


**Figure 3.** Layout of wind erosion study in a pinyon-juniper fuelwood harvest area.

Table 1. Mean sediment collected during the summer at four heights above the ground surface at Ancient Wind Study Site, 1991.

| Location | Height above the ground 1.0 m | 0.2 m | 0.1 m | 0.05 m |
|---|---|---|---|---|
| | | kg/m$^2$ | | |
| Windward | 1.3 | 1.6 | 2.8 | 5.6 |
| Crushed | 0.3 | 2.8 | 8.7 | 11.5 |
| Burned | | | | |
| Windward | 3.5 | 145.0 | 464.0 | 947.0 |
| Middle | 12.5 | 274.0 | 953.0 | 1154.0 |
| Leeward | 17.9 | 228.0 | 610.0 | 1164.0 |

The one-day catch immediately after slash burning was particularly high (Table 2). May is typically windy in the Southwest. On the day following the burn, winds gusted up to 95 km/hr. This one-day "sediment catch" represents 100% of the season catch at the 1-m height for the windward and crushed sampler locations. Catches in the lower samplers were 10% to 25% of the total seasonal catch. The one-day catch in the burned area was about 40% to 50% of the total catch.

Table 2. Mean sediment collected at four heights above the ground surface at Ancient Wind Study Site on 5/15/91, one day after slash was burned.

| | Height above the ground | | | |
|---|---|---|---|---|
| Location | 1.0 m | 0.2 m | 0.1 m | 0.05 m |
| | kg/m$^2$ | | | |
| Windward | 1.3 | 1.0 | 0.7 | 1.1 |
| Crushed | 0.3 | 0.6 | 1.0 | 1.9 |
| Burned | | | | |
| Windward | 1.5 | 69.0 | 242.0 | 549.0 |
| Middle | 5.5 | 115.0 | 470.0 | 492.0 |
| Leeward | 8.8 | 110.0 | 301.0 | 642.0 |

## CONCLUSIONS

Management practices may affect site productivity by changing organic matter, soil porosity, and soil depth in a given ecosystem. Changes in these three factors influence the availability of nutrients, water, and gases to the vegetation.

Although erosion is a typically slow process in all ecosystems, natural disturbances (such as wildfire, floods, and wind) and human disturbances often accelerate the erosion rates. Although humans generally have little control over natural disturbances, a better understanding of their influence on the productivity of southwestern ecosystems is needed to develop better management strategies, which can be used following such disasters. A better knowledge of the effects of natural disturbances also allows managers to isolate these effects from those caused by human activities.

Manipulations or uses of natural ecosystems can potentially increase the risk of erosion. The impact of erosion on site productivity depends mainly on the depth, areal extent, and rate of soil loss along with redistribution of eroded material. Better knowledge of these factors is needed to reduce their impacts on productivity.

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# DECREASING TRENDS OF SUSPENDED SEDIMENT CONCENTRATIONS AT SELECTED STREAMFLOW STATIONS IN NEW MEXICO

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## INTRODUCTION

Data collected from six U.S. Geological Survey streamflow-gaging stations in New Mexico indicate a decrease in annual suspended sediment concentrations. Average annual rates of sediment accumulation in three reservoirs in New Mexico also are showing a decrease. This decrease in sediment concentrations from streamflow-gaging stations and in accumulation rates in reservoirs may reflect a change in the sediment delivery from tributary arroyos through time.

From 1880 to 1920, many arroyos in New Mexico incised and contributed large volumes of sediment to main channels, such as the Rio Grande and Pecos River. Since then many of these arroyos have been evolving. Arroyo evolution begins with channel deepening, and is followed by channel widening, floodplain formation, and the establishment of vegetation. These sequential channel changes proceed upstream through the watershed and ultimately lead to channel aggradation and reduced sediment yields.

The evolution of arroyos may be an important consideration to conservationists and erosion-control planners. In a watershed affected by channel incision, the downstream reaches of the watershed are generally aggrading, whereas upstream reaches are still eroding their bed and banks. Therefore, the stage of channel evolution in a particular reach can be an important consideration in determining the placement of erosion-control structures.

## PURPOSE AND SCOPE

Suspended sediment data for selected streamflow stations in New Mexico were analyzed to show if there is a trend to the data. Stations that had at least a 20-year record were selected. Sedimentation surveys for selected reservoirs in New Mexico were analyzed to show if the accumulation rates of sediment have been changing through time. Causes for increasing or decreasing trends in either suspended sediment or reservoir sedimentation rates were examined and tested. Arroyos, which are major contributors of sediment in New Mexico, were examined for channel changes through time and their possible relation to increasing or decreasing trends in suspended sediment or reservoir sedimentation rates.

## SUSPENDED SEDIMENT DATA

Suspended sediment sampling techniques used in New Mexico have varied through time and among agencies. The International Boundary and Water Commission (IBWC) collected suspended sediment at the station Rio Grande at San Marcial (Fig. 1) beginning in 1897 and was subsequently continued by the U.S. Geological Survey (USGS) in

1946. After 1950, flow at this station was divided into two channels, a floodway and a conveyance channel. Suspended sediment data for the Rio Grande at San Marcial after 1950 were reported as the sum of both channels. The IBWC collected suspended sediment using one or more of four methods described in Summary Water Bulletin Number 1 (International Boundary and Water Commission 1956). Daily, monthly, and annual totals were reported as suspended silt in acre-feet, at 1,452 tons of suspended silt per acre-foot. The USGS and the IBWC used the Rio Grande sampler for suspended sediment collection at streamflow-gaging stations in New Mexico until 1948. In 1939 an interagency committee was formed to study and develop accurate methods of suspended sediment sampling (U.S. Interagency Committee on Water Resources 1944). A standardized depth-integrated sampler, the US D-48, was developed and incorporated into use by the USGS in 1948. The USGS collects suspended sediment in accordance with guidelines presented by Guy and Norman (1970). Changes in suspended sediment concentrations as a result of sampler modifications, sampling methods, and laboratory methods are not known, but could be expected; however, whether these modifications might increase or decrease suspended sediment concentrations is unclear. Gellis and others (1991) reported that the decrease in suspended sediment loads in the 1940s in the Colorado River basin probably was not due to a change in samplers or sampling methods. Comparative laboratory tests of the Colorado River sampler and the replacement sampler, the US D-48, indicated that the US D-48 resulted in higher concentrations than did the earlier model. This increase in suspended sediment concentrations as a result of sampler changes contrasts with the lower concentrations observed in the 1940s in suspended sediment records.

Annual suspended sediment load data from eight streamflow-gaging stations in New Mexico (Fig. 1) were obtained from USGS annual data reports, IBWC Summary Water Bulletins, and the USGS hydrologic database WATSTORE. Characteristics of each station are listed in Table 1. Annual suspended sediment concentrations, in tons per acre-foot, at stations 1 through 6 (Tab. 1) were calculated by dividing annual suspended sediment

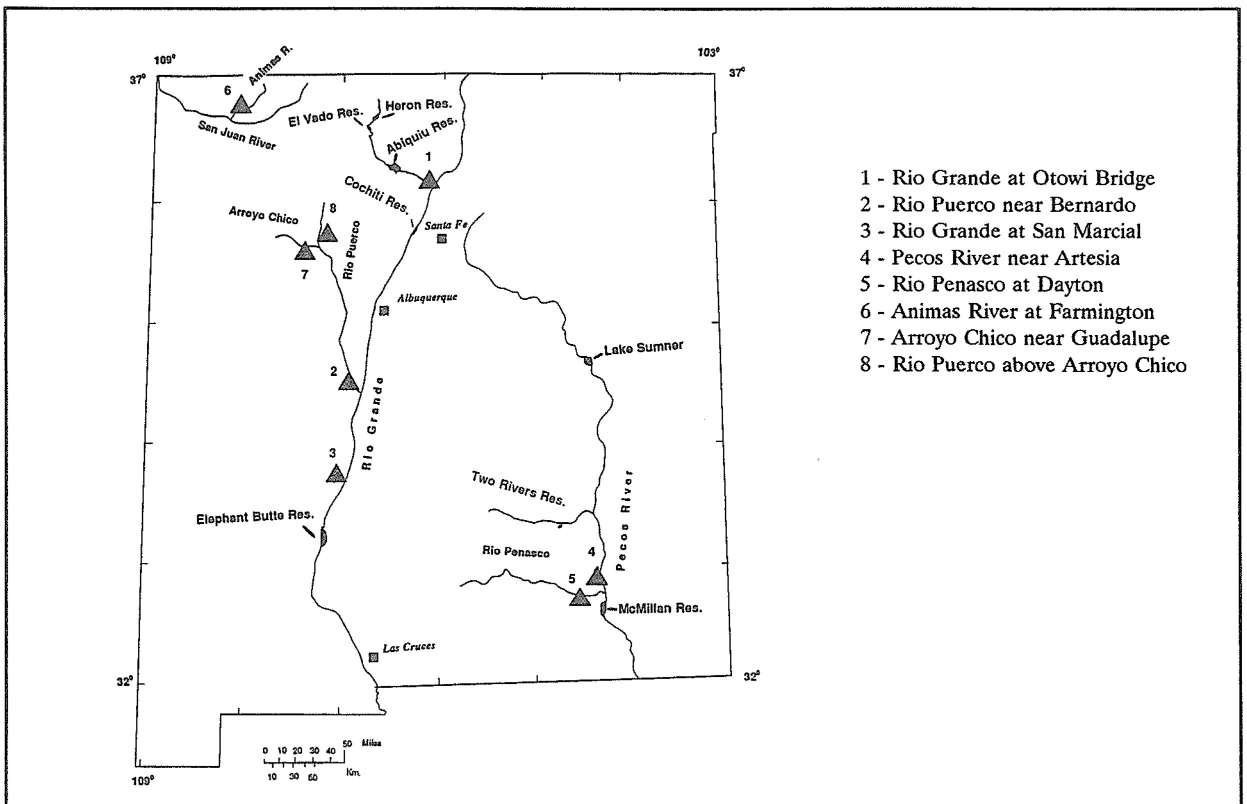


**Figure 1.** Location of selected streamflow-gaging stations in New Mexico.

Table 1. Characteristics of selected streamflow gaging stations.

| Station name | Drainage area ($mi^2$) | Period of record | Average annual suspended sediment load (tons) | Upstream reservoirs & completion dates |
|---|---|---|---|---|
| 1-Rio Grande at Otowi Bridge | 14,300 | 1948-1990 | 2,046,700 | El Vado - 1935<br>Abiqui - 1963<br>Heron - 1971 |
| 2-Rio Puerco near Bernardo | 7,350 | 1948-1990 | 4,292,900 | None |
| 3-Rio Grande at San Marcial | 27,700 | 1897-1990 | 12,100,600 | El Vado - 1935<br>Abiqui - 1963<br>Heron - 1971<br>Cochiti - 1975 |
| 4-Pecos near Artesia | 15,300 | 1949-1990 | 520,000 | Lake Sumner - 1937<br>Two Rivers - 1963 |
| 5-Rio Penasco at Dayton | 1,060 | 1952-1973 | 688,100 | None |
| 6-Animas River at Farmington | 1,360 | 1951-1990 | 106,100 | None |
| 7-Arroyo Chico near Guadalupe | 1,390 | 1949-1955<br>1979-1986 | 1,910,400 | None |
| 8-Rio Puerco above Arroyo Chico | 420 | 1949-1955<br>1982-1990 | 867,200 | None |

loads, in tons, by annual runoff, in acre-feet (Figs. 2-7). As indicated by the best-fit regression lines in Figures 2-7, annual suspended sediment concentrations at all stations have decreased through time. At Rio Grande at Otowi Bridge (Fig. 2), the annual sediment concentration, as indicated by the best-fit regression line, decreased 71 percent, from 3.5 tons per acre-foot in 1948 to 1.0 ton per acre-foot in 1990. At the station Rio Grande at San Marcial (Fig. 4), annual suspended sediment concentrations decreased 85 percent, from 27.0 tons per acre-foot in 1897 to 4.0 tons per acre-foot in 1990.

Because large amounts of sediment are transported in relatively few days of high runoff, factoring out runoff on an annual basis could have some inherent errors. For example, a high runoff year might be the result of high snowmelt runoff, which does not characteristically transport large amounts of suspended sediment. A seasonal trend test might resolve some of these problems, but for the purpose of this report such a test was not performed.

Statistical analysis was performed on the data shown in Figures 2-7 to determine the significance of the trend (Table 2). Statistical analysis consisted of testing the hypothesis that fluctuations in the data are random, and testing the hypothesis that there is a trend to the data (Miller and Kahn 1962). The test for randomness involves assigning a (+) to values above the median and a (-) to values below the median. The number of runs in the data or the number of sequences of one or more like values (+ or -), preceded and followed by a different value is determined. Using a significance level of 0.025 for the lower tail, and 0.025 for the upper tail, we would reject the hypothesis of random fluctuations in the data if the probability, $P(\mu) < 0.050$.

Spearman's rank correlation method computes the correlation between an observed sequence and a regular rising or falling of variables (Miller and Kahn 1962). Spearman's rank correlation coefficient ranges from -1 to 1, so a high negative correlation would indicate the possibility of a downward trend.

Table 2. Results of statistical analysis on annual suspended sediment concentrations using data from Figures 2-7.

| Station name | Test for random order, P($\mu$) correlation coefficient | Spearman's rank |
|---|---|---|
| 1-Rio Grande at Otowi Bridge | 0.001 | -0.719 |
| 2-Rio Puerco near Bernardo | 0.011 | -0.668 |
| 3-Rio Grande at San Marcial | 0.00002 | -0.602 |
| 4-Pecos River near Artesia | 0.0001 | -0.736 |
| 5-Rio Penasco at Dayton | 0.033 | -0.319 |
| 6-Animas River at Farmington | 0.124 | -0.565 |

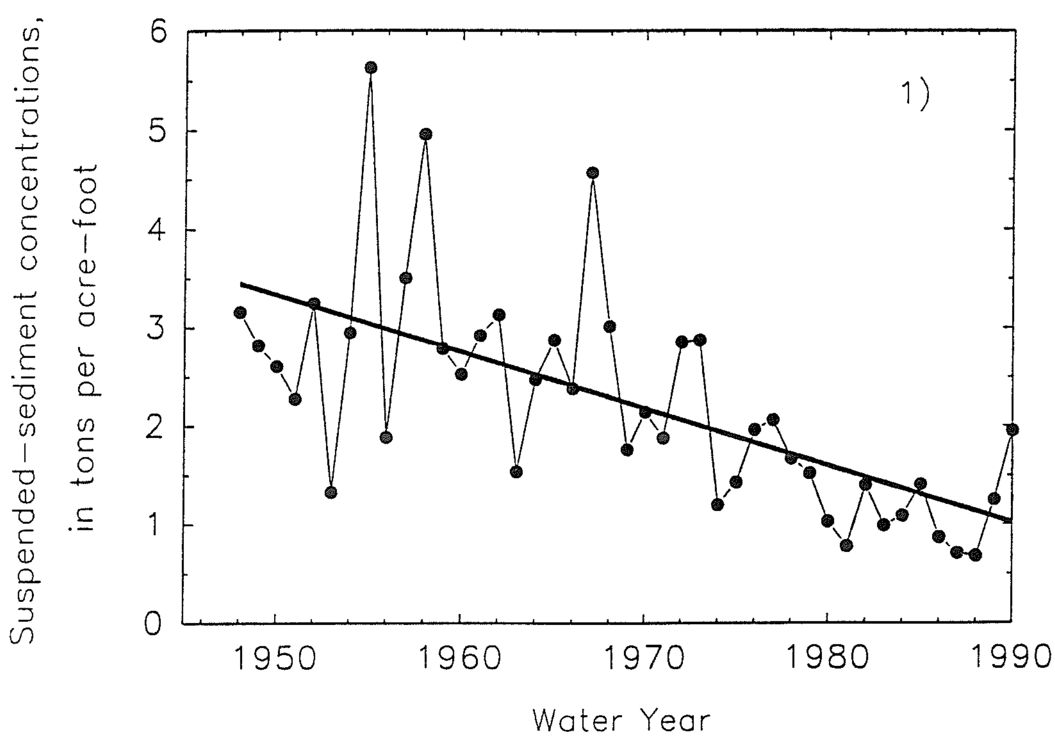


**Figure 2.** Annual suspended sediment concentrations through time including best-fit regression line for Rio Grande at Otowi Bridge station.

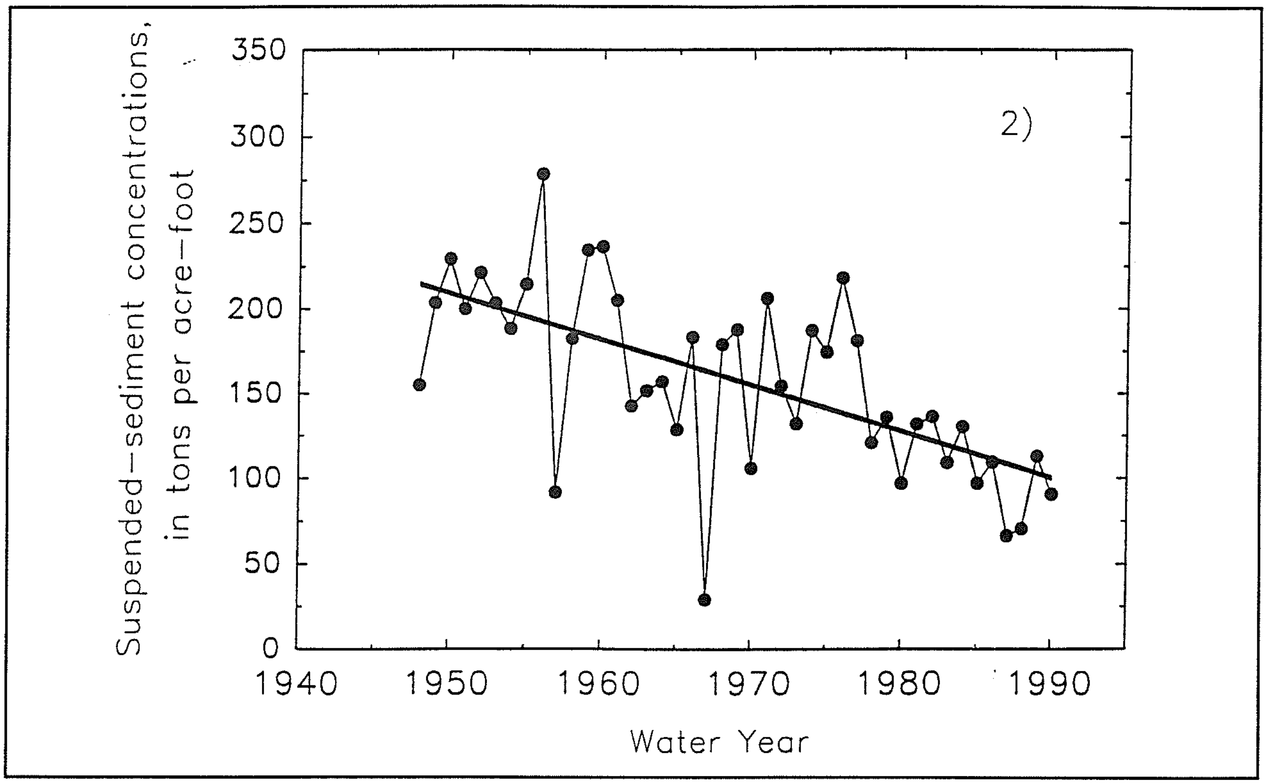


**Figure 3.** Annual suspended sediment concentrations through time including best-fit regression line for Rio Puerco near Bernardo station.

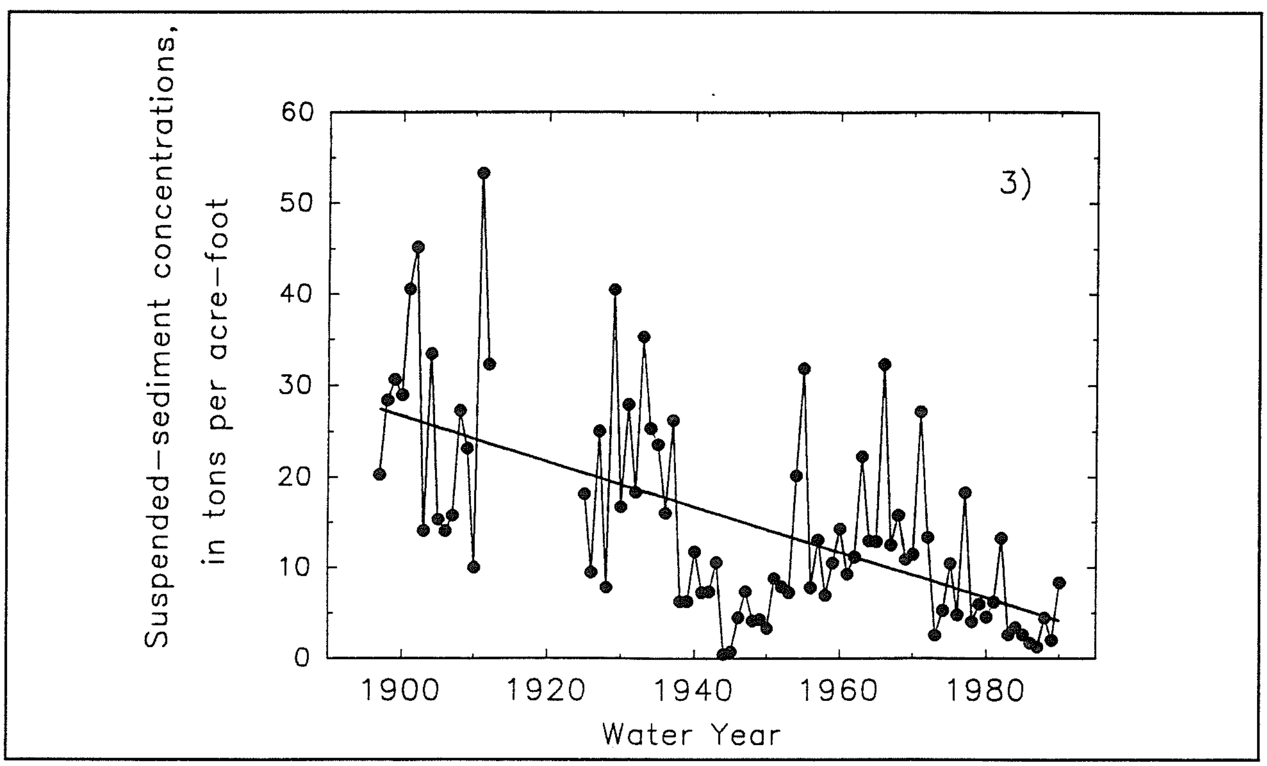


**Figure 4.** Annual suspended sediment concentrations through time including best-fit regression line for Rio Grande at San Marcial station.

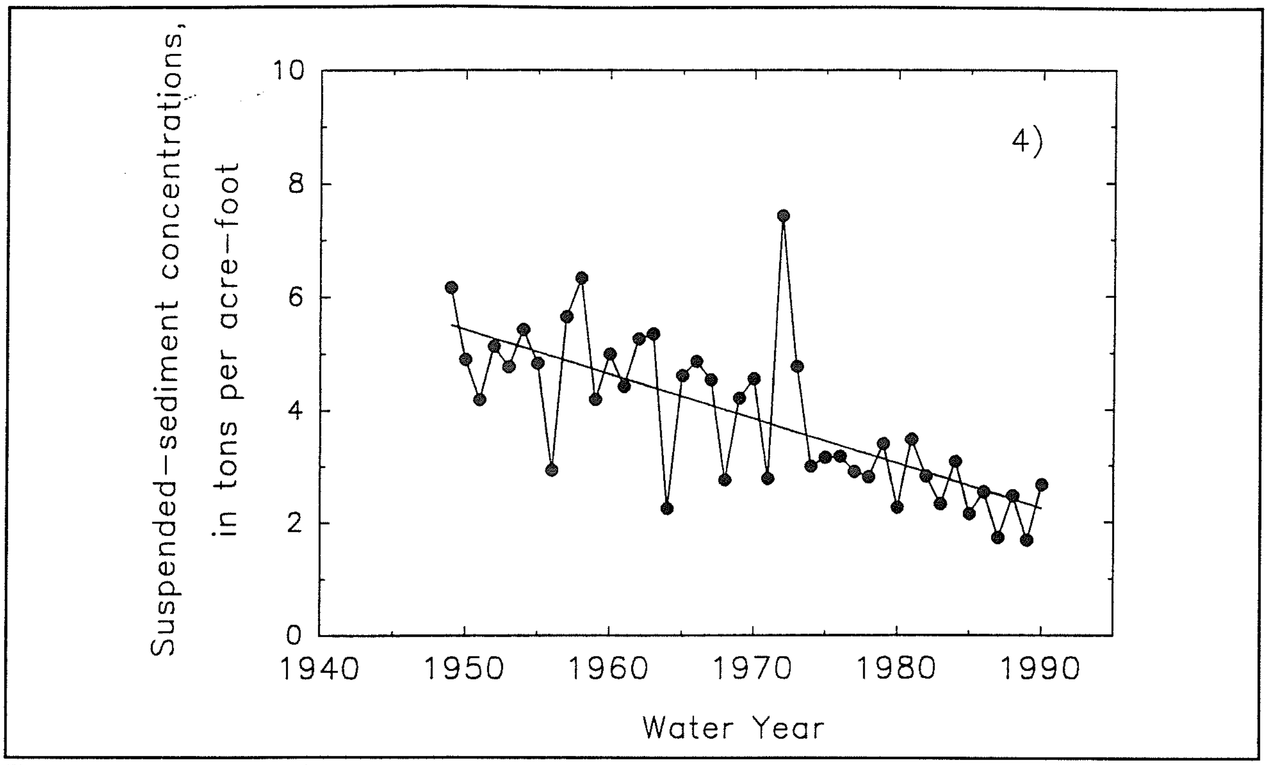


**Figure 5.** Annual suspended sediment concentrations through time including best-fit regression line for Pecos River near Artesia station.

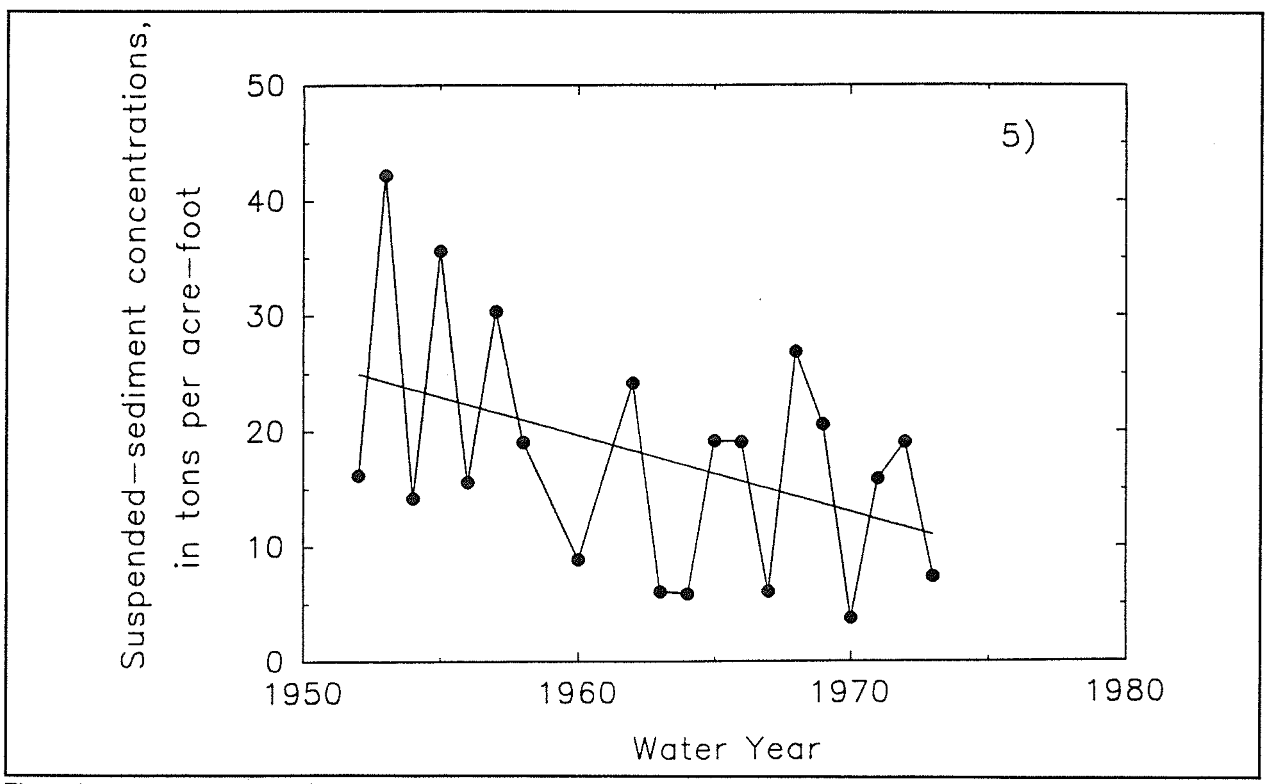


**Figure 6.** Annual suspended sediment concentrations through time including best-fit regression line for Rio Penasco at Dayton station.

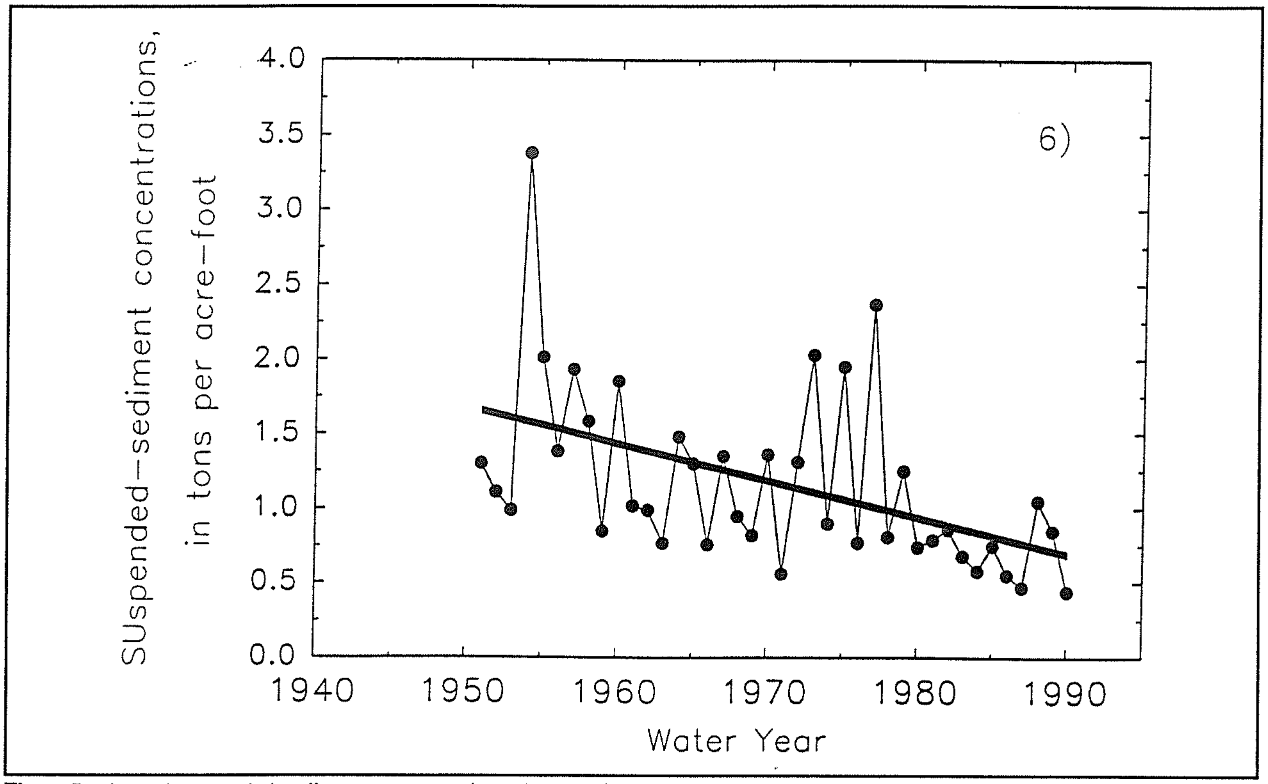


**Figure 7.** Annual suspended sediment concentrations through time including best-fit regression line for Animas River at Farmington station.

Of the six stations in Figure 1 tested for random order, all except the Animas River at Farmington indicate that fluctuations in the data are not random (Table 2). A Spearman rank correlation coefficient less than -0.5 was interpreted as being significant. Results of Spearman's rank correlation test indicate a strong possibility of a downward trend at all stations except for Rio Penasco at Dayton (Table 2). Although the Rio Penasco station shows a decrease in the best-fit regression line in Figure 6, this decrease may not be statistically significant. Therefore, the hypothesis that fluctuations in the data are not random and indicate a decreasing trend is supported for the stations Rio Grande at Otowi Bridge, Rio Puerco near Bernardo, Rio Grande at San Marcial, and Pecos River near Artesia.

## CAUSES FOR THE DECREASE IN SEDIMENT

The causes for the decrease in annual suspended sediment concentrations could include the following: upstream reservoir closures, change in sediment-sampling procedures, or arroyo evolution.

Reservoirs generally have little impact on annual runoff, but affect peak flow and trap substantial quantities of suspended sediment. A change in sediment-sampling procedures might have affected suspended sediment concentrations. To test the hypothesis that reservoirs and a change in sediment samplers affected annual suspended sediment loads, double-mass curves were constructed for all the stations shown in Table 1 (Figs. 8-13). In double-mass curve analysis, cumulative annual suspended sediment load is plotted against cumulative annual runoff (Searcy and Hardison 1960). A break in the slope of the double-mass curve in any direction means that a change has occurred in the constant of proportionality between runoff and suspended sediment load. The effects of a reservoir on reducing sediment loads should appear as a downward break in slope in a double-mass curve. A change in sediment samplers might also appear as a break in slope of the relation between suspended sediment loads and runoff. Thompson (1984a,b) used the double-mass curve to analyze changes in suspended sediment characteristics for the Utah stations, Colorado River near Cisco and

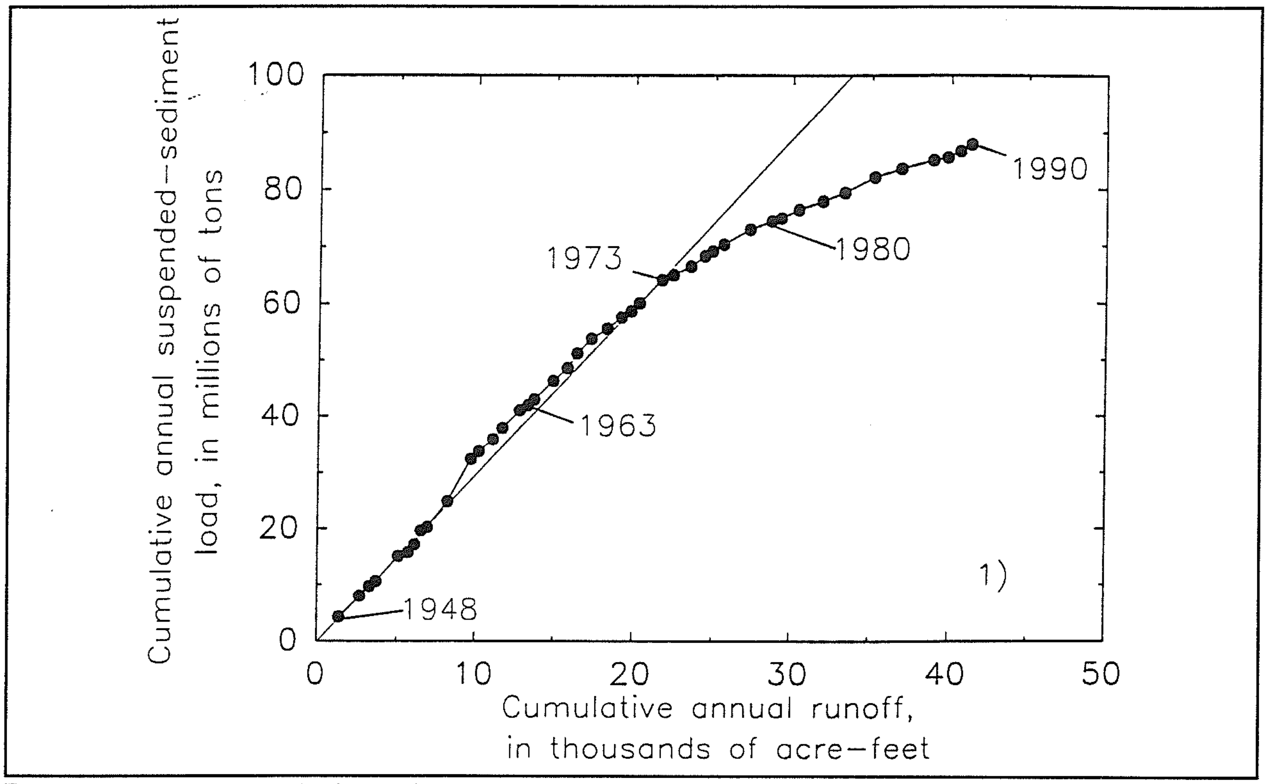


**Figure 8.** Double-mass curves showing relation between annual suspended sediment load and annual runoff for Rio Grande at Otowi Bridge station.

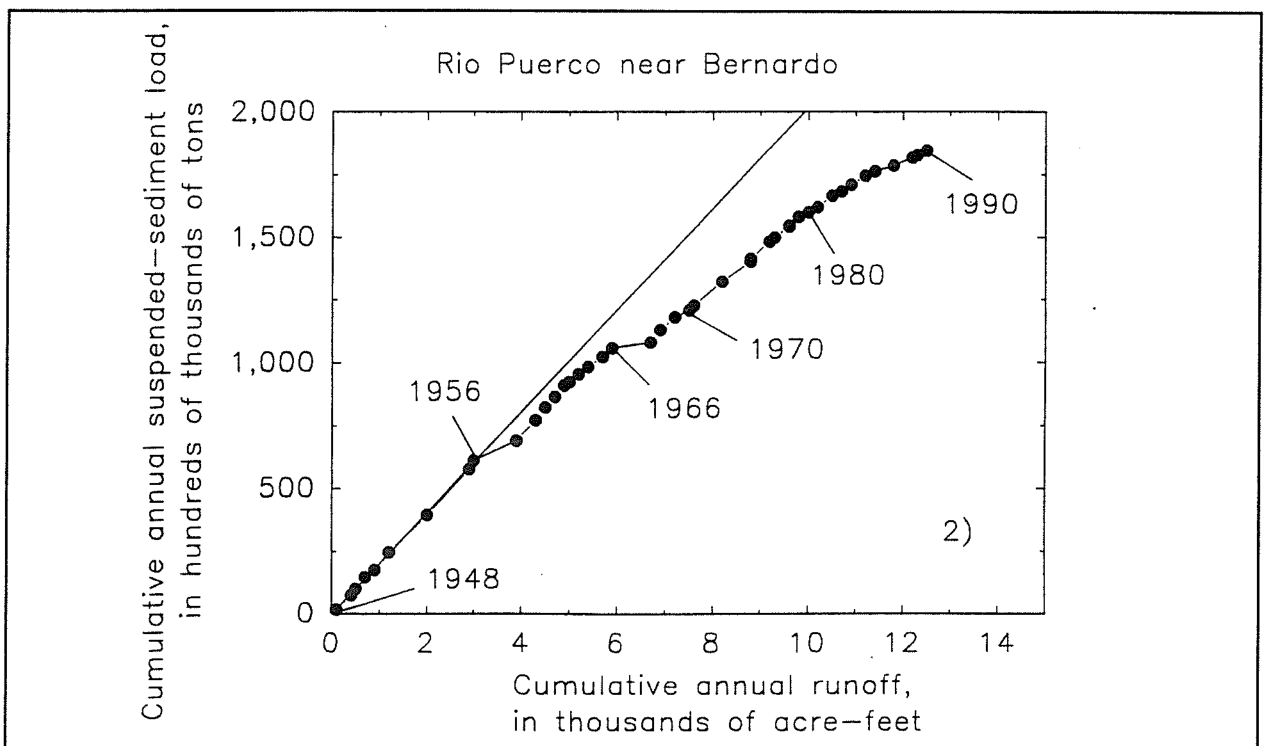


**Figure 9.** Double-mass curves showing relation between annual suspended sediment load and annual runoff for Rio Puerco near Bernardo station.

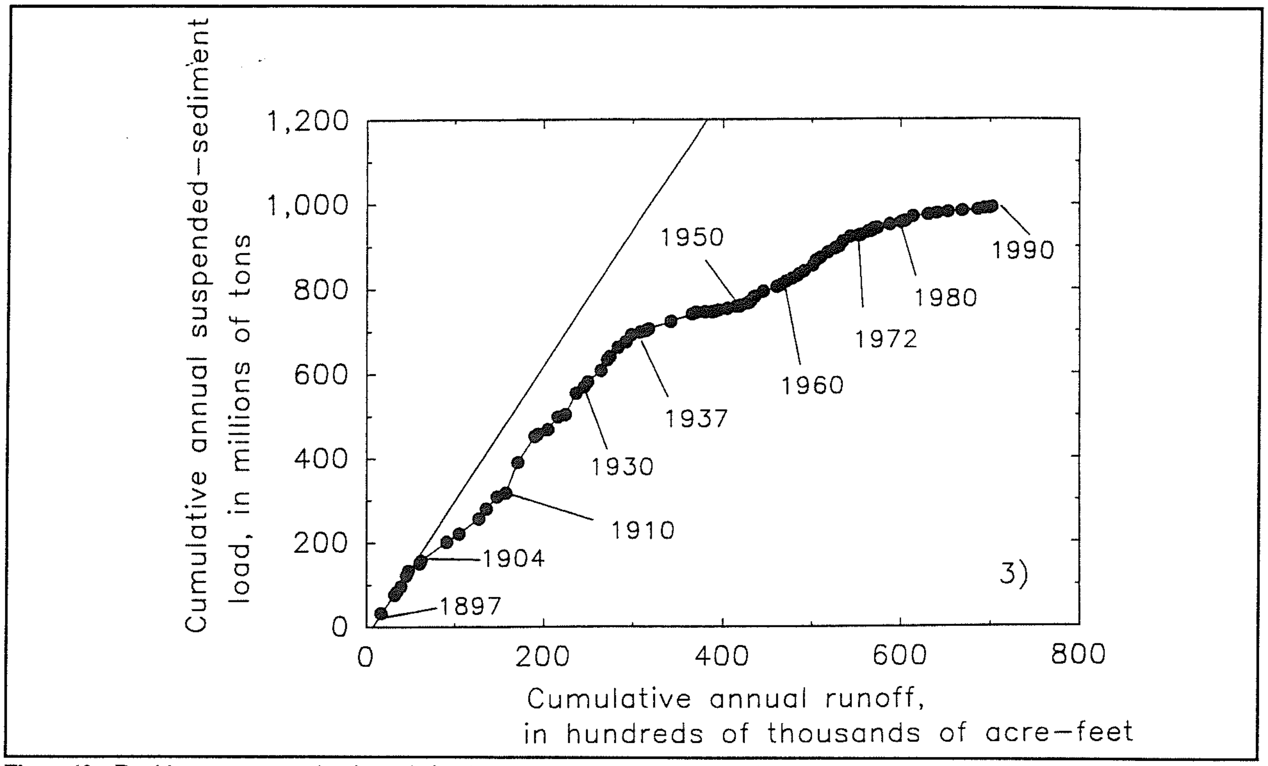


**Figure 10.** Double-mass curves showing relation between annual suspended sediment load and annual runoff for Rio Grande at San Marcial station.

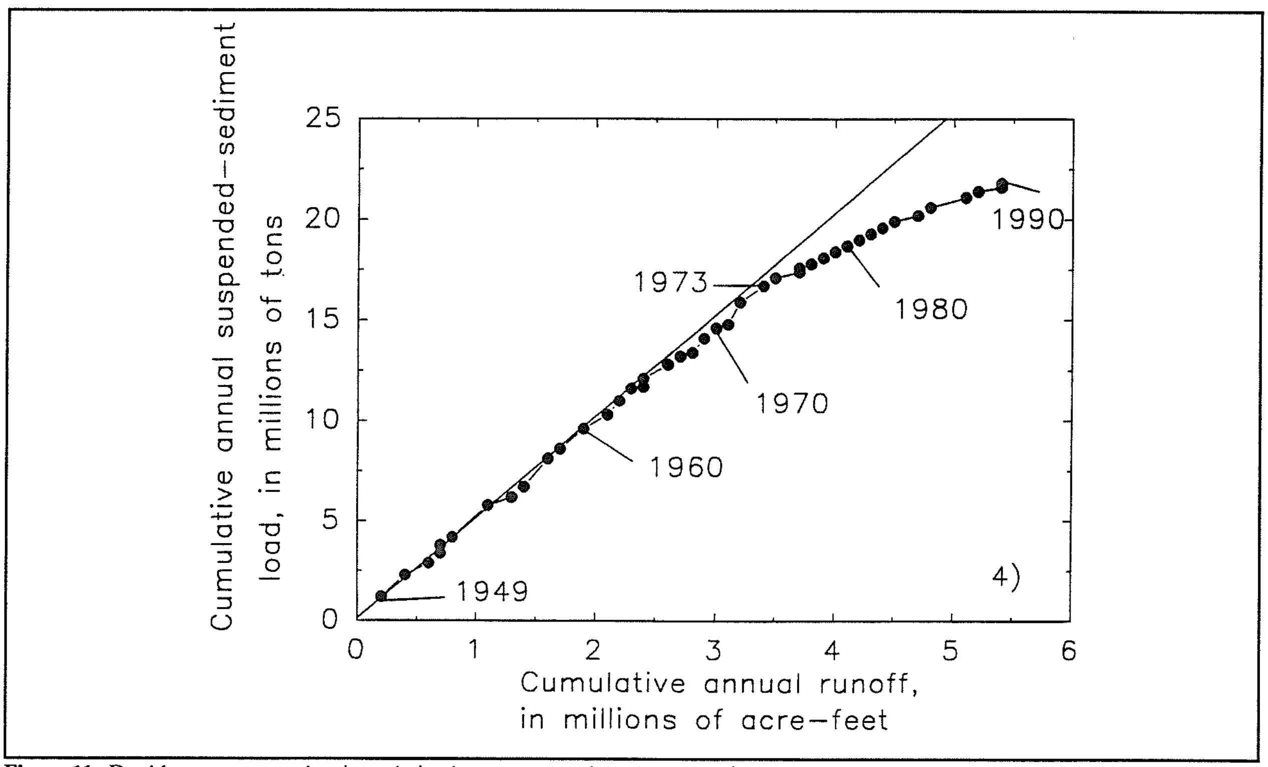


**Figure 11.** Double-mass curves showing relation between annual suspended sediment load and annual runoff for Pecos River near Artesia station.

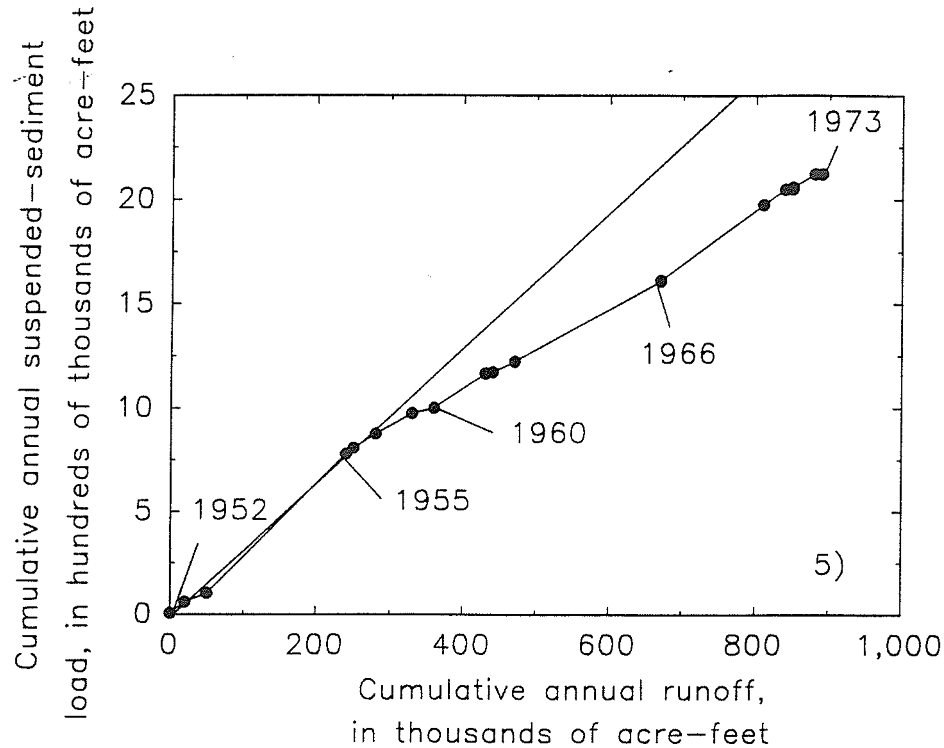


**Figure 12.** Double-mass curves showing relation between annual suspended sediment load and annual runoff for Rio Penasco at Dayton station.

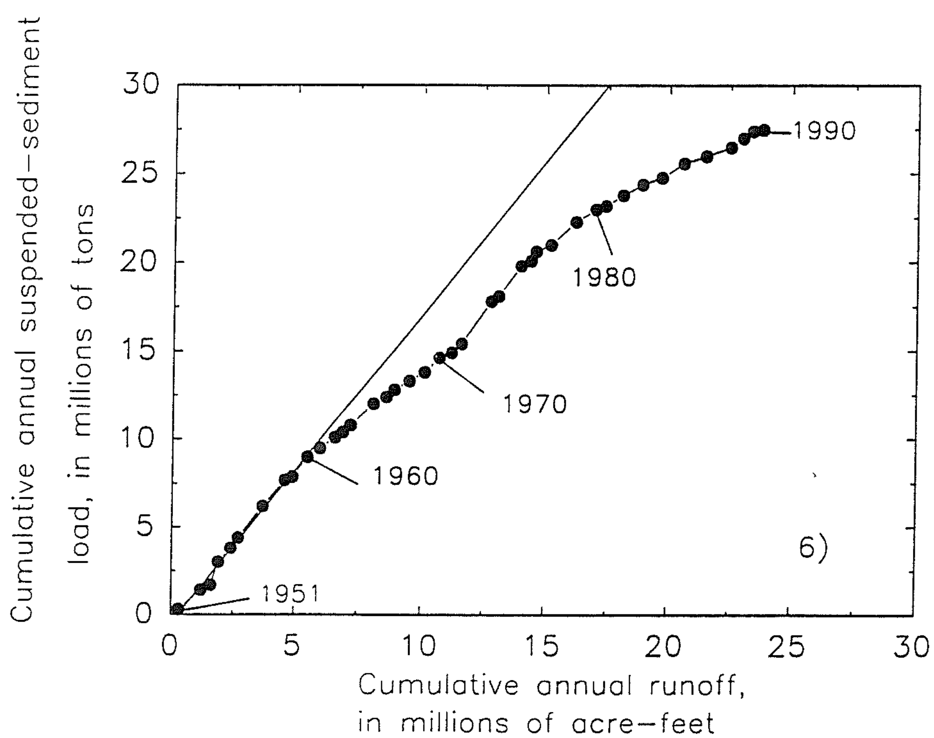


**Figure 13.** Double-mass curves showing relation between annual suspended sediment load and annual runoff for Animas River at Farmington station.

Green River at Green River. Changes in the slope of the double-mass curve in 1963 reflected the closures of several dams upstream from these stations.

Three major reservoirs were constructed upstream from the station Rio Grande at Otowi Bridge (Table 1). El Vado and Abiquiu reservoirs, completed in 1935 and 1963, respectively, apparently had no significant effect on the relation between suspended sediment load and runoff (Fig. 8). A break in slope of the double-mass curve at the station Rio Grande at Otowi Bridge occurred in 1973. It is unclear if this break in slope is due to the influence of Heron Reservoir, constructed in 1971. Heron Reservoir is located upstream from both El Vado and Abiquiu reservoirs and, therefore, its effect on suspended sediment loads is obscured by El Vado and Abiquiu reservoirs. At the station Rio Grande at San Marcial, downward breaks in the suspended sediment load/runoff relation occurred in 1904, 1937, and 1972 (Fig. 10). The 1937 and 1972 dates follow closely the closure of El Vado and Heron reservoirs, respectively. However, if this change in slope was due to closure of these reservoirs, it is unclear why the suspended sediment loads at the station Rio Grande at Otowi Bridge, which is located much closer to these reservoirs, was unaffected. At the station Pecos River near Artesia a change in the suspended sediment load/runoff relation occurred in 1973, and is not coincident with the closure of any upstream reservoirs (Table 1). A break in slope does not appear at the station Rio Grande at San Marcial in 1948 when the USGS changed sediment-sampling equipment; therefore, the change in sediment sampler does not seem to have affected suspended sediment concentrations at this station.

The double-mass curves in Figures 8-13 do not indicate that reservoir closures were a factor altering the suspended sediment load/runoff relation. However, these stations show the change in slope of the double-mass curve to be negative, indicating a decrease in annual suspended sediment loads relative to annual runoff.

## RESERVOIR ANALYSIS

To determine if sediment concentrations are decreasing in New Mexico's rivers, reservoir sedimentation surveys were analyzed through time. At Elephant Butte Reservoir, Lake Sumner and McMillan Reservoir, sedimentation surveys were used to determine the average annual rate of sedimentation for the period of time between surveys (Dendy and Champion 1978). The loss in storage capacity between surveys, in acre-feet, was assumed to be equal to the volume of sediment deposited in the reservoir. To eliminate the effects of variable runoff, mean annual sedimentation rates were divided by mean annual runoff, in acre-feet, for the period between surveys (Figs. 14-16). The resulting normalized annual sedimentation rate is unit-less (acre-foot of sediment per acre-foot of runoff). At Elephant Butte Reservoir, a general decrease in the sedimentation rate is observed from the 1920s to the 1950s. Lake Sumner shows a decrease in the annual sedimentation rate from 1940 to 1973. McMillan Reservoir shows a high annual sedimentation rate in the first survey of 1915 (Fig. 16). Subsequent surveys indicate a much lower rate of sedimentation. Therefore, a decrease in the amount of sediment deposited versus runoff per year has been occurring since the closure of each reservoir (Figs. 14-16). This reservoir analysis confirms the downward trends of suspended sediment shown in Figures 2-7.

## ARROYO EVOLUTION

During the period 1880 to 1920, many washes and channels in New Mexico incised and formed large arroyos (Bryan 1925; Antevs 1952; Cooke and Reeves 1976). Generally, two theories have prevailed for arroyo incision: incision caused by a climatic change (Leopold 1951; Bull 1964; Webb 1990) or incision caused by a change in land use (Rich 1911; Thornthwaite and others 1942; Antevs 1952). This paper does not address the cause(s) of arroyo incision but rather how arroyo channels may be affecting sediment production in several areas of New Mexico.

Field evidence of arroyos in New Mexico and elsewhere in the Southwest may provide a geomorphic explanation for the decrease in sediment measured at streamflow-gaging stations and reservoirs in New Mexico (Emmett 1974; Elliott 1979; Graf 1987; Gellis and others 1991). Following a period of channel incision, channel geometry in arroyos develops in a systematic fashion, known as arroyo evolution. When incision begins in an alluvial valley, downstream locations are affected first. The

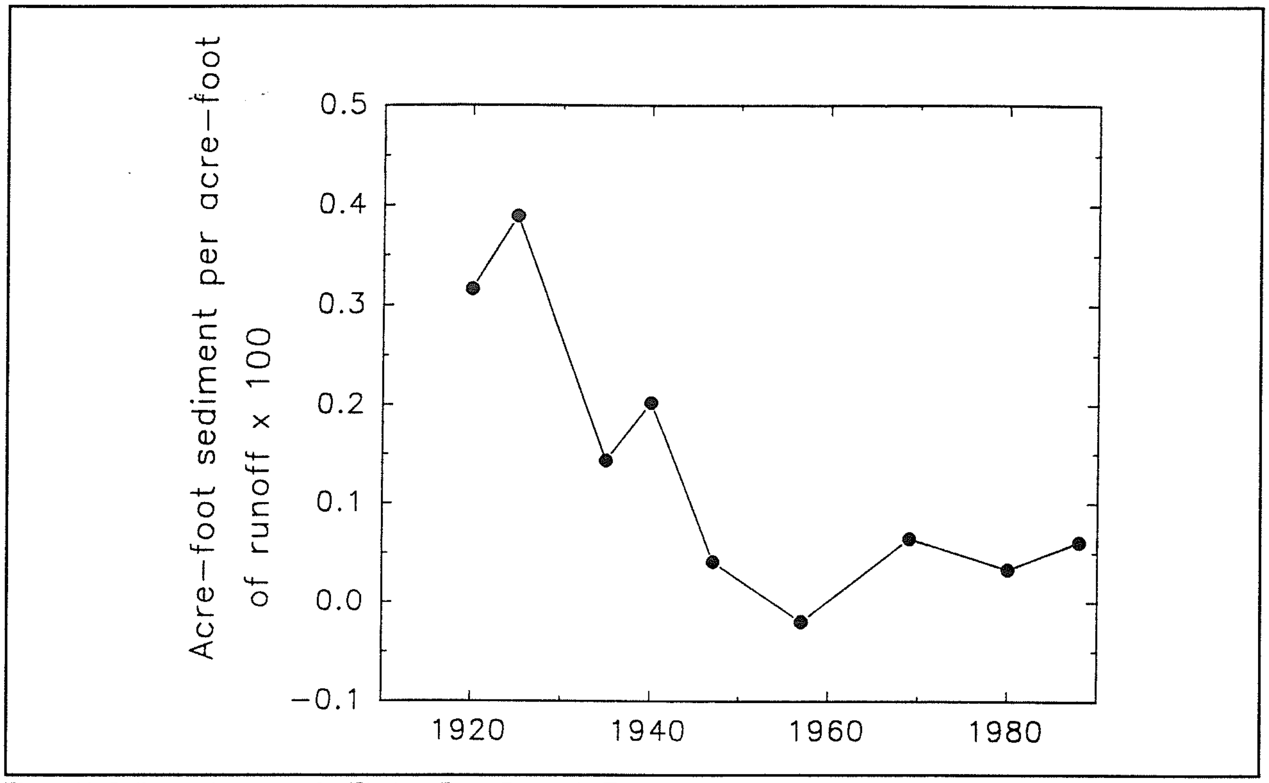


**Figure 14.** Sedimentation survey for Elephant Butte Reservoir. The values plotted represent average values for time periods between reservoir surveys.

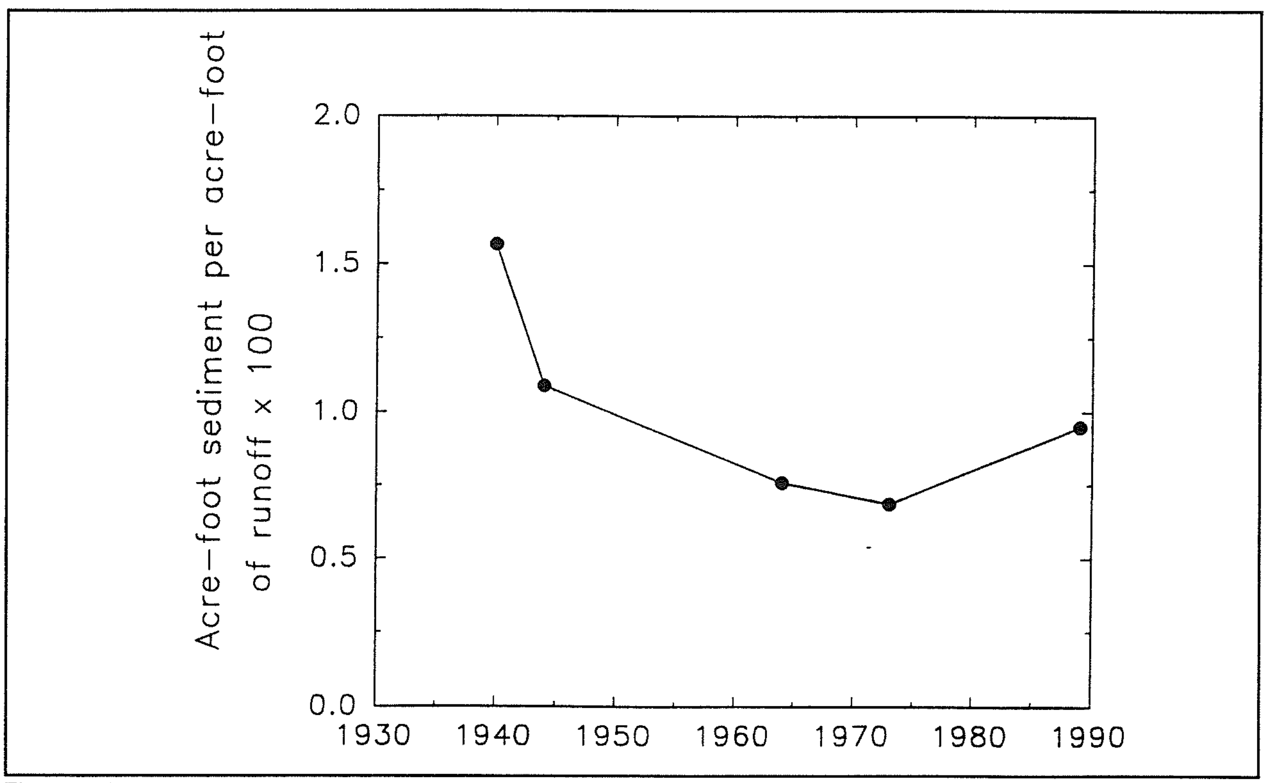


**Figure 15.** Sedimentation survey for Lake Sumner. The values plotted represent average values for time periods between reservoir surveys.

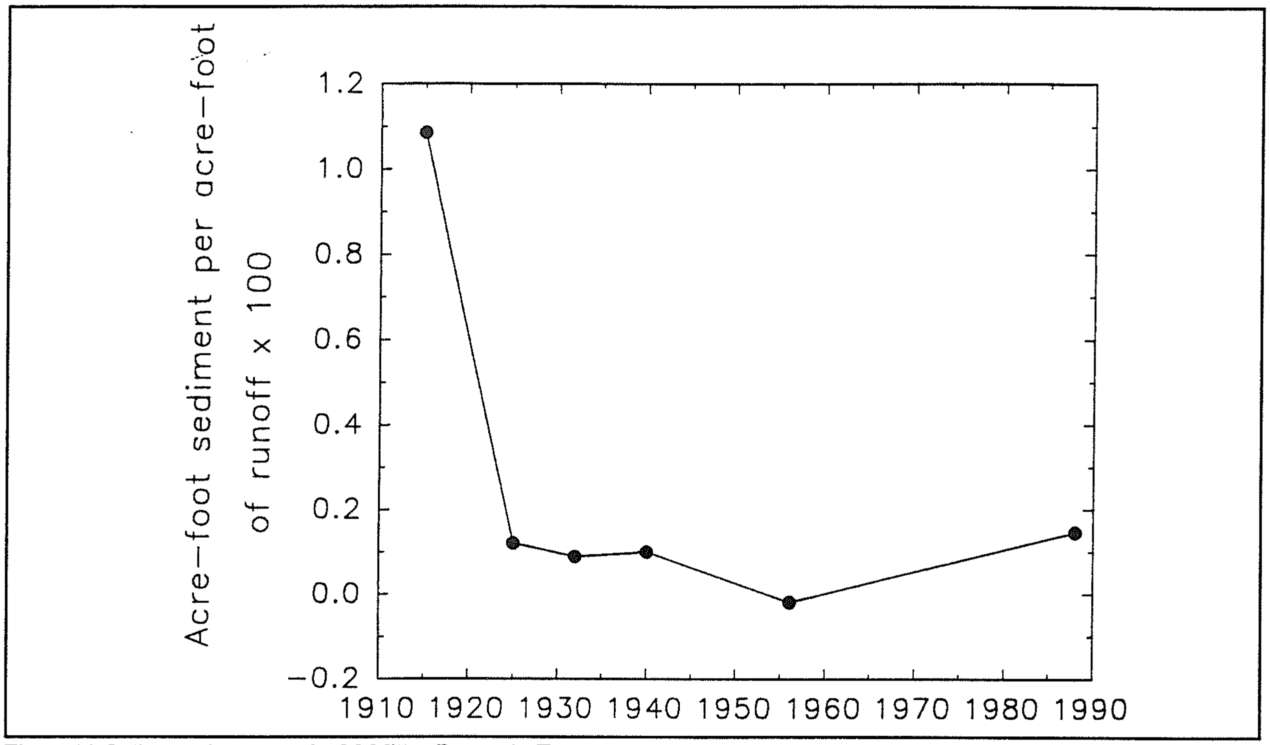


**Figure 16.** Sedimentation survey for McMillan Reservoir. The values plotted represent average values for time periods between reservoir surveys.

incision usually occurs as a series of headcuts that move upstream through time.

Changes that occur through time in the watershed, from downstream to upstream reaches, can be substituted by comparing changes that occur at one location through time as depicted in Figure 17 (Schumm and others 1984; Paine 1985). The first stage shown in Figure 17 is the channel before incision occurs (Stage A). As one or a series of headcuts moves up the watershed, the channel incises (Stage B). In Stage C the channel widens due to bank instability and braiding of the channel. As the channel continues to widen, a stage is reached where peak flows no longer impinge on the arroyo walls and the channel begins to aggrade (Stage D). Vegetation colonizes the incipient floodplain, increases the hydraulic roughness, and further enhances sediment deposition (Stage E). At this stage in arroyo evolution, the channel may completely fill (Stage F1) and become similar in form to Stage A, or it may incise again due to the oversteepening of the deposited sediment (Stage F2-G3). These sequential channel changes lead to an initial period of high erosion and sediment yields that decrease through time.

Studies of incised-channel evolution in western Tennessee support the arroyo evolution model (Simon 1989). Incision of channels in western Tennessee as a result of channelization and channel straightening increased sediment loads dramatically. As the channels adjusted to incision, decreases in sediment loads were measured through time. Simon (1989) used the changes in slope of the discharge suspended sediment relation to assess sediment changes through stages of channel evolution.

## RIO PUERCO

Suspended sediment records are available for a large arroyo in New Mexico, the Rio Puerco near Bernardo (Fig. 1). Incision in the Rio Puerco began in the 1880s (Bryan and Post 1927). Bryan and Post estimated that during the period 1885-1927, 395,000 acre-feet of sediment was eroded or an average of 13.6 million tons of sediment was eroded annually. In the 42 years between 1948 and 1990, an average of 4.3 million tons of sediment was transported annually out of the Rio Puerco, which is 32 percent of the annual amount eroded between 1885 and 1927. Suspended sediment sam-

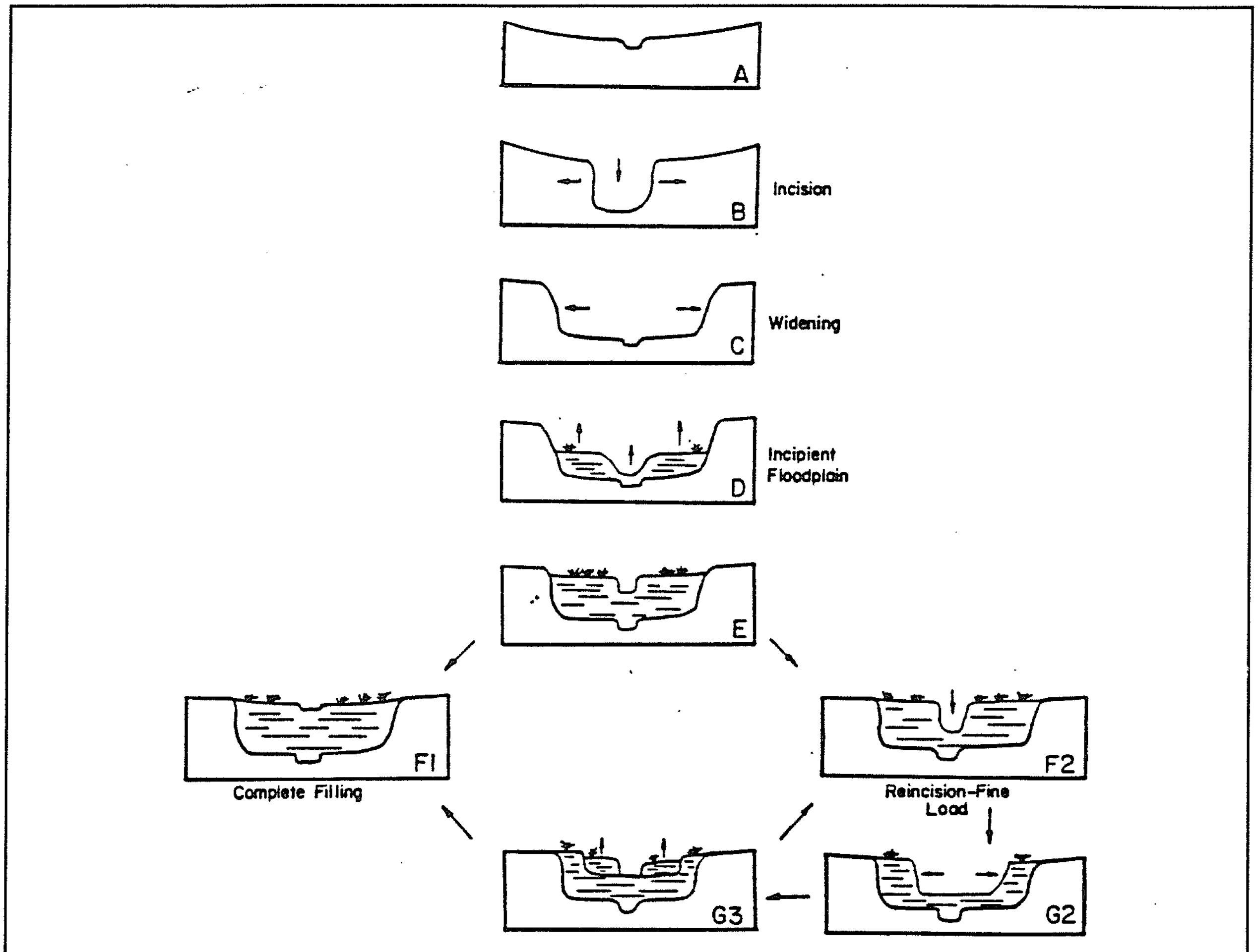


**Figure 17.** Arroyo evolution: stages A through G can represent changes at a cross-section through time or changes from the lower reaches to the upper reaches of the watershed at any point in time (Gellis 1988).

pling began at the Rio Puerco near Bernardo in 1948. Since 1948 suspended sediment loads have been decreasing relative to runoff (Figs. 2-13). Other suspended sediment records on the Rio Puerco are available at various times for the Arroyo Chico near Guadalupe and Rio Puerco above Arroyo Chico (Figs. 18,19). Although the suspended sediment records for these two stations are interrupted, there is a decrease in the mean of the annual suspended sediment concentrations for the two periods (Figs. 18,19).

Elliott (1979) documented arroyo changes in the Rio Puerco through time and through the watershed. The decreased suspended sediment loads measured at stations in the Rio Puerco watershed are probably a result of these channel changes. Similar channel changes and decreased suspended sediment loads were observed in arroyos draining northern Arizona in the Colorado River basin (Gellis and others 1991). If other arroyos in New Mexico are evolving like the Rio Puerco and northern Arizona washes, then a regional decrease in suspended sediment loads can be assumed.

## CONCLUSION

Six streamflow-gaging stations in New Mexico:

- Rio Grande at Otowi Bridge
- Rio Puerco near Bernardo
- Rio Grande at San Marcial
- Pecos River near Artesia
- Rio Penasco at Dayton
- Animas River at Farmington

were tested for decreasing trends in suspended sediment loads relative to annual runoff. At all stations a negative slope for the best-fit regression line of annual suspended sediment concentration was observed. At four of the stations tested, the

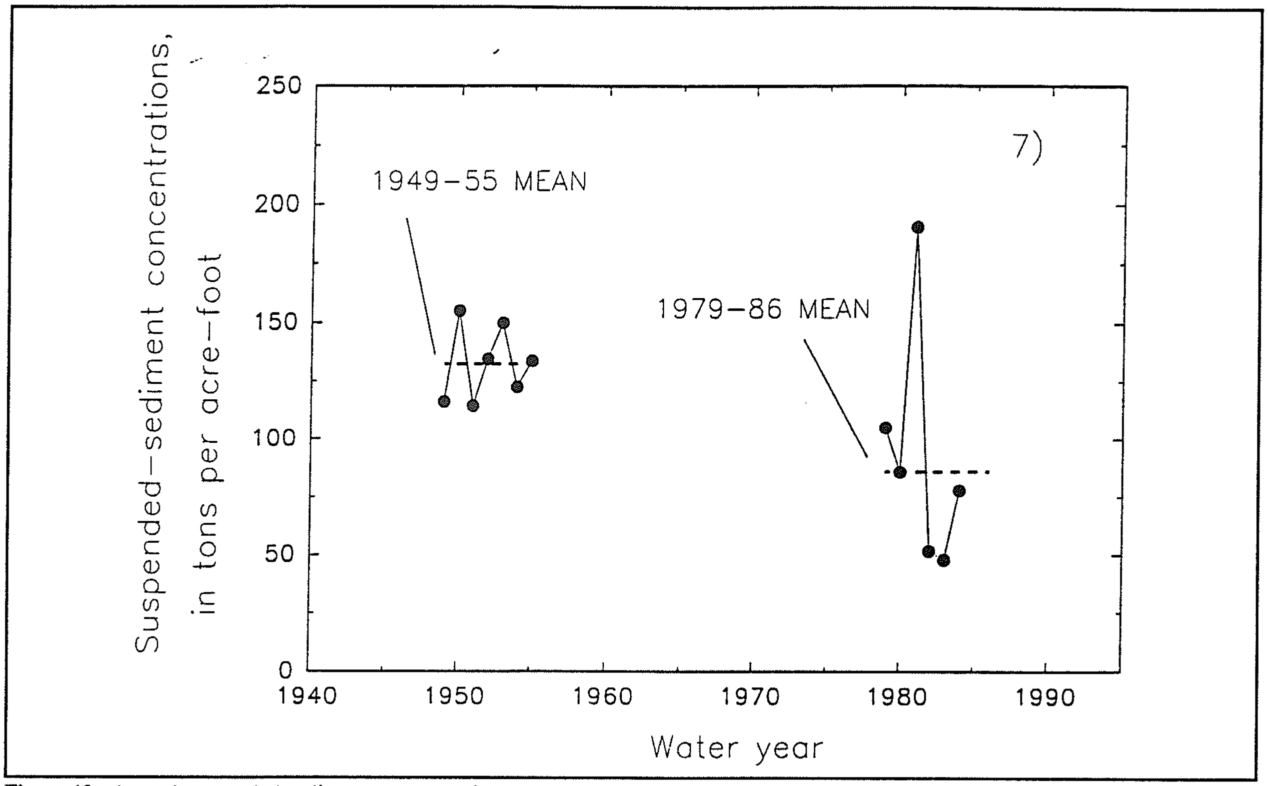


**Figure 18.** Annual suspended sediment concentrations and means through time for Arroyo Chico near Guadalupe station.

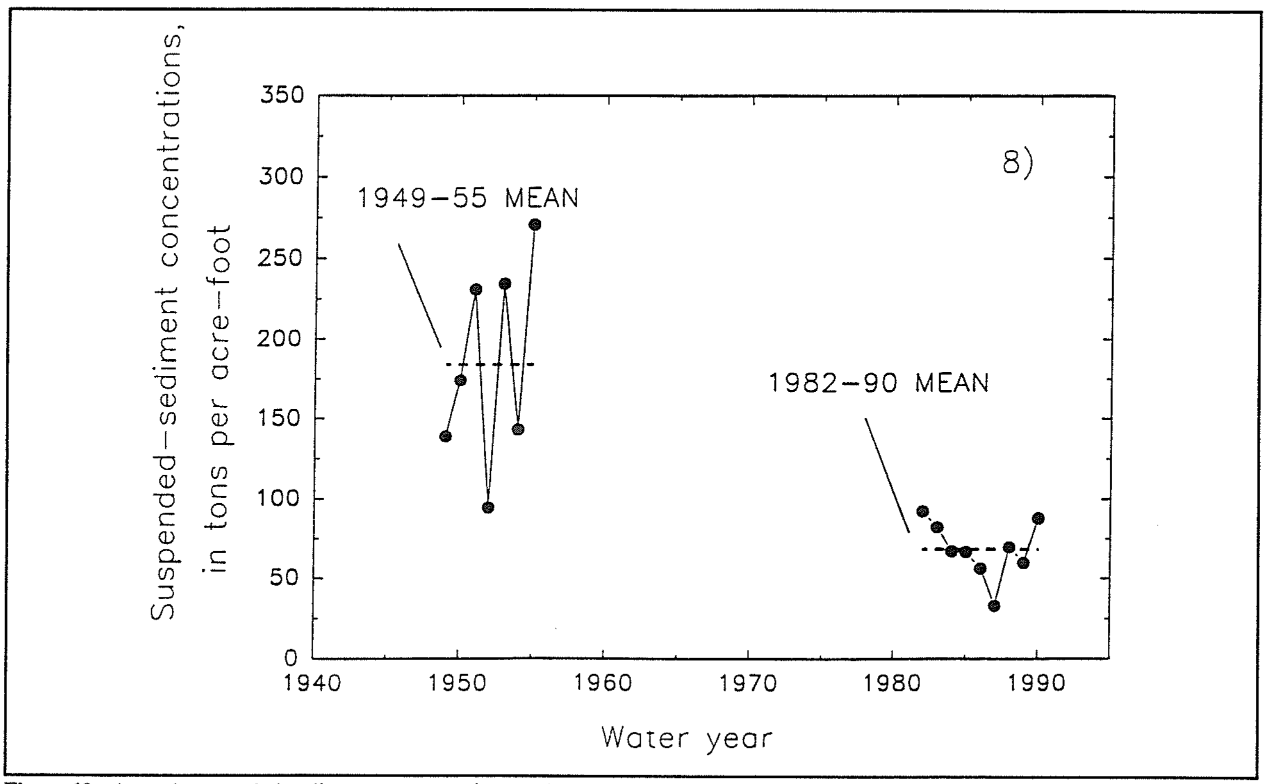


**Figure 19.** Annual suspended sediment concentrations and means through time for Rio Puerco above Arroyo Chico station.

hypotheses that fluctuations in the data are not random and that the data indicate a significant decreasing trend were supported by statistical analysis. Sediment surveys of Elephant Butte Reservoir, Lake Sumner, and McMillan Reservoir support the hypothesis of decreasing trends by showing an overall decrease in the annual amount of sediment deposited by runoff through time.

The hypothesis that reservoir closures and changes in sediment samplers affected the suspended sediment concentrations at these stations is probably not valid solely on the basis of the analysis of double-mass curves. The observed decrease in sediment loads may be due to the reduction in sediment delivery from tributary arroyos.

Arroyos that delivered vast quantities of sediment in the beginning of this century, as a result of incision and gullying, have been aggrading and delivering less sediment to the main channels. Field studies in selected arroyos of the Southwest indicate that channel aggradation follows a generalized channel geometry development through time called arroyo evolution. Coinciding with arroyo evolution is a decrease in sediment delivery through time. Annual suspended sediment loads in the Rio Puerco, a major sediment-producing arroyo, support this decrease through time and can be considered to reflect similar conditions for other arroyos in New Mexico and the Southwest. Therefore, the decreased suspended sediment loads measured at streamflow-gaging stations and the decreased sedimentation rates in selected reservoirs of New Mexico are at least in part due to the decrease in sediment from tributary arroyos.

Studies have shown that arroyos are aggrading and that sediment production is decreasing. This condition might be of interest to agencies involved in erosion control. By examining changes in channel behavior throughout the watershed, land managers and conservationists might be able to evaluate times and locations in the arroyo evolutionary cycle so that erosion controls could be used effectively.

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# WATER QUALITY IN THE RIO COSTILLA WATERSHED: MULTIPLE AGENCIES, MULTIPLYING PROBLEMS

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## INTRODUCTION

The Rio Costilla watershed includes over 180,000 acres in northern Taos County near the Colorado-New Mexico border. Rio Costilla originates in the Sangre de Cristo mountains of Colorado at an elevation of over 11,000 feet, passes southward through New Mexico, turns north into Colorado and joins the Rio Grande in Colorado at an elevation of less than 7,500 feet. Vegetation types range from mountain wet meadow and spruce-fir to sage brush and piñon-juniper. Tributaries include Casias Creek, Powderhouse Creek, Comanche Creek, Latir Creek, Cordova Creek, and Ute Creek.

Within the watershed are the communities of Costilla and Amalia, part of the Vermejo Ranch, the Rio Costilla Cooperative Livestock Association properties, Ski Rio, and the Valle Vidal Unit of the Carson National Forest. The Rio Costilla plays a role in each of these group's economies and day-to-day operations. Each, in turn, influences water quality in the Rio Costilla and its tributaries.

As a perennial tributary of the Rio Grande in Taos County, the Rio Costilla and its tributaries are part of Stream Segment 2-120, designated by the New Mexico Water Quality Control Commission. The commission has assigned the designated uses of high quality coldwater fishery, secondary contact recreation, domestic water supply, irrigated agriculture, and livestock and wildlife watering to segment 2-120. These uses of the Rio Costilla play a vital role in the well-being of area residents and the state as a whole. Currently, the uses of Costilla Creek are significantly impaired by non-point source (NPS) pollution.[1]

The New Mexico Environment Department has recently received a grant under the NPS program of the federal Clean Water Act for a 5-year effort to monitor NPS control efforts and their effectiveness in the Rio Costilla watershed. We have been working with the Forest Service for some time on the Comanche Creek project. As the state begins to expand its efforts in this watershed, we felt this conference was a good place to present the program. As this project develops there will indeed be "many agencies working for the future."

### The NPS Program: A Need for Cooperation between Agencies

The New Mexico Environment Department's activities in the Rio Costilla watershed are part of the New Mexico NPS Management Program adopted by the Water Quality Control Commission in response to Section 319 of the federal Clean Water Act. The goal of the Clean Water Act is to restore the physical, chemical and biological integrity of the nation's waters. Section 319, enacted in 1987, required states to assess NPS impacts on water quality and implement a management program to address those impacts. In New Mexico, over 98 percent of known surface water pollution is due to NPS impacts, while approximately half of New Mexico's streams are significantly affected. New Mexico's management program has a statewide component and a component focusing on targeted watersheds. Both components of the NPS management program rely heavily on multi-agency cooperation and voluntary implementation of Best Management Practices (BMPs) to control NPS impacts on water quality. Comanche Creek and Costilla Creek watersheds have been targeted under the NPS management program.

You may ask, as many in the Costilla Creek watershed have asked, "Why Costilla Creek?" First, in the Valle Vidal Unit of the Carson National Forest, the U.S. Forest Service is implementing several watershed improvement projects. These provide us with on-the-ground implementation of NPS controls so that we can study their effectiveness in a New Mexico situation. The state is receiving excellent cooperation from the Forest Service. In addition to the Forest Service, the Taos County Soil and Water Conservation District is interested in participating in the NPS management program, so we have an agency working with private landowners in the watershed. Finally, we felt that with cooperation from the Forest Service and the Taos County Soil and Water Conservation District, the NPS problems presented in the Costilla Creek watershed appeared to be problems that could begin to be addressed during one person's career. Most NPS problems in the Rio Costilla are related to erosion and sedimentation—we are not dealing with a stream that is so far gone that being able to document recovery could be impossible for decades. The state may be able to use Rio Costilla to document how a voluntary NPS control program can be implemented and how water quality can be improved.

**Water Quality Issues in the Costilla Creek Watershed**

Table 1 lists water quality sampling stations in the Costilla Creek watershed utilized by the Environment Department. Over the last decade, the state has documented that Costilla Creek, Comanche Creek, and Cordova Creek are impaired by NPS pollution.[2] The designated fishery, domestic water supply use, irrigation use and secondary contact recreation use of Costilla Creek are impaired by metals, siltation, nutrient enrichment (total phosphorus and nitrogen), un-ionized ammonia, streambank destabilization and loss of riparian vegetation. Comanche Creek is impaired by pH, high temperatures, turbidity, siltation, un-ionized ammonia, reduction of riparian vegetation and streambank destabilization. Cordova Creek is impaired by siltation, nutrients, turbidity and metals. We have very little data for Powderhouse and Latir creeks but believe, in general, NPS impacts are less on these streams.

TABLE 1. WATER QUALITY MONITORING STATIONS IN THE RIO COSTILLA WATERSHED USED BY NMED.

| |
|---|
| Rio Costilla at USGS Gage above the Village of Costilla |
| Rio Costilla below Latir Creek |
| Rio Costilla above Latir Creek |
| Latir Creek above Rio Costilla |
| Rio Costilla at lower Valle Vidal boundary |
| Rio Costilla below Comanche Creek |
| Rio Costilla above Comanche Creek |
| Comanche Creek above Rio Costilla |
| Comanche Creek at cattle guard 3 mi. above Rio Costilla |
| Comanche Creek below revetment 4 mi. above Rio Costilla |
| Comanche Creek below upper exclosure |
| Comanche Creek above upper exclosure 4.5 mi. above Rio Costilla |
| Comanche Creed above Foreman Creek confluence |
| Rio Costilla at upper Valle Vidal boundary |

**Sources of Water Quality Impairment**

Water quality in the Rio Costilla watershed is impacted by several non-point sources. These include grazing, hydromodification, roads, recreational development, irrigated agriculture and wastewater disposal through septic systems. Except for on-site liquid waste systems, the major impacts caused by these sources are destruction of riparian and stream habitat, streambank destabilization and sedimentation caused by erosion. The sediment inputs result from water quality standards violations discussed earlier.

Historically, grazing has been a significant source of NPS impacts. Many reaches of the Rio Costilla and Comanche Creek exhibit the destabilized banks, downcutting and changes in channel morphology that occur when cattle grazing is not properly managed. In the Valle Vidal, an additional factor may be grazing impacts associated with wild ungulates, primarily elk.

Road runoff and road maintenance and construction are major influences on water quality in the watershed. The most dramatic example of water quality impairment from road building in the Rio Costilla watershed is State Road 196 along Cordova Creek. The construction of this high standard road resulted in the filling of the original stream channel and the dredging of an unstable ditch into which this trout stream was diverted. This diversion has resulted in the elimination of the historical biota, massive sediment transport, slope and road destabilization and impairments of downstream waters. Comanche Creek and Costilla Creek are also negatively impacted by roads.

Recreation is having an impact in certain areas. Most recreation impacts relate to roads and vehicles and from eroding ski slopes at Ski Rio.

Above Amalia, flows are diverted for irrigated agriculture. Water quality impacts from irrigated agriculture return flows have not been extensively studied in the watershed. It has been documented that return flows are significantly warmer and more turbid than in the receiving waters. Other identified impacts from irrigated agriculture relate to hydromodification.

Some of the most dramatic water quality impairment in the Rio Costilla occurred as a result of the Costilla Dam rehabilitation project. Failure to contain sediment during construction and dam drawdown resulted in extreme violations of water quality standards. On August 29, 1989 the Environment Department measured turbidity at 200 nephelometric units (NTU), over 800 percent of the state standard of 25 NTU. Total phosphorus concentrations were 0.66 mg/l and 0.76 mg/l or 660 percent and 760 percent of the state water quality standard for phosphorus. Sediment deposition occurred throughout the reach on stream bottoms and banks and dead fish were noted on the streambank.

In September, 1988 and in April, May, August, September and October of 1989 water quality standards were repeatedly violated according to monitoring data collected by the Interstate Steam Commission. Fully 36 percent of reported values exceeded state standards in a reach never known previously to exceed the state standard.[3] Study of aquatic macroinvertebrates during the project documented a 90 percent reduction in standing crop of those organisms below the dam which form the prey base for fish.

**Water Quality Protection Programs**

Stream ecosystems can recover from the effects of NPS pollution. First, however, the pollution must be controlled. The state's NPS management program seeks control of NPS pollution through voluntary implementation of Best Management Practices. Success in the Rio Costilla watershed project will require the cooperative efforts, at a minimum, of the U.S. Forest Service, the U.S. Soil Conservation Service, the U.S. Agricultural Conservation and Stabilization Service, the U.S. Environmental Protection Agency, the U.S. Federal Deposit Insurance Corporation, the New Mexico Environment Department, the Interstate Stream Commission, the New Mexico State Highway and Transportation Department, the Taos County Soil and Water Conservation District, and private citizens living in Amalia and Costilla or owning land in the watershed. Again, our goal is to demonstrate that a voluntary approach will work to control NPS pollution.

The Forest Service has undertaken numerous activities to control NPS pollution in the Valle Vidal. These include road closings, vehicle access control, installation of erosion control and fish habitat improvement structures, exclosures to stop cattle and elk impacts at selected sites, revegetation of cut-and-fill slopes along roads, removal of cattle from much of the unit and closer management of remaining cattle, and planting riparian plants. Due to these activities, many of the incised banks in the upper Comanche Creek area show evidence of natural healing.

The Forest Service is planning road work along Costilla Creek to accommodate the area's increase in recreational use. Working through the new management agency agreement with the Environment Department, the Forest Service should be able to carry out the road improvement project without damage to water quality.

The Taos County Soil and Water Conservation District has initiated an inventory of NPS problems on private lands within the watershed using monies passed through the Environment Department from the U.S. Environmental Protection Agency. In addition to creating an inventory of NPS problems, the district hopes to increase public awareness of water pollution problems and the methods available to correct such problems so that public support for the district in implementing NPS control plans will increase. The district has committed to provide over $100,000 each year to carry out a natural resource conservation program in Taos County, including the Rio Costilla watershed. With 75 percent of the watershed privately owned, the work of the Soil and Water Conservation District and cooperating landowners will be essential to realizing progress in achieving water quality goals. As the watershed project proceeds, the U.S. Soil Conservation Service and Agricultural Stabilization Service will be involved in helping to plan and cost-share implementation of BMPs for NPS control.

Several other entities will play a role in the watershed. The Interstate Stream Commission (ISC) will be involved with operation of the Costilla Dam now that rehabilitation work is in its final stages. The ISC has committed to assisting in mitigation for habitat damage done during the rehabilitation project. The agency may also play a role in helping to fund certain BMPs if they relate to use of water in irrigation.

The State Highway and Transportation Department has responsibility for State Highway 196 along Cordova Creek. This area will require intensive actions to stabilize the stream.

Interestingly, the federal government now owns Ski Rio, as a casualty of the Savings and Loan crisis. The Taos County Soil and Water Conservation District has already informed Ski Rio that eroding ski slopes are a potential NPS of pollution in the watershed. While the federal government owns these properties, provisions in the federal Clean Water Act (e.g., section 313) requires it to manage the facility in a manner which insures attainment of the state's water quality standards.

The Environment Department will work with all these entities to coordinate activities and make sure the state is demonstrating progress in the NPS management program. Water quality monitoring will be conducted during all seasons for at least five years. Monitoring will occur upstream and downstream of locations in which BMPs are being implemented. The monitoring should identify success stories and assist in program refinement.

Environment Department monitoring in the Costilla Creek watershed will also address biological and physical measurements of water quality. While we continue to sample for chemical constituents such as nutrients, metals and pH, the department will also be conducting surveys of riparian and stream habitat conditions and using methods that will give an indication of how the biological components of the stream system are responding to NPS controls. The impacts of flow manipulation on fishery habitat in the stream also will be investigated.

**SUMMARY**

The Rio Costilla, impaired by various NPS impacts, can meet the goals of the Clean Water Act if the many agencies and individuals with a stake in the stream make water quality a priority and cooperation and coordination a reality. Streams can recover, if the damage is halted and repaired. Too often, actions by various agencies have actually aggravated NPS problems.

Many believe a voluntary approach to containing NPS pollution will not work. We hope that it will. Certainly, the citizens and the U.S. Congress will insist that progress be made either by voluntary action or through regulation. Senator David Durenberger summarized Congress' position on using a voluntary approach to control NPS pollution of the nation's waters in an address to the Senate Subcommittee on Environmental Protection, of the Committee on Environment and Public Works, in July, 1991:

> "Has section 319 improved water quality by controlling non-point source pollution? There is absolutely no evidence that it has. Some will discount the

lessons we should draw from the 319 experience. Some will say it was never funded and that a large commitment of federal dollars will turn the corner on the problem. Some will say that the new Coastal Zone Management amendments will provide the tools to make it work. Some will say that another round of voluntary programs based on the 1990 farm bill should be given a chance.

Well, all of that speculation on what might be should not obscure the lesson to be learned. Section 319 has not improved water quality one iota. And I told you it wouldn't way back when.

We have had any number of voluntary planning programs since the founding of the Soil Conservation Service in 1935. We have spent more than $30 billion on voluntary cost share programs and water quality planning over that 50-year history only to find today that non-point source pollution, principally from agriculture, remains our biggest water quality problem.

So what do we do now? My recommendation would be that we go back to the fundamentals of the Clean Water Act. We need criteria documents that focus on the non-point problem. We need state standards and monitoring programs that are intended to measure non-point, rather than point source, impacts. We need watershed plans under Section 303 (the Total Maximum Daily Load section-ED) that carefully define the load reductions necessary to meet water quality standards. We need enforceable requirements applicable to private business entities and municipal activities that are polluting the waters that belong to all of the people of the United States.

...We can't just throw away the fundamental tools of the Clean Water Act and expect to solve the non-point problem. We don't need a new program of a different approach. We just need a commitment to carry out the requirement of the Clean Water Act for all sources of pollution.

'Publish' and 'promulgate' and 'fund' are not the verbs that are going to solve the non-point problem. We need to 'monitor', 'identify', 'allocate', 'specify', 'implement', and 'enforce' if we are to solve this problem. The solutions are site-specific, water quality-related and in need of constant maintenance and adjustment. If we still don't have the political will to carry out that kind of effort, we ought to just acknowledge it and put our scarce resource into some other human problem more easily solved".[4]

The New Mexico Environment Department is not quite ready to give up on the voluntary approach. We do believe, however, that Congress and the American public will not walk away from the goals of the Clean Water Act. There is the political will, we believe, to assure attainment of Clean Water Act goals. The Rio Costilla watershed project provides New Mexicans with an excellent opportunity to demonstrate we are serious about cleaning up water and know how to do it. There are multiple agencies, there are multiple problems. But there are also multiple opportunities for success.

**ENDNOTES**

1. New Mexico Water Quality Control Commission. 1990. Water quality and water pollution control in New Mexico, 1990. NMWQCC, Santa Fe, NM.
2. Ibid.
3. 1 December 1989 letter from Kathleen Sisneros, NMED to Steve Dougan, U.S. Army Corps of Engineers.
4. EPA News Notes. September 1991. No. 15, pp 7-8.

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# SEWAGE SLUDGE APPLICATION IN SEMIARID GRASSLANDS: EFFECTS ON RUNOFF AND SURFACE WATER QUALITY

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## INTRODUCTION

Approximately 6 million metric tons of municipal sewage sludge are produced annually in the United States alone (U.S. Environmental Protection Agency 1990). In many large urban areas of the Southwest, including the city of Albuquerque, New Mexico, liquid waste is processed in a sewage treatment plant. This process greatly improves the quality of effluent leaving the plant, but disposal of the solid, sewage sludge-extracted wastes remains a problem. Presently, Albuquerque's sewage sludge is applied over large acreages of rangeland set aside specifically for disposal purposes and tilled into the subsoil. Safe, economically feasible disposal of the sludge, not rehabilitation of the rangeland affected, is the city's main objective.

A primary concern limiting the use of sludge as a soil amendment is the potential introduction of contaminants into the environment, including surface and groundwater resources. Yet sewage sludge has been successfully used as a fertilizer and mulch for agricultural purposes (Berglund et al. 1984; Catroux et al. 1981) and in mined land reclamation efforts (Sopper and Kerr 1979). Recently, a pioneering study has shown that degraded rangeland responds favorably to the application of sewage sludge as a fertilizer and organic matter amendment (Fresquez et al. 1990a). The results of this preliminary study further showed that a one-time surface application of 22.5 to 45.0 Mg $ha^{-1}$ (10-20 tons/acre) of anaerobically digested sewage sludge did not lead to contamination of soil or plant tissue (Fresquez et al. 1990b, 1991).

Runoff and erosion on hillslopes increase with decreasing vegetative cover and increasing slope gradient. Both factors are recognized as important parameters in existing erosion prediction equations and models (Wischmeier and Smith 1978; Alberts et al. 1989; Hernandez et al. 1989). Vegetative cover disrupts overland flow on hillslopes and promotes greater infiltration while reducing runoff.

Much of the southwestern rangelands experienced heavy livestock grazing over the past century, leading to a substantial reduction in total plant cover and density (Dortignac and Hickey 1963). Thus, any successful attempt at increasing vegetative cover (canopy cover, canopy height, and residue or litter cover) in New Mexico rangeland should lead to reduced runoff and sediment yields.

Rogers and Schumm (1991) conducted an experimental study on changes in runoff and sediment yield resulting from changing vegetative cover from 43% to 0% on a 10% slope. Their data showed that sediment yield increased as vegetative cover was decreased from 43% to 15%, but below 15%, further reduction in vegetative cover did not increase sediment yield appreciably. We believe applying sewage sludge to New Mexico rangeland will reduce erosion from hillslopes because favorable vegetative response (increased biomass production, basal and canopy cover) will increase surface roughness and soil stability. These factors in turn should lead to reduced runoff on degraded rangeland.

The specific objectives of our research were: 1) to evaluate differences in runoff yield induced by natural and simulated rainfall in sludge-amended (treated) and unamended (control) plots in a semiarid grassland, and 2) to determine the extent of transfer of potential sludge-borne contaminants within the immediate area of sludge application by surface runoff.

This paper reports the differences in runoff quantity and runoff water quality measured on rangeland treated with sewage sludge and untreated rangeland during the initial growing season following sludge application. Continued research at the site will address the changes in soil properties and vegetation induced by the sludge treatment and the subsequent effects of these changes on surface hydrology.

## STUDY SITE DESCRIPTION

The study was established on a sloping alluvial fan located within the Sevilleta National Wildlife Refuge (Fig. 1). The refuge, managed by the U.S.D.I. Fish and Wildlife Service, provides an excellent opportunity to compare treatment effects within rangeland because the area is completely fenced off, public access is restricted, and livestock grazing is prohibited.

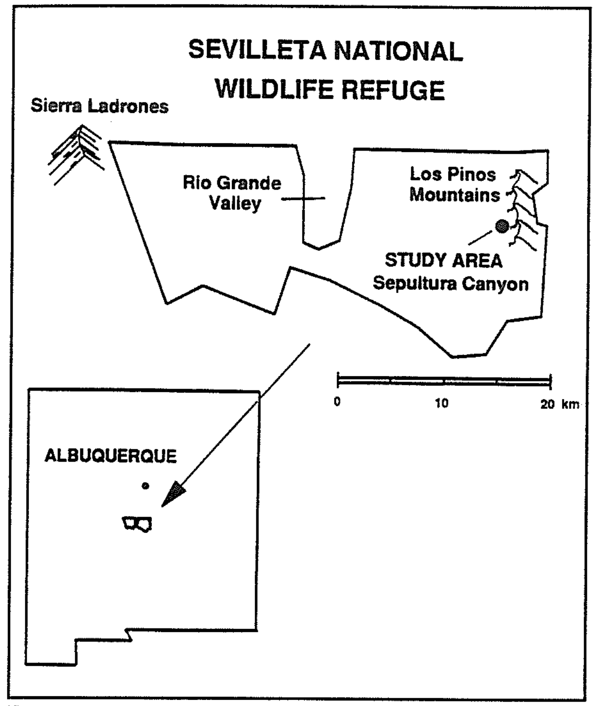


**Figure 1.** Location of the sludge application study within the Sevilleta National Wildlife Refuge.

Climate at the Sevilleta National Wildlife Refuge is arid to semiarid with mean annual precipitation ranging from 200 to 250 mm (personal communication, Doug Moore, Research Associate, Dept. of Biology, University of New Mexico, Sevilleta Refuge LTER Meteorological Investigations). Summers are relatively hot and winters are cool. Vegetation within the refuge is dominated by semiarid grassland and shrubland at low elevations in the Rio Grande Valley. Pinyon-juniper stands dominate the vegetation at high elevations.

The soils at the study site have been mapped as components of the Harvey-Dean association, 1%-9% slopes (U.S.D.A. Soil Conservation Service 1988). The Harvey and Dean soils are both deep and well drained. The Harvey soil is classified as fine-loamy, mixed, mesic Ustollic Calciorthid; the Dean soil is classified as fine-loamy, carbonatic, mesic Ustollic Calciorthid. The soils are formed in alluvium and colluvium derived primarily from limestone, and both have been strongly influenced by eolian processes. Surface soil textures range from gravelly fine sandy loam to very fine sandy loam. Subsoil horizons range in texture from sandy clay loam to gravelly loam.

## STUDY DESIGN

Within the Sevilleta Refuge, a blue grama/hairy grama (*Bouteloua gracilis/B. hirsuta*) dominated community was selected for study on both a moderately sloping and strongly sloping component of a stable alluvial fan. The site is located along the flanks of the Los Pinos Mountains at the mouth of Sepultura Canyon (Fig. 1). Three pairs of runoff plots, each consisting of a treated (sludge-amended) and a control (no sludge) plot, 10-m long and 3-m wide, were established within each of the slope gradient classes (Fig. 2). The three paired plots established at the lower component of the landscape (6% slope gradient) were designated as 1L-T (for treated or sludge-amended) and 1L-C (for control), 2L-T and 2L-C, and 3L-T and 3L-C. The three paired plots located in the upper (high) portion of the study area (10%-11% slope gradient) were designated as plots 1H-T and 1H-C, 2H-T and 2H-C, and 3H-T and 3H-C.

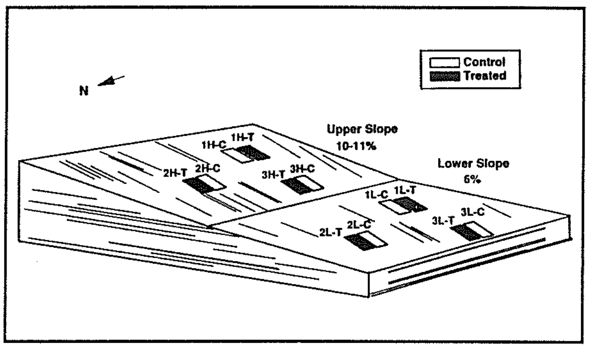


**Figure 2.** Experimental layout of sewage sludge-amended plots (treated) and unamended (control) plots within two landscape components at the Sevilleta Refuge study site. (not to scale)

The sludge treatment, applied in early April 1991, consisted of a one-time surface amendment of 45 Mg $ha^{-1}$ (20 t $acre^{-1}$ on an oven-dry basis) of municipal sewage sludge provided by the City of Albuquerque. The City's anaerobically digested and mechanically de-watered sewage sludge, at approximately 17% dry solids (82.5% water), is gelatinous and thus relatively easy to transport and handle.

The plots were bordered by 15-cm (6-inch) aluminum flashing to exclude external runoff. Runoff within the borders was collected in reservoirs (galvanized steel livestock tanks, 1800-liter capacity) buried at the base of the plots. The tanks were positioned with a 1% drop in slope across the base of the plot to facilitate water measurements and sampling following small runoff events. Soil was back-filled and tamped around each tank. Gaps between plot boundaries and tank edges were lined with concrete to prevent leakage and loss of runoff water. Each tank was calibrated by recording the level of water in the tank at each sequential addition of a known amount of water. Water-sealed plywood lids were placed over the tanks to prevent direct precipitation into the tanks and minimize evaporation following rainfall events.

Total precipitation occurring during summer storms was measured with two standard rain gauges (rainfall collection buckets). Additionally, a self-activating recording rain gauge was installed at the site on August 1, 1991, allowing measurements of storm intensity (mm $hr^{-1}$) for subsequent events.

A large rainfall simulator was used in September 1991 to allow observations of response to high-intensity rainfall under controlled conditions (Ward 1986). The rainfall simulator consisted of 15 sprinklers mounted on 3-m standpipes. The simulator distributed water simultaneously to each plot in a pair so infiltration and runoff yield could be observed and recorded on the two plots concurrently.

We evaluated the sludge's water absorption capability during the rainfall simulation by placing 30 g to 50 g of air-dry sludge on five 30-$cm^2$ screen mesh platforms located along the plot boundaries; the samples received the same amount of precipitation as the plots. The samples were collected immediately after the rainfall simulation runs and placed in airtight tin containers. Five additional sludge samples were collected before rainfall simulation to assess the field moisture content of the sludge prior to wetting.

Samples of runoff water, obtained after stirring the contents in the collection reservoirs to uniformity, were collected in acid-washed plastic bottles after each major rainfall event and immediately following each rainfall simulation run. The samples were then transported to the lab in an ice chest for subsequent nitrate and metal analyses. Samples tested for nitrate were preserved with concentrated sulfuric acid (2.0 ml $H_2SO_4$ per liter of water sample) and those tested for metal concentrations were preserved with concentrated nitric acid (5.0 ml

$HNO_3^-$ per liter of water sample). All water samples were analyzed within 28 days after collection.

Nitrate in water samples was determined by flow injection analysis according to the colorimetric Cd-reduction method (APHA 1985). Concentrations of Cu, Cd, and Pb were determined by inductively coupled plasma emission spectroscopy (ICP).

Repeated measures analysis of variance was used to compare observed differences in runoff yield, nitrate levels, and trace element concentrations in the runoff water between slope gradients and between treated and control plots. Paired treated and control plots were designated as repeated measures (to incorporate the pairing structure into the analysis) and slope gradient was treated as an analysis of variance factor. A Type I error $\alpha$ = 0.1 was adopted for all analyses.

## RESULTS AND DISCUSSION

### Runoff Produced by Natural Storms

We recorded runoff from four natural storm events of high intensity during July and August 1991 (Table 1). Storm duration measurements for July are not available because self-activating recording rain gauges had not yet been installed. Quantities of runoff generated from the study plots during the four natural storm events are also shown in Table 1.

Table 1. Natural storm characteristics and runoff yields at the Sevilleta National Wildlife Refuge sludge study area, 1991.

| Storm date | July 22 | July 25 | Aug 2 | Aug 10 |
|---|---|---|---|---|
| Storm Characteristics: | | | | |
| Total Precipitation (mm) | 12.7 | 9.7 | 18.5 | 12.7 |
| Storm duration (min) | -- | -- | 120.0 | 30.0 |
| Storm intensity (mm $hr^{-1}$) | -- | -- | 9.3 | 25.4 |
| Plot | Runoff yield (mm) | | | |
| 1L-C | 0.09 | 0.45 | 0.37 | 1.12 |
| 1L-T | 0.00 | 0.00 | 0.00 | 0.00 |
| 2L-C | 0.00 | 0.19 | 0.02 | 0.93 |
| 2L-T | 0.00 | 0.07 | 0.02 | 0.03 |
| 3L-C | 0.04 | 0.45 | 0.09 | 0.43 |
| 3L-T | 0.00 | 0.02 | 0.04 | 0.04 |
| 1H-C | 0.02 | 1.12 | 0.12 | 0.71 |
| 1H-T | 0.00 | 0.53 | 0.00 | 0.00 |
| 2H-C | 0.00 | 0.73 | 0.06 | 0.48 |
| 2H-T | 0.00 | 0.41 | 0.00 | 0.05 |
| 3H-C | 0.08 | 0.99 | 0.21 | 0.80 |
| 3H-T | 0.01 | 0.12 | 0.00 | 0.00 |

An analysis of variance comparing runoff yields among plot pairs using slope gradient as the variable found no significant differences ($p \geq 0.1$) based on slope class, except for the July 25 storm (Table 2). However, comparison between treated and control plots clearly shows the sludge's effectiveness in reducing runoff.

Differences in runoff yield among control plots within the two slope gradients were attributed to differences in resistance to surface water flow brought about by microtopographical variation and differences in plant cover. The major factor responsible for the reduced runoff in the sludge-amended plots was apparently an increase in surface roughness. This increased surface roughness greatly reduced surface water flow and likely enhanced infiltration.

Mean runoff yield on control and treated plots for the four natural storm events are plotted in Figure 3. The control and treated plots were significantly different at $p < 0.05$ for all storms except the July 22 event, wherein the large variance among the six control plots reduced the significance level to $p = 0.09$.

Differences in runoff yield among the four natural storms were attributed primarily to variations in storm intensity. Mean runoff yield from the control plots during the August 10 storm was more than five times greater than that produced during the August 2 storm (Fig. 3), yet the August 2 storm was higher in total precipitation (Table 1). The sludge's effectiveness at reducing runoff is evident here in that the difference in mean runoff from the treated plots was only two times greater during the August 10 storm than during the August 2 storm (Fig. 3).

Antecedent soil moisture contents highly influence infiltration and runoff yield, and this factor is likely responsible for the greater quantity of runoff from the treated plots on July 25; this storm was preceded by 27.9 mm of rainfall on July 21 and 12.7 mm precipitation on July 22. Unlike conditions prior to the other three natural storms, the sludge on the treated plots may have been fairly moist upon the onset of the July 25 event; thus, runoff from the sludge-amended plots was appreciably higher during this storm.

### Runoff Produced by Rainfall Simulation

Total precipitation inputs and intensities for the rainfall simulation experiments were much

Table 2. Means and variance for the 1991 natural storm runoff yields from the three upper (10%-11% slope) and three lower (6% slope) landscape segments of the sludge application study site.

| Storm | Slope Segment | Mean Runoff (mm) | SD | SE |
|---|---|---|---|---|
| Control plots: | | | | |
| July 22 | Low | 0.043a[1] | 0.045 | 0.026 |
| | High | 0.033a | 0.416 | 0.024 |
| July 25 | Low | 0.363a | 0.150 | 0.087 |
| | High | 0.947b | 0.199 | 0.115 |
| Aug. 2 | Low | 0.160a | 0.185 | 0.107 |
| | High | 0.130a | 0.076 | 0.044 |
| Aug. 10 | Low | 0.827a | 0.356 | 0.206 |
| | High | 0.663a | 0.165 | 0.095 |
| Sludge-amended plots: | | | | |
| July 22 | Low | 0.000a | 0.000 | 0.000 |
| | High | 0.003a | 0.006 | 0.003 |
| July 25 | Low | 0.030a | 0.036 | 0.021 |
| | High | 0.353b | 0.211 | 0.122 |
| Aug. 2 | Low | 0.020a | 0.020 | 0.012 |
| | High | 0.000a | 0.000 | 0.000 |
| Aug. 10 | Low | 0.023a | 0.021 | 0.012 |
| | High | 0.017a | 0.029 | 0.017 |

[1]Paired means followed by same letter are not significantly different at the 0.10 level.

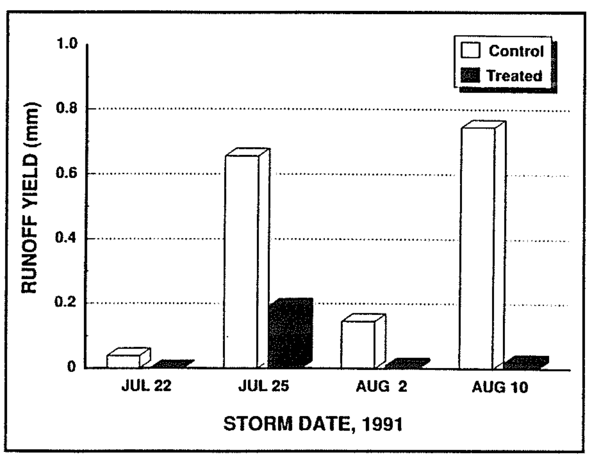


**Figure 3.** Mean runoff yield from all treated ($n = 6$) versus all control plots ($n = 6$) during four natural storm events in 1991. (Note: differences in mean runoff between control and treated plots were significant at $p < 0.05$ for all storms except the July 22 event, wherein $p = 0.09$).

higher than those for the natural storms because we wanted to evaluate the effects of the higher precipitation quantities and intensities that can commonly occur in this region (Table 3). Mechanical pump problems prevented application of similar amounts of rainfall over a 30-minute interval on all plots. Consequently, precipitation on plots 2H-C and 2H-T, though only slightly lower in total amount than that applied to other plots, was interrupted during the 30-minute simulation run. Simulated rainfall on plots 1H-C and 1H-T was terminated after 13 minutes. However, the data from these two rainfall simulation experiments, though not statistically comparable to the remaining trials, provide valuable information on plot response to intermittent rainfall and short-duration rainfall, respectively. Differences in total precipitation

Table 3. Precipitation input (Ppt.), storm duration, and runoff produced by rainfall simulation on sludge-amended (T) and unamended (C) plots in September, 1991. Ratio of runoff quantity (mm) to total precipitation input (mm) standardizes runoff yields among all plots.

| Plot No. | Ppt. Input (mm) | Duration (min.) | Runoff (mm) | Runoff/ppt. (mm/mm) | Runoff Yield % |
|---|---|---|---|---|---|
| 1L-C | 43.0 | 30 | 9.20 | 0.214 | 21.4 |
| 1L-T | 49.0 | 30 | 0.29 | 0.006 | 0.6 |
| 2L-C | 49.0 | 30 | 14.00 | 0.286 | 28.6 |
| 2L-T | 50.0 | 30 | 0.00 | 0.000 | 0.0 |
| 3L-C | 42.0 | 30 | 4.00 | 0.095 | 9.5 |
| 3L-T | 33.0 | 30 | 0.20 | 0.006 | 0.6 |
| 1H-C | 13.0 | 13 | 0.70 | 0.054 | 5.4 |
| 1H-T | 18.0 | 13 | 0.04 | 0.002 | 0.3 |
| 2H-C | 35.0 | 30 | 6.40 | 0.183 | 18.3 |
| 2H-T | 39.0 | 30 | 0.20 | 0.005 | 0.5 |
| 3H-C | 53.0 | 30 | 13.00 | 0.245 | 24.5 |
| 3H-T | 50.0 | 30 | 0.40 | 0.008 | 0.8 |

among and within the other paired plots treated with continuous 30-minute simulated rainfall were due to the presence or absence of wind gusts, their prevailing directions, and velocities.

Quantities of runoff generated from control plots during the rainfall simulation runs were generally an order of magnitude greater than the quantities generated during the natural storms. For example, the August 10 storm generated an average of 0.82-mm runoff in 30 minutes for plots 1L-C, 2L-C, 3L-C, and 3H-C (Table 1). Increasing precipitation three to four times (40 mm - 50 mm) over the same time period during the simulation runs resulted in an average of 10.0-mm runoff for these four plots (Table 3), indicating a nonlinear increase in runoff yield in relation to increased precipitation for the control plots.

Quantities of runoff generated during the rainfall simulation runs were divided by the total amount of precipitation input on each plot in order to calculate the quantity of runoff produced per millimeter of rainfall (Table 3). Expression of runoff yield per millimeter of rainfall standardizes runoff yields for comparison between plots (treated vs. control) and among plot pairs within a given slope class or across the entire landscape. A highly significant difference in runoff yield per millimeter of precipitation was observed between the six control and six treated plots (Fig. 4).

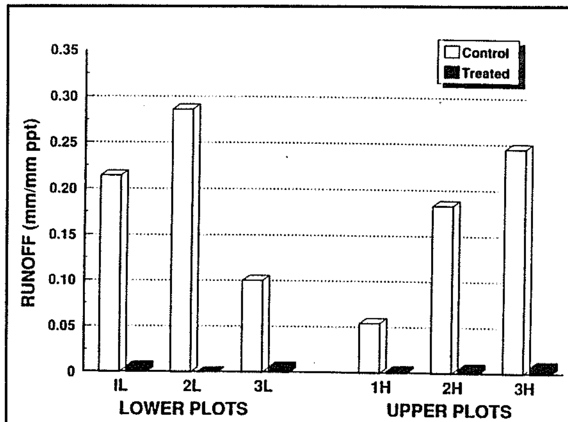


**Figure 4.** Runoff yield from sludge-amended (treated) and unamended (control) plots during rainfall simulation runs. Experession of runoff yield as runoff (mm) per millimeter of precipitation standardizes the runoff yields for comparison among plots because there were differences in total precipitation input among plot pairs and between paired plots. (Note: difference in runoff yield (mm runoff/mm precipitation) between treated ($n = 6$) and control ($n = 6$) plots was highly significant at $p = 0.005$.)

The proportion of total precipitation input lost as runoff from the control plots ranged from 5.4% for plot 1H-C to 28.6% for plot 2L-C (Table 3). As with natural rainfall, an increasingly higher proportion of runoff per unit quantity of precipitation can be expected from the control plots as precipitation is increased. In contrast, the proportion of the total precipitation input that was lost as runoff on sludge-amended plots remained below 1% for all simulation runs. The sludge appears to have reduced runoff yield to the extent that slight differences observed among the treated plots were independent of total precipitation input or storm duration (Table 3). The small differences in runoff yield (mm/mm ppt) among the treated plots were likely due to differences in microtopography and ground cover (Fig. 4).

**Water Absorption by Sludge**

Water absorption by sludge (Table 4) was also found to be a contributing factor to the reduced runoff from treated plots. Average increases in percent water in sludge samples were 83% and 105% for plots 1H-C and 1H-T and plots 2H-C and 2H-T, respectively. Using these average increases in

Table 4. Water absorption by sludge during rainfall simulation on plots 1H-C and 1H-T and plots 2H-C and 2H-T. Five samples of sludge at field moisture conditions were collected before (Pre-T) and after (T) the simulated rainfall to determine the percent water absorbed by the sludge.

| Sample | Rep. | Weight (g) Oven-dry | Wet | | Water(%) |
|---|---|---|---|---|---|
| Plots 1H-C and 1H-T (average precipitation for plot pair = 15 mm): | | | | | |
| Pre-T | 1 | 88.90 | 94.30 | | 6.07 |
| Pre-T | 2 | 107.27 | 113.79 | | 6.08 |
| Pre-T | 3 | 97.19 | 103.11 | | 6.09 |
| Pre-T | 4 | 90.85 | 96.42 | | 6.13 |
| Pre-T | 5 | 85.90 | 90.40 | | 6.24 |
| | | | | **Mean:** | **6.12** |
| T | 1 | 85.22 | 150.30 | | 76.37 |
| T | 2 | 65.95 | 122.68 | | 86.02 |
| T | 3 | 75.66 | 147.09 | | 94.41 |
| T | 4 | 67.81 | 129.31 | | 90.69 |
| T | 5 | 51.33 | 102.26 | | 99.22 |
| | | | | **Mean:** | **89.34** |
| Plots 2H-C and 2H-T (average precipitation for plot pair = 37.0 mm): | | | | | |
| Pre-T | 1 | 40.75 | 43.99 | | 7.95 |
| Pre-T | 2 | 76.33 | 82.22 | | 7.72 |
| Pre-T | 3 | 68.47 | 73.93 | | 7.97 |
| Pre-T | 4 | 67.92 | 73.17 | | 7.73 |
| Pre-T | 5 | 95.77 | 103.34 | | 7.90 |
| | | | | **Mean:** | **7.86** |
| T | 1 | 81.72 | 168.53 | | 106.23[1] |
| T | 2 | 69.66 | 147.62 | | 111.92 |
| T | 3 | 77.69 | 174.46 | | 124.56 |
| T | 4 | 79.31 | 171.96 | | 116.82 |
| T | 5 | 75.90 | 155.66 | | 105.09 |
| | | | | **Mean:** | **112.92** |

[1]Sludge water content can exceed 100% because the water is expressed as a percentage of the sludge's oven-dry weight and organic matter can readily hold 2-3 times its dry weight in water.

sludge water content, we estimated the portion of total plot precipitation absorbed by the sludge during the two rainfall simulation trials to be 13% and 25% for plots 2H-T and 1H-T, respectively. These relationships indicate retention of a larger proportion of total precipitation input by sludge during smaller rainfall events.

**Nitrate and Heavy Metal Concentrations in Runoff**

Nitrate concentrations in runoff water collected from natural storms and the simulated rainfall were consistently well below the recommended standard for groundwater or stream water supplies (Table 5). Current New Mexico standards consider ≥10 mg $l^{-1}$ nitrate discharge as unacceptable (New Mexico Water Quality Control Commission 1991a). The higher nitrate concentrations in runoff collected after rainfall simulation were likely due to external nitrate inputs and may have been associated with litter and/or sediment in the water supply tanks or rainfall simulation equipment such as hoses, standpipes, and sprinklers. No significant differences were found when comparing mean nitrate concentrations in the runoff from treated plots with nitrate concentrations in runoff collected from control plots after natural storms and rainfall simulations. These results indicate that the sewage sludge did not introduce significant nitrate levels to runoff water.

New Mexico standards for groundwater allow ≤ 0.01 mg $l^{-1}$ Cd and ≤ 1.0 mg $l^{-1}$ Cu (New Mexico Water Quality Control Commission 1991a) and ≤ 0.05 mg $l^{-1}$ Cd and ≤ 0.5 mg $l^{-1}$ Cu for livestock and wildlife watering (New Mexico Water Quality Control Commission 1991b). Cd and Cu in runoff were well below these standards, with the exception of the slightly elevated Cd concentration in runoff collected from Plot 1A High (control) after the July 25 storm (Table 6). However, we found no significant differences between mean Cd and Cu concentrations in the six treated versus control plots, indicating that Cd and Cu contamination to surface water runoff from the added sludge is not a concern.

We measured Pb concentrations exceeding current New Mexico standards for groundwater (0.05 mg $l^{-1}$) and livestock and wildlife watering (0.1 mg $l^{-1}$), but could not attribute such Pb levels to the sludge (Table 6). We found no significant difference between the Pb concentrations in runoff collected from the sludge-amended plots and the runoff from the control plots for any of the precipitation events, including the rainfall simulation. The elevated Pb levels in the runoff water may either be attributable to elevated Pb in the soils or to Pb solubilization from the galvanized steel runoff collection tanks.

Table 5. Nitrate concentrations (mg $l^{-1}$) in runoff water collected from sewage sludge-amended (T) versus unamended (C) plots at the Sevilleta National Wildlife Refuge following natural and simulated rainfall events, 1991. Runoff samples were not collected for chemical analysis on July 22.

| Plot | July 25 | August 2 | August 10 | Simulation |
|---|---|---|---|---|
| 1L-C | 0.018 | 0.004 | 0.005 | 0.295 |
| 1L-T | 0.046 | 0.008 | 0.004 | 0.396 |
| 2L-C | 0.026 | 0.004 | 0.095 | 0.620 |
| 2L-T | 0.026 | 0.004 | 0.094 | 0.552 |
| 3L-C | 0.019 | 0.006 | 0.027 | 0.284 |
| 3L-T | 0.023 | 0.007 | 0.094 | 0.209 |
| 1H-C | 0.062 | 0.007 | 0.008 | 0.343 |
| 1H-T | 0.023 | 0.086 | 0.007 | 0.595 |
| 2H-C | 0.002 | 0.004 | 0.008 | 0.383 |
| 2H-T | 0.006 | 0.009 | 0.007 | 1.037 |
| 3H-C | 0.072 | 0.059 | 0.006 | 0.000 |
| 3H-T | 0.018 | 0.068 | 0.007 | 0.253 |

Table 6. Concentrations (mg $l^{-1}$) of Cd, Cu, and Pb in runoff collected from sludge-amended (T) and untreated (C) plots at the Sevilleta Wildlife Refuge, 1991. Mean Pb concentrations between treated ($n=6$) and control ($n=6$) plots were not significantly different at $p < 0.10$ for any of the precipitation events, including rainfall simulation.

| PLOT | Cd | Cu | Pb | Cd | Cu | Pb |
|---|---|---|---|---|---|---|
| | July 25 Storm | | | August 2 Storm | | |
| 1L-C | <0.005 | <0.02 | 0.31 | <0.005 | <0.02 | 0.11 |
| 1L-T | <0.005 | <0.02 | 0.36 | <0.005 | <0.02 | 0.25 |
| 2L-C | 0.005 | <0.02 | 0.21 | <0.005 | <0.02 | <0.05 |
| 2L-T | <0.005 | <0.02 | 0.26 | <0.005 | <0.02 | <0.05 |
| 3L-C | <0.005 | <0.02 | 0.19 | <0.005 | <0.02 | <0.05 |
| 3L-T | 0.008 | <0.02 | 0.48 | <0.005 | <0.02 | <0.05 |
| 1H-C | 0.016 | 0.02 | 0.47 | <0.005 | <0.02 | 0.09 |
| 1H-T | <0.005 | <0.02 | 0.23 | <0.005 | <0.02 | 0.24 |
| 2H-C | <0.005 | <0.02 | 0.66 | <0.005 | <0.02 | 0.10 |
| 2H-T | <0.005 | <0.02 | 0.82 | <0.005 | <0.02 | <0.05 |
| 3H-C | <0.005 | <0.02 | 0.34 | <0.005 | <0.02 | 0.07 |
| 3H-T | <0.005 | <0.02 | 0.37 | <0.005 | <0.02 | 0.25 |
| | August 10 Storm | | | September Rainfall Simulation | | |
| 1L-C | <0.005 | <0.02 | 0.13 | <0.005 | <0.02 | <0.05 |
| 1L-T | <0.005 | <0.02 | 0.20 | <0.005 | <0.02 | 0.13 |
| 2L-C | <0.005 | <0.02 | <0.21 | <0.005 | <0.02 | 0.40 |
| 2L-T | <0.005 | 0.52 | 2.52 | <0.005 | <0.02 | 0.11 |
| 3L-C | <0.005 | <0.02 | 0.16 | <0.005 | <0.02 | 0.11 |
| 3L-T | <0.005 | <0.02 | 0.05 | <0.005 | <0.02 | 0.17 |
| 1H-C | <0.005 | <0.02 | 0.10 | <0.005 | <0.02 | 0.13 |
| 1H-T | <0.005 | <0.02 | 0.39 | <0.005 | <0.02 | 0.13 |
| 2H-C | <0.005 | <0.02 | 0.16 | <0.005 | <0.02 | 0.12 |
| 2H-T | <0.005 | <0.02 | 0.14 | <0.005 | <0.02 | 0.21 |
| 3H-C | <0.005 | <0.02 | 0.16 | <0.005 | <0.02 | <0.05 |
| 3H-T | <0.005 | <0.05 | 0.46 | <0.005 | <0.02 | <0.05 |

## SUMMARY AND CONCLUSIONS

We conclude that surface application of treated municipal sewage sludge can significantly reduce runoff in semiarid grasslands. The two factors we considered most important for the reduction in runoff yield are increased ground surface roughness and absorption of water by the dry sludge.

Runoff yields were greatest during high-intensity storm events. Runoff rates from the control plots increased progressively with increased precipitation and storm duration. Yet a similar pattern was not observed in the sludge-amended plots, wherein the proportion of total precipitation lost from the plots as runoff remained under 1% of the input regardless of total precipitation and storm duration.

Potential contamination of surface water by constituents in the sludge does not appear to be a limitation for sludge application as a fertilizer and mulch amendment in this environment. Nitrate, Cu, and Cd concentrations in the runoff water were well below established New Mexico groundwater and livestock and wildlife watering standards, and we found no statistical differences in these potentially toxic constituents between sludge-amended and control plots. Although we detected Pb concentrations exceeding current New Mexico standards for groundwater and livestock and wildlife watering after some storms, we found no significant difference between the mean Pb concentrations in runoff from treated and control plots.

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# SEDIMENTATION EFFECTS ON WATER QUALITY AT ELEPHANT BUTTE RESERVOIR

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## INTRODUCTION

The Rio Grande has always been a heavily silt-laden stream with turbidity levels that rivals the Colorado River. With the construction of Abiquiu, Cochiti, Galisteo, and Jemez reservoirs, the Rio Grande's sediment load has been decreased. This leaves the Rio Puerco as the last remaining major sediment-contributing tributary. The average annual sediment load of the Rio Puerco and its tributaries is over 7,000 acre-feet of sediment per year. Rio Puerco sediment, due to its physical and chemical characteristics, requires annual maintenance and repair to the Rio Grande river channel and the low flow conveyance channel, and damages fish and wildlife habitat.

Along with continued soil conservation, construction of a proposed flood and sediment control dam on the Rio Puerco and incorporation of watershed treatment practices by the U.S. Forest Service, will enhance greatly the long-term productivity of the middle Rio Grande valley. These activities also will curtail possible contamination to the water supply at Elephant Butte Reservoir. This interagency effort will improve grazing and agricultural potentials throughout the tributary area. By reducing the turbidity at the headwaters of Elephant Butte, the fish spawn will be increased.

## POTENTIAL FLOOD DAMAGE

The Army Corps of Engineers has significantly reduced the flood threat to the Middle Rio Grande floodway by constructing Abiquiu, Cochiti, Galisteo, and Jemez Canyon dams. A potential for vast flood damage exists when a summer or fall transition storm system centers on the western portion of New Mexico or specifically over the Rio Puerco and Rio Salado watersheds. Historically these tributary river basins have caused major damage to the Rio Grande floodway when moist air from the Gulf of California or the Gulf of Mexico has moved north as a result of tropical storms.

The storm of September 20-23, 1929, might be considered typical of a major summer-to-fall transition over the Rio Grande basin. The following is quoted directly from the Meteorological Summary, U.S. Weather Bureau, dated August 1, 1946.

> "The source of moist air for this storm was the Pacific Ocean off the coast of Mexico where three tropical disturbances were tracked between September 10 to the 27th. During the period of the tropical storms a polar air mass was moving south into New Mexico. The pressure gradient between a stationary high pressure centered over the east coast and the low pressure of the polar air mass produced a sustained flow of tropical air into the Colorado Plateau. The heavy showers

that resulted dumped 4.81 inches of rain on Santa Fe, New Mexico within a 60 hour period. A secondary rainfall center was observed in the San Juan and Chama River basins."

Another storm with tropical air beginnings occurred in October 1911, when a tropical cyclone moved into eastern Arizona, western New Mexico, and southwestern Colorado. Recorded runoff at San Marcial gage measured in excess of 203,000 acre-feet on October 6-16.

Storms of similar origin in the fall of 1929 and again in 1933 deposited large amounts of sediment in the Rio Grande floodway below the mouths of the Rio Puerco and Rio Salado and led to the abandonment of the town of San Marcial, which was located at the headwaters of Elephant Butte Reservoir.

## SEDIMENTATION DAMAGES

The extent of damage caused by sedimentation to the Rio Grande Valley is severe. Sedimentation results in increased maintenance costs to the floodway, irrigation water distribution systems, and the low flow conveyance channel. Sediment-laden waters that enter the Rio Grande from the Rio Puerco and Rio Salado watersheds have a detrimental effect on crop production and in some instances, crops have been killed when the sediment-laden waters have been used for irrigation. The flood of September 1929 destroyed the town of San Marcial when sediment deposits of over nine feet covered the floodway. The results of a similar flood event today would be devastating. In addition to sediment deposition problems in the floodway, storage efficiency in Elephant Butte Reservoir is curtailed by the increasing amount of lake surface exposed to evaporation. In 1916 the capacity of Elephant Butte Reservoir was 2,634,800 acre-feet at the spillway elevation. A 1988 sedimentation survey conducted by the Bureau of Reclamation showed a capacity of 2,065,010 acre-feet. This difference indicates a capacity loss of 569,700 acre-feet during the 73-year period between the dam's completion and the sedimentation survey.

Currently, the Bureau of Reclamation is engaged in an effort to remove numerous sediment plugs deposited as a result of sediment transport into the reservoir. In calendar year 1991 the Bureau removed over 265,000 cubic yards of silt and sediment from the Rio Grande channel in the San Marcial reach at a cost of approximately $1 million.

Average annual flow into Elephant Butte for the 25-year period, 1961 to 1985, is 725,000 acre-feet. Between 1978 and 1989 inflows into the reservoir were significantly above normal in seven of the twelve years. Average annual inflow for the twelve years is 896,027 acre-feet. These large inflows transported great quantities of sediment and have deposited the sediment in the reservoir's upper reaches. For the twelve-year survey period the average annual computed sediment loads at San Marcial were:

| | |
|---|---|
| Silt and clay loads | 2,405,975 tons/year |
| Bed material load | 2,133,124 tons/year |
| Total load | 4,539,099 tons/year |

An analysis of the sediment-producing area above Elephant Butte (25,923 square miles) shows that sediment is trapped in the upstream reservoirs constructed by the Army Corps of Engineers.

Table 1. Dams upstream from Elephant Butte Reservoir containing trapped sediment.

| Site | Year Completed | Square Miles |
|---|---|---|
| Jemez Canyon Dam | 1953 | 1,034 |
| Galisteo Dam | 1970 | 596 |
| Cochiti Dam | 1973 | 11,960 |
| **Total** | | 13,590 |

Subtracting the total square miles of these three dams from the 25,923 square miles above Elephant Butte, results in 12,333 square miles of watershed area unprotected from flood and sediment damage. The Rio Puerco and Rio Salado basins make up the majority of this unprotected area.

The Rio Puerco and Rio Salado watersheds contain 7,340 and 1,350 square miles, respectively. The watersheds' total area, 8,690 square miles, is 70 percent of the sediment-contributing areas to Elephant Butte Reservoir. A soil analysis of the Rio Grande floodway between San Acacia and Elephant Butte shows that the soils have been formed from the highly colloidal materials deposited by the Rio Puerco and are generally of a heavy texture according to a 1977 study by the U.S. Bureau of Reclamation.

## ENVIRONMENTAL DAMAGE

A far more serious effect is the potential from heavy metal contaminated sediment from the Grants mining area, which is drained by the Rio San Jose tributary to the Rio Puerco. Materials derived from uranium mine tailings piles or waste ponds can be especially significant to the Rio Puerco due to its high sediment load. In 1981 there were 42 active mines and five processing mills in this area. The Rio Puerco has been estimated to contribute only 16 percent of the water to the Rio Grande but over 60 percent of the sediment load. Above the mouth of the Rio Puerco at Bernardo, the Rio Grande (before flows from the Rio Puerco) has been estimated to have an average annual sediment load of 1,600 acre-feet per year. The Rio Puerco at Bernardo before it discharges into the Rio Grande basin is estimated to have an average annual estimated sediment load of 5,584 acre-feet.

Of particular concern are the waste materials accumulated in ponds from mine dewatering or from ion exchange plants. Water in ion-exchange plants generally pass through settling/evaporation basins, and then are either discharged or used as makeup water. As mining progresses, the uranium content of the mine water increases due to oxidation. Ion-exchange plants lower the uranium content to approximately 0.5 ppm. The water is then discharged into the Rio Puerco watershed. Since upstream water is diverted for agricultural, municipal, and industrial use, the Rio San Jose is normally dry. Radionuclides and heavy metals are commonly absorbed by clay soils. Most soils in the Rio Puerco and Rio San Jose watersheds are of a clay origin. The possibility then exists that uranium and other heavy metals are being transported downstream by sediment movement. During flash floods or heavy runoff, water remobilizes and transports absorbed or precipitated heavy metals. Studies conducted during the 1980s by Dr. Carl Popp and Dr. Donald Brandvold of the New Mexico Institute of Mining indicate that heavy metal contaminated sediment is being transported to the mainstem of the Rio Grande and into Elephant Butte Reservoir.

In April 1990, Dr. Donald Brandvold and Lynn Brandvold of the New Mexico Bureau of Mines and Mineral Resources presented a compilation of data obtained from different studies that sampled the waters of the Rio Grande basin at approximately 43 sites (New Mexico Water Resources Research Institute Miscellaneous Report No. M22). These sampling sites began at the Colorado/New Mexico state line and ended at the Texas/New Mexico state line. Studies were done for dissolved metals as well as metals in suspended, bottom, and bank sediment. The report summarizes the findings of four M.S. theses, an Interstate Stream Commission report, a study done for the EPA, and a report for the Office of Surface Mining. Only two elements, mercury and selenium, exceeded the New Mexico Environment Department criteria for Public Drinking Water Standards.

## SUMMARY

This paper's purpose is to bring attention to the possibility of serious environmental, flood, and sediment damage to the Rio Grande floodway and Elephant Butte Reservoir. In 1915 when Elephant Butte Reservoir was completed, it had a storage capacity of 2,534,800 acre-feet. In 1988 as a result of a sedimentation survey conducted by the Bureau of Reclamation, the reservoir's capacity was 2,065,000 acre-feet for a loss of 569,700 acre-feet during the 73-year period. This loss threatens the water supply for agricultural and municipal purposes below Elephant Butte. The sediment deposited at the upper regions of the Elephant Butte Reservoir has destroyed an enormous amount of wildlife habitat. About 50 percent of the cottonwood trees, and even salt cedars, have been killed because of this sediment. This results in a loss of fish and wildlife habitat, and jeopardizes the municipal, agricultural, and industrial water supply for the people below Elephant Butte Reservoir.

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# THE RIO GRANDE JOINT INITIATIVES — A DEMONSTRATION OF INTERAGENCY COLLABORATION IN WATER MANAGEMENT

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## INTRODUCTION

In November 1990, the Army Corps of Engineers, Bureau of Reclamation, and Fish and Wildlife Service initiated an interagency process to evaluate three possible modifications to reservoir operations in the Upper Rio Grande basin in New Mexico. The changes could potentially conserve water, enhance fish and wildlife habitat, improve water quality, and increase recreational opportunities in the system. At an initial meeting, more than 40 people representing the scientific community, management agencies, and governmental units discussed these modifications and subsequently formed three committees (Fig. 1), chaired by the authors of this paper. The committees' goal was to explore the positive and negative implications of the different plans to modify reservoir operation and to make recommendations. All committee members have the support of their agencies, although committee work is in addition to members' job responsibilities.

**Abiquiu Pre-evacuation Initiative**
- Chairperson - Dick Kreiner (Army Corps of Engineers)
- Bureau of Reclamation
- Army Corps of Engineers
- Forest Service
- Bureau of Land Management
- Fish and Wildlife Service
- NM Game and Fish
- Ghost Ranch
- Rio Chama Acequia Association
- NM Interstate Stream Commission
- City of Albuquerque
- Los Alamos County
- Middle Rio Grande Conservancy District
- Rio Grande Compact Commission Engineer Advisors for CO and TX

**Cochiti Re-regulation Initiative**
- Chairperson - Rob Leutheuser (Bureau of Reclamation)
- Bureau of Reclamation
- Army Corps of Engineers
- Bureau of Indian Affairs
- Forest Service
- National Park Service
- NM Interstate Streams Commission
- Middle Rio Grande Conservancy District
- Cochiti Pueblo
- NM Game and Fish
- Fish and Wildlife Service
- College of Santa Fe
- Wildlife Consultant
- Rio Grande Compact Commission Engineer Advisors for CO and TX

**Minimum Flow Initiative**
- Chairperson - Dr. Eleonora Trotter (University of New Mexico/Rio Grande Basin Consortium)
- City of Albuquerque
- Middle Rio Grande Conservancy District
- Bureau of Reclamation
- Army Corps of Engineers
- Fish and Wildlife Service
- Rio Grande Basin Consortium
- NM Interstate Streams Commission
- NM Game and Fish
- Rio Grande Compact Commission Engineer Advisors for CO and TX
- Bureau of Indian Affairs

**Figure 1.** Rio Grande Joint Initiatives Representation

Implementing any one of the initiatives will require Congressional approval. A goal of this interagency effort, therefore, is to develop a consensus at the local and regional level providing Congress a clear mandate to authorize management changes, if recommended.

The geographic area of the Rio Grande basin under examination is shown in Figure 2. The area begins with the Rio Chama in northern New Mexico and extends downstream to the Isleta Diversion Dam on the Isleta Pueblo, south of Albuquerque.

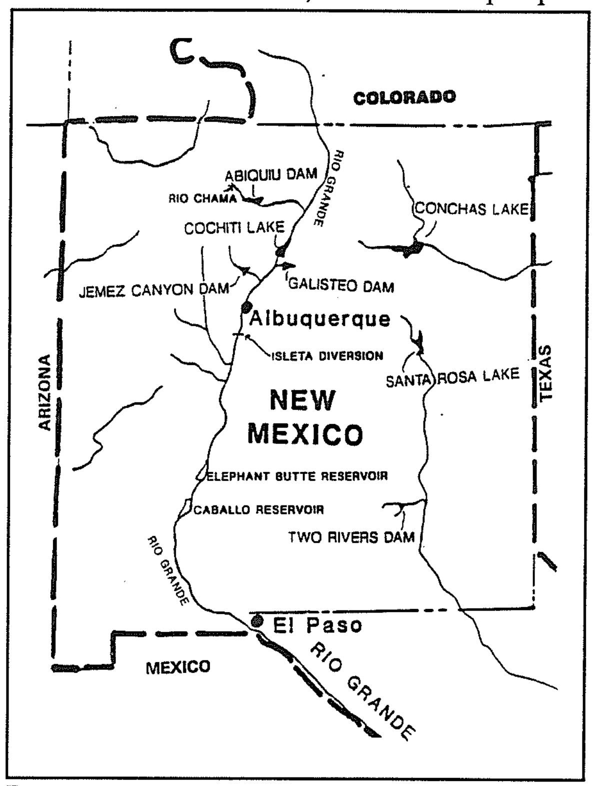


**Figure 2.** Geographic area of the Rio Grande Joint Initiatives

The three concepts, collectively referred to as the Rio Grande Joint Initiatives are:

- pre-evacuation of water belonging to the City of Albuquerque from Abiquiu Reservoir before the spring snowmelt runoff
- creation of a small irrigation re-regulation pool in Cochiti Lake
- establishment of a minimum flow in the Rio Grande from the Cochiti Dam to Isleta Diversion Dam

This paper's purpose is to describe briefly each initiative and provide an interim report of the committee's work. Also discussed are the emerging benefits of this process that go beyond the specific issues addressed by each committee.

## ABIQUIU PRE-EVACUATION

This committee's charge is to explore the feasibility of pre-evacuating water belonging to the City of Albuquerque from Abiquiu Reservoir to limit the adverse impacts flood control operations have on recreational uses, such as rafting, on the upper Rio Chama. Albuquerque's San Juan-Chama water is stored in Abiquiu Reservoir as a hedge against a future demand on water as the population increases. The concept is that reservoir storage would begin to be evacuated in early February in years of above normal snowmelt runoff. The National Weather Service/Soil Conservation Service snowmelt runoff forecasts will be used to determine the magnitude of the pre-evacuation. The water pre-evacuated from Abiquiu Reservoir, before the runoff, would be replaced by the natural inflow as the runoff progresses. The committee divided itself into two groups to deal with the biological and water management implications of pre-evacuation.

Constraints on pre-evacuation include:

- the unanimous consent of the Rio Grande Compact Commission, because of the water exchange involved
- limited downstream channel capacity, caused by numerous rock and brush diversions
- downstream bank erosion

Major issues being studied include the impacts on the reservoir and downstream fisheries, and inundation of a favorite rafting take-out at the upper end of the reservoir. Last year the committee began identifying key issues and work began on developing pre-evacuation criteria to determine the magnitude of storage to be evacuated for various runoff projections.

## COCHITI RE-REGULATION

The Cochiti re-regulation initiative will explore the feasibility of increasing Rio Grande operational flexibility by authorizing irrigation storage in Cochiti Lake. This could be achieved by establishing a 5,000 acre-foot conservation pool in the lake. This would allow for the temporary capture of water released from upstream storage for irrigation, which is no longer needed due to adequate rainfall in the irrigated areas within the Middle Rio Grande Valley.

The initiative is being evaluated, recognizing the following institutional constraints:

- no instantaneous native (natural) flows would be re-regulated
- additional management opportunities involve only water released from upstream storage for downstream water users
- there would be no changes in overall flood or sediment control operations

This committee, which also is divided into water management and biological work groups, identified biological resources and social issues that could be influenced by re-regulation. Relevant biological resources of interest include the wetlands at the headwaters of Cochiti Lake (with secondary effects on waterfowl and wintering bald eagle populations), game fishes in the lake, and stream flows immediately below Isleta Diversion Dam. Social issues identified include the potential for increased seepage from the lake and its effects on downstream Indian Pueblos, additional public access to portions of Bandelier National Monument, and recreational fishing opportunities on Cochiti Lake.

Over the past year, the committee has been very active in evaluating these issues. The emphasis has thus far focussed on the biological resources, supplemented by the water management group developing hydrologic scenarios.

Ultimately, the full committee will prepare recommendations for future actions, which will be submitted to concerned governmental agency heads, the Rio Grande Compact Commission, water users, and the congressional delegation. These recommendations could range from no action, to a range of alternative actions, to a preferred action. If recommendations include changes in current operations, it is likely that the documentation would be used to secure the necessary federal legislative authority.

## MINIMUM FLOW THROUGH THE CITY OF ALBUQUERQUE

The third committee's charge is to explore the feasibility of establishing a minimum flow in the Rio Grande from Cochiti Dam, through Albuquerque, to the Isleta Diversion Dam on the Isleta Pueblo. This committee did not divide itself into two groups, partially because the issue is highly focused, the costs and benefits are relatively clear cut, and the path to a minimum flow is well marked. The concept entails an agreement between the City of Albuquerque and the Middle Rio Grande Conservancy District (MRGCD) to leave some irrigation water in the Rio Grande instead of diverting it and running it in riverside canals to its destination at the Isleta Diversion Dam.

Benefits of this concept include meeting the Environmental Protection Agency (EPA) standards for the discharge of sewage effluent from Albuquerque's sewage treatment plant. The EPA permit issued to the City of Albuquerque to discharge sewage effluent into the Rio Grande has lapsed and this minimum flow concept is being used as a basis for the new permit. In recent years it was not unusual for the main channel of the Rio Grande through Albuquerque to be nearly dry during the summer when most of the water was diverted to irrigation canals. EPA standards for discharge into a dry river bed are higher than for other flow regimes. Therefore, EPA standards could be based on a higher flow if there were an established minimum flow agreement between the City of Albuquerque and the MRGCD.

Another benefit concerns rare and endangered species like the Rio Grande silvery minnow found within this middle section of river, which is dependent on year-round flow. Minimum flow would create habitat for the silvery minnow, which has been recommended for inclusion in the U.S. Endangered Species Act.

Costs include the trading of water among water users. However, it is difficult to assign economic value to intrinsic qualities of the river system and the species or organisms using the system. Giving up the idea that the river is something used only by people is also difficult. The river has been and could continue to be a place to learn more about the many uses of water. The suggested plan is for Albuquerque to give the MRGCD a volume of water from its San Juan-Chama reserves when the MRGCD needs more water to maintain the minimum flow. It appears that both users would benefit from this arrangement and enjoy the good opinion of the community because of their cooperation to put water to more "beneficial use" by increasing the variety of habitats for riparian plants and animals as well as for the public's enjoyment in the middle Rio Grande. One of the greatest benefits of minimum flow is the protection of biodiversity.

One problem with forging an agreement between the City of Albuquerque and the MRGCD is the concern that once minimum flow is provided, the U.S. Endangered Species Act will forever require that minimum flow and there will be no way to adjust or cancel the agreement. Another problem is that the MRGCD does not have river gages accurate enough to monitor the flow in the Rio Grande above Albuquerque. Therefore, MRGCD has agreed to provide a certain discharge at the Central Avenue Bridge, where there is an accurate gage. This does not mean that the water will flow at the agreed flow rate above the bridge.

At an early meeting, Gary Daves, representing the City of Albuquerque, was asked what information he needed to consider the idea of a water trade. Daves asked the Army Corps of Engineers and the Bureau of Reclamation for different scenarios of how much water would be needed. Bob Hogrefe, of the city's sewage treatment plant, was asked how much water he needed to have to show EPA that Albuquerque was moving ahead in good faith to meet EPA standards for sewage effluent discharge. At a subsequent meeting the Corps, Bureau of Reclamation and the city's sewage plant produced data and were able to agree that 250 cubic feet-per-second (cfs) would be adequate for a maintained minimum flow, based on the hydrologic information assembled. Even with this information, the City of Albuquerque and the MRGCD balked at a long-term commitment, but agreed to a one-year trial period for assessing what actually occurred in the attempt to maintain the agreed upon 250 cfs. The city and MRGCD began to discuss a longer term agreement of 10 years, but the city is concerned that a long-term agreement will be made mandatory by the Federal Endangered Species Act to protect the Rio Grande silvery minnow. Albuquerque does not want its water encumbered in the future. It wants to be prepared so that if the groundwater becomes badly polluted, the city residents can use San Juan-Chama surface water for drinking.

## CONCLUSIONS

Why are the Rio Grande Joint Initiatives an important step in the shared management and use of Rio Grande water? In the case of minimum flow, the issues were clearly defined, the area of impact specific, and people could focus on solving a problem of limited dimensions. Each problem addressed was of local interest, had clearly defined costs and benefits, and the interested parties had explicitly state positions and needs. Information needed by the users was available almost immediately from the water managers. Those involved were willing to put aside differences to concentrate on solving a problem whose solution benefited all sides as well as benefiting other users of the river. We believe the people who attended the first general meeting one year ago, and the people who attended the second annual meeting were there not so much to defend their position, but to share their concerns and work together, to recreate a part of the Rio Grande. A network of people concerned with the river system's health has been formed. People have a forum in which to express their concerns, and because users and managers are working together, informed policy decisions can be made more rapidly. Most importantly, the people who live with the river in New Mexico now have a way to inform Congress of their wishes for the management and use of the Rio Grande.

The continued level of interest in the Rio Grande Joint Initiatives, and the progress made in evaluating the three plans, underscores the value of these ideas and validates the appropriateness of the process. Agencies, interest groups, and individuals have all donated their time and resources to address the initiatives. We are working together to develop better ideas about operating this portion of the Rio Grande system based on a changing definition of beneficial use. This cooperation will set the state for developing a future consensus on how Rio Grande resources can best benefit New Mexicans.

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# FIRE AND GILA TROUT RECOVERY IN WILDERNESS WATERSHEDS

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## INTRODUCTION

The recovery of endangered wildlife presents many challenges to science, research, and technology. The cooperative efforts in restoring the endangered Gila trout (*Oncorhynchus gilae*) provide an excellent example of how management agency staff and university scientists are working together to meet these challenges.

Strong cooperative efforts in the Gila National Forest wilderness areas have actually brought the Gila trout back from a level of near extinction. Long-term recovery and management of this native trout require a knowledge of complex interactions in forest ecosystems. A current interaction being examined involves the effect of fire and ash on aquatic systems.

A large wildfire recently occurred in the headwaters of the Aldo Leopold Wilderness. Emergency actions were successful in rescuing hundreds of Gila trout from threats to the native population in Main Diamond Creek. Because of this event, several issues have come to the forefront including the crucial need to predict the effects of intense fire and ash on aquatic systems.

**Figure 1.** Gila Wilderness - USDA Forest Service

Biologists, fire ecologists, chemists, fisheries scientists, and others are working to address the specific interactions of fire and ash effects on native Gila trout populations in wilderness areas on the Gila National Forest. This ongoing research is crucial in assuring the long-term recovery and management of the Gila trout species.

## GILA TROUT: THE NATIVE TROUT TO GILA WILDERNESS

The Gila trout is the only trout native to the upper Gila River drainage. Early in this century Gila trout became in serious danger of extinction primarily due to introduced populations of rainbow and brown trout. Habitat alterations in lower river systems around the turn of the century also effected the species' stability.

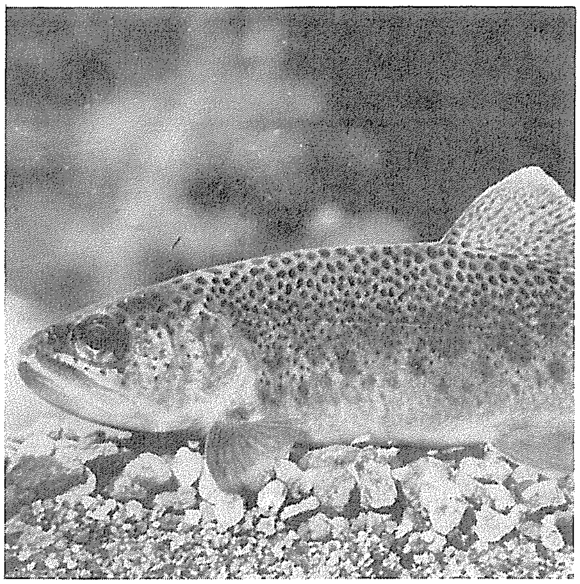

**Figure 2.** Gila trout.

The Gila National Forest has essentially been a refuge for several species lost throughout other parts of their historic range. During the 1960s, the world's population of Gila trout was reduced to only five small headwater streams in the Gila and Aldo Leopold Wildernesses.

## SPECIES RECOVERY

Recovery efforts over the last fifteen years were initiated by biologists and other scientists from several agencies and institutions. The U.S. Forest Service, New Mexico Department of Game & Fish, and U.S. Fish and Wildlife Service joined with researchers from New Mexico State University, University of New Mexico, and New Mexico Highlands University to develop several transplant techniques and to initiate Gila trout recovery.

Through cooperative efforts, the Gila trout was restored to a point during 1989 where it was considered for down-listing from endangered species status. The situation looked good and the recovery of this trout was well on its way toward the primary goal of restoring the trout to a game species.[1,2]

**Figure 3.** Cooperative efforts resulted in the recovery of Gila trout to its native waters.

## WILDFIRE IN WILDERNESS

In 1989 after two years of below normal winter precipitation, the Gila National Forest went into a dry fire season.[3] A series of wildfires broke out in several areas of the forest and one fire known as the "Divide Fire" burned into the upper watershed of Main Diamond Creek.

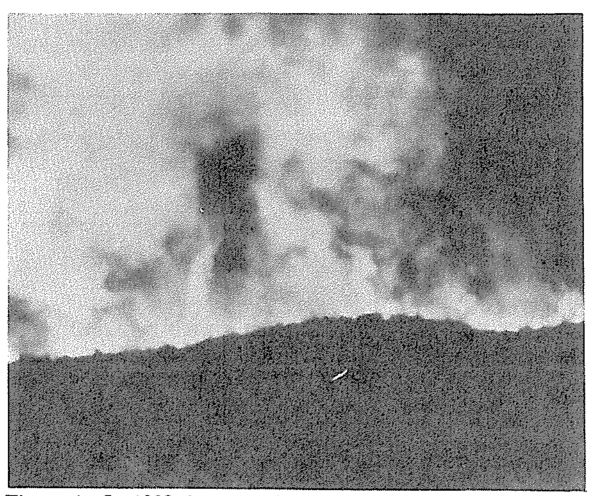

**Figure 4.** In 1989, intense wildfires struck in several areas of the Gila National Forest.

The Forest Supervisor and Black Range Ranger District placed a high priority on protecting the stream containing the Gila trout.

**Figure 5.** U.S. Forest Service fire fighters fought hard to keep the fire out of the immediate stream area containing a native population of Gila trout.

Fire fighters did a tremendous job of keeping the fire away from the immediate stream zone considering the extreme fire conditions and the wildfire's high intensity. While the fire was burning in several areas, an intense hail storm scoured portions of the charred slopes in the watershed above the Gila trout stream.

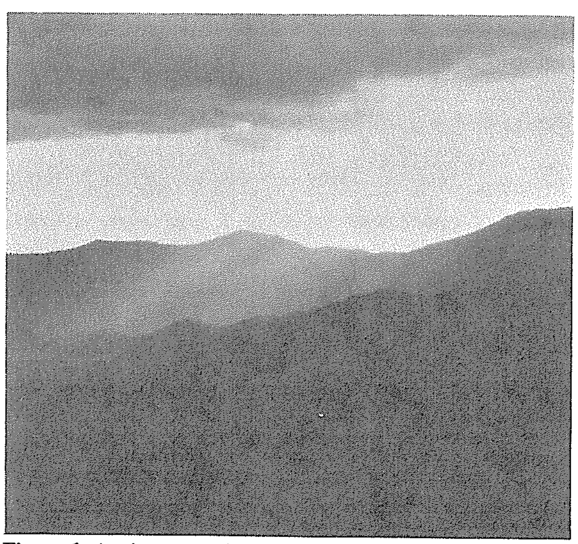

**Figure 6.** An intense hail storm washed tons of ash into the Gila trout stream.

Tons of ash filled the stream area. Biologists considered this situation to be a serious threat to the Gila trout in Main Diamond Creek. The U.S. Forest Service, U.S. Fish and Wildlife Service, and New Mexico Department of Game and Fish pooled their resources to address this emergency situation. Rescued trout were provided a temporary home at the Mescalero Fish Hatchery.

**Figure 7.** An emergency effort rescued 566 live Gila trout. The trout were packed out on horses and mules as fire threatened the Main Diamond population.

Within one week of the Divide Fire, Dr. David Propst of the New Mexico Department of Game and Fish began evaluating the remaining fish population. Within the entire stream zone that previously supported between 5000 and 10,000 Gila trout, only one live fish could be found. Follow-up surveys during the next year confirmed that the entire native population of Gila trout had been extirpated.

Needless to say, this fire effect caused a setback in recovery efforts. The recovery team recommended that the species not be down-listed until the potential effects of fire and ash could be included in the long-term recovery plan for the species.

## FINDING ANSWERS THROUGH COOPERATIVE RESEARCH

This situation provided a tremendous opportunity to study the inter-relationships among fire, ash, and aquatic systems. Several interesting and exciting projects currently are being conducted in the area of fire research.

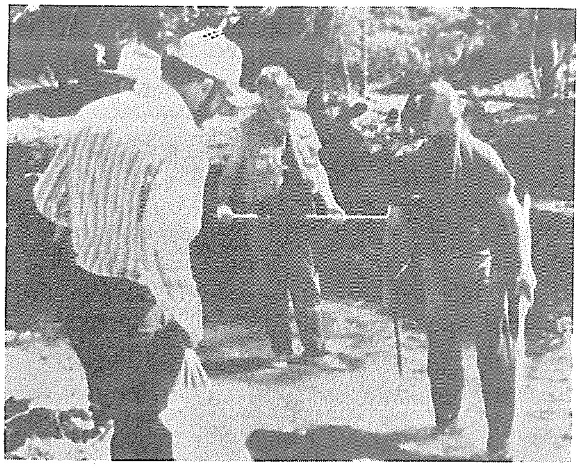

**Figure 8.** All remaining Gila trout in Main Diamond Creek were lost as tons of ash filled the stream.

Soon after the fire, Dr. Jerry Jacobi from New Mexico Highlands University established several sampling areas to evaluate aquatic invertebrates. These aquatic insects are a primary food source supporting Gila trout. The effect of the heavy ash and fine silt deposits following the fire is being evaluated. This will help determine when the stream can again support the native trout in the future.

Initially the aquatic macro-invertebrates declined, but they started a brief recovery during the next year. A harsh storm then flooded the area bringing additional ash-laden sediments, which resulted in drastic declines in all aquatic insect populations. A slow and relatively unstable recovery in aquatic insects is now being noted.[4]

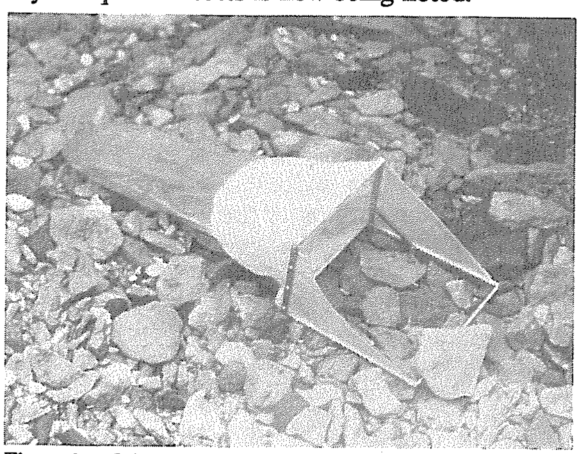

**Figure 9.** Scientists conducted research on aquatic macro-invertebrates in the streams affected by ash.

Dr. Paul Turner, a member of the recovery team from New Mexico State University, has initiated a study to quantify the recovery of fisheries carrying capacity. His evaluations focus on the many physical and biological factors that support trout populations in the wild.

**Figure 10.** Fisheries research under the supervision of Dr. Paul Turner.

A little over two years has passed and although some stabilization has been seen in several components, the stream area is still not fully capable of sustaining viable populations of trout over time.[5]

Dr. M. Karl Wood, a watershed specialist from New Mexico State University, has instrumented several zones of the upper watersheds. Large amounts of ash and sediments have moved through the system and some portions of the watershed appear to be stabilizing at this time.

Jerry Stefferud and John Pittenger, fisheries biologists with the U.S. Forest Service and New Mexico Department of Game and Fish, respectively, have established several stations to monitor stream morphology and several habitat parameters.

In addition, Drs. John Rinnie and Al Medina from the Rocky Mountain Forest and Range Experiment Station are working on several specific interrelationships of fire, ash, and aquatic species.

Rinnie and Medina are studying the reaction of fresh ash when first exposed to water. One of several chemical reactions occurs involving a conversion of free nitrogen as ammonia ($NH_4$) to nitrates ($NO_3$). During this reaction, a very brief but potentially toxic level of $NO_2$ (nitrogen dioxide) can form.

**Figure 11.** Instrumentation and monitoring of several zones of the upper watersheds.

**Figure 12.** Potential $NO_2$ toxicity under certain conditions relative to fire, ash, and aquatic systems is being studied.

Nitrogen dioxide is notably toxic, especially to fish. This research may help explain the consequences of large amounts of ash being deposited all at once in Main Diamond creek.

In contrast, a slow rain or snow on ash in upper watersheds may have little detrimental effect on the stream since the reaction would simply take place well away from the stream's aquatic life. Research results are anxiously awaited.

Quantified data from these studies will help determine when the native trout populations can be restored again to stream zones affected by wildfire. This information also should provide managers with tools to help predict the potential effects of wildfires near streams and help identify when rescue efforts may be needed.

## FIRE HISTORY AND WILDERNESS HABITATS

Based on dendrochronology studies, we know fire has always played a significant role in the Gila and Aldo Leopold Wilderness areas.[6] The many native species in this area certainly adapted to natural fire frequencies over hundreds of thousands of years of evolution and adaption.

**Figure 13.** Historically, natural fires occurred at higher frequencies but lower intensities in the Gila Wilderness. Restoring the frequencies of natural fire may enable long-term maintenance of native wildlife that adapted to those fire patterns over thousands of years.

The use of both "prescribed natural fire" and "managed ignited fire" appear to be the key management tools needed to restore natural fire patterns.[7] Managed burns are necessary to reduce the unnatural buildup of heavy fuel, which can, at times, pose serious threats to native species.

## SUMMARY

The future most definitely looks bright and is keyed to strong cooperation between both management and research.

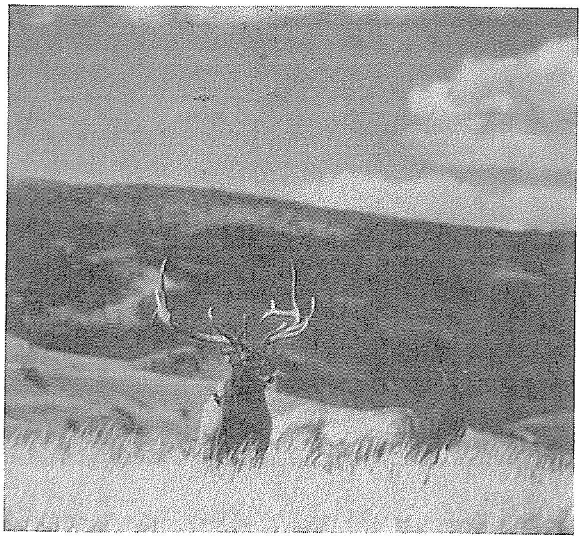

**Figure 14.** A bright future.

This has been one of those rare times when we have had the opportunity to study the specific interactions between fire, watersheds, and the associated aquatic ecosystem. Information and knowledge compiled through these cooperative studies can help answer several key questions facing managers today. Biologists need answers to help predict the effects of wildfire and assure the long-term recovery of the endangered Gila trout species.

We are fortunate to have such a high caliber staff involved in research and management in this area. Their efforts have put us on the leading edge of knowledge about the complex relationships involving recovery of endangered species and fire relationships in wilderness areas.

## ACKNOWLEDGEMENT

I want to thank KGGM TV News 13, Albuquerque, New Mexico and photographer Paul Burt and reporter Glenn Griffin for their help in providing condensed news program footage used with this presentation. I also wish to recognize the photography by Kirk Loy and outdoor reports by Lilia Chacon used in portions of these segments.

## ENDNOTES

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***Darren Divine** received his B.S. in Biology from the University of New Mexico in 1990 and is currently working on his M.S. in Wildlife Science. Darren's thesis research involves evaluating wildlife benefits of artificial and human-altered wildlife water units on White Sands Missile Range.*

# HYDROLOGIC CONSIDERATIONS RELATED TO INVENTORY AND EVALUATION OF WILDLIFE WATER UNITS AT WHITE SANDS MISSILE RANGE

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## INTRODUCTION

Wildlife populations in the desert southwest often are thought to be limited by water availability, at least during some periods of the year. Although many native species are adapted to water limitation, populations can be increased by additional water sources (Yoakum et al. 1980). Wildlife managers continue to improve designs for wildlife watering systems (Elderkin and Morris 1989). Historically, the White Sands Missile Range (WSMR) wildlife management program has emphasized development and/or renovation of water sources for wildlife habitat enhancement. Despite this program emphasis, inventory, inspection, maintenance, and repair of water units have had relatively low priority and have been accomplished with limited personnel resources. Currently, only a few of the previously developed units provide a reliable water source for wildlife, according to WSMR natural resources staff.

Given past water unit development, the existence of a baseline wildlife water unit system at WSMR, and WSMR's desire to enhance wildlife, it would be helpful to evaluate how water units should be included economically in wildlife management planning. The evaluation must document the current status of water units, identify the actions and costs necessary to make units functional, and assess conditions and locations where wildlife will make the best use of water units. The evaluation will facilitate decisions about which wildlife species to feature in the water program; analyze budget requirements for scheduling water unit maintenance and repair; and help determine the need for new units in context with natural water sources. Further, pre-military, rancher-established watering points not currently functional should be identified and evaluated for their role in future development or renovation planning.

## PREVIOUS WORK AND PRESENT OUTLOOK

Prior to withdrawal of the WSMR area for exclusive military use, rancher-maintained water sources provided wildlife and livestock with drinking water. Once livestock were removed, normal maintenance and repair of these facilities ceased and many wildlife watering points became nonfunctional. Natural springs, seeps and intermittent surface water became the only surface water sources for wildlife. Limited water availability, especially during drought periods, likely has restricted surface water-dependent wildlife species.

The WSMR Wildlife Management Program was first staffed in 1963. Primary emphasis during the first 20 years was to enhance available wildlife habitat by renovating abandoned livestock water sources and developing new sources, especially for big game species (Anderson and Taylor 1983). A few springs also were modified to provide permanent water sources. Most springs and seeps located in mountainous areas of WSMR were not altered because of their inaccessibility. Since initiation of the WSMR Wildlife Management Program, about 100 water sources have either been renovated, enhanced, or created. Wildlife water units consist of windmills, dirt tanks, rainwater catchments, haul tanks, and spring boxes. These units contain a variety of water retrieval apparatuses, storage facilities, and piping systems. Wildlife drinkers have been installed in most of the mechanized units.

Planned research will take place throughout the entire missile range, an area of approximately 760,000 hectares in the Chihuahuan desert ecosystem of southern New Mexico. This area has a variety of surface relief, ranging from the Tularosa Basin and Jornada del Muerto plains at 1220 to 1520 meters, respectively, to the San Andres and Oscura Mountains with peaks approaching 2745 meters. The WSMR environmental office has developed and placed approximately 100 artificial wildlife watering units to aid wildlife populations. These units are located throughout WSMR, but are concentrated in the San Andres and Oscura Mountain ranges.

For clarity, the following list defines various water unit types at WSMR:

- Enhanced spring - Natural springs and seeps which have been human-altered to provide a more dependable water source for wildlife. Alterations include but are not limited to addition of spring boxes, piping, masonry dams, and hand-dug storage.
- Windmill - Wells with windmill pumping systems.
- Rainwater catchment - Inverted umbrella-style or roof-style rain collection and storage systems fabricated from metal, fiberglass, concrete, or other materials.
- Haul unit - Storage and drinker system without water collection mechanism which must be filled by water hauled from another source.
- Earthen tank - Catchment constructed from native earth to hold rainwater and run-off behind earthen berms that intercept drainage systems.
- Historic water unit - Rancher established nonfunctional water unit with potential to be made functional.

Records of varying quantity and quality have been collected through the years regarding these water units, but the records have not been compiled in an organized, readily accessible format (personal communication, P. Morrow). Thus, it is not possible to go to a single source and conveniently retrieve important data concerning site condition, location, and physical attributes, and expected wildlife use.

## HYPOTHESES AND OBJECTIVES

The underlying hypothesis for this research is that artificial water sources enhance wildlife populations detectably relative to unaltered areas and that artificial water sources can be provided cost effectively relative to benefits derived. Hypothesis evaluation requires specific data regarding measurable wildlife benefits and potential costs necessary for routine maintenance and operation of various water unit designs.

### Specific Research Objectives

- To compile baseline physical attributes data for about 70 wildlife water units and identify systematic procedures needed for annual maintenance and repair to support use by big game, upland gamebirds, and other wildlife in that priority order.

- To estimate the relative suitability of current wildlife water unit placement for meeting WSMR wildlife water requirements as expressed in terms of species diversity, frequency of use, and volume of water provided versus potential wildlife populations served.
- To identify and evaluate up to 20 historic water units for their relative potential value as renovation or development sites based on cost effectiveness and anticipated wildlife use.
- To develop a working data base system using Dbase III Plus (or comparable software acceptable to WSMR staff) for organizing physical data on wildlife water units, categorizing expected wildlife use of units, and tracking maintenance and repair schedules.

**PLANNED PROCEDURES**

This project is organized into three major components:

- locating and evaluating the watering units
- wildlife use detection
- analysis of vegetative community structure

Location and evaluation of units will consist of finding a unit; recording its latitude, longitude, and universal transverse mercator coordinates with the aid of a global positioning system; and recording that location on USGS 1:24,000 and 1:50,000 scale topographic maps. An additional list of inspection items has also been identified, which includes, but is not exclusive to, calculated storage capacity of any and all storage tanks, surrounding vegetation association or community, and the overall condition of the unit. Watering units that have at one time or another been documented and/or maintained by WSMR as well as a minimum of 20 undocumented, nonfunctional, historic units, will be located and evaluated.

WSMR provides an extensive and unique laboratory for assessing wildlife use of artificial water sources, which is the second research component. A distinct opportunity exists for determining competitive interactions between native and exotic ungulates in arid environments. Following identification, location, and evaluation of all specified watering units, functional units will be selected at random to represent rain catchment, windmill, human-altered spring, earthen tank, and haul style categories. These sites will be examined for relative wildlife use among different styles of functioning watering units. For our research, wildlife benefit will be assessed as differences in measurable wildlife presence between water unit sites and comparable sites of natural vegetation and relief. The purpose of the wildlife data collection will be to ascertain measurable differences in wildlife activity in areas containing artificial watering units versus areas devoid of artificial units. Specific priority will be given to mule deer, pronghorn antelope, bighorn sheep, oryx, barbary sheep, feral horses, and upland game birds. Additional field work will employ a wide variety of techniques (observation, sign detection, fecal counts, capture, etc.) to measure use and presence by all wildlife categories.

Vegetation analysis will be the project's third major component. It has been suggested that ungulates have a significant detrimental impact on vegetation surrounding watering units as expressed in an increase in unpalatable plants, a decrease in palatable plants, or overall change in vegetative structure important to native animal species (Tembo 1990). Vegetation sampling will be done using a combination of quadrats and transects established in concentric belts centered on sample units. Each evaluation unit will be stratified into three concentric circles, and each circle will be further stratified into three sections. Each section will then have a line transect chosen perpendicular to the center of the unit. Finally, each line within each section will be divided into equal sections in which herbaceous and woody plants will be recorded as to species, number, height, and basal or canopy diameter.

Regarding procedures, it is important to illustrate one key point, notably access control. WSMR is first and foremost a high technology, high security military installation. Because of this security, the project has several conditions or restraints. Special and highly controlled permitting is required to take photographs on WSMR. Additionally, we must call the base a week in advance, check on any planned missions, and put our visits on the mission planning board. The day before scheduled field work, we must call the base and check on roadblocks. We must call the day of the planned work and inform

Range Control where we will be, and must call back when we are out of the area. Each of these conditions may result in postponement, rearrangement, or rescheduling of field work—starting the entire process all over again. These are significant planning constraints.

## PROGRESS

As of November 1991, the project has proceeded to the watering unit location stage. All units will have been located and cataloged by the middle of January 1992. The first wildlife and vegetation study period will begin in March 1992 and go through May 1992, while the second, and final, study period will be June through August 1992. The final study report and a working data base comprised of a watering unit maintenance and repair schedule is due on or before September 30, 1992.

## IMPLICATIONS TO NEW MEXICO WATER RESOURCES

Watering habits and water requirements of exotic ungulates has particular significance to New Mexico hydrology. According to a May 1991 aerial survey, there are approximately 1200 $\pm$ 100 feral horses on WSMR. Resource personnel feel that such a large herd may negatively impact on riparian areas. As a rule of thumb, horses require 4.2 liters of water per 100 kilograms of horse per day (J.B. Armstrong, personal communication). An average horse weighing 500 kilograms requires about 21 liters of water per day. To sustain a herd at WSMR at its current level, the horses would consume an estimated 25,200 liters of water per day, 176,400 liters of water per week, and almost 9.2 million liters of water per year. This amount of water removal coupled with trampling and compaction of surrounding vegetation and soils can be a significant resource consideration, especially in sites such as Malpais Springs where the state endangered White Sands pupfish (Cyprinodon tularosa) occurs. Further, it is possible that exotic ungulates can negatively impact native ungulates through potential introduction of diseases during common use of water sources.

Research results are expected to add to knowledge regarding the types of hydrologic settings where artificial watering sources may provide most benefit to wildlife in Chihuahuan desert and adjacent mountainous ecosystems. This added insight should reduce future placement of watering structures in surface water features where little good accrues to wildlife but impacts on other hydrologic considerations exist.

## COOPERATION

This project is being conducted by the New Mexico Cooperative Fish and Wildlife Research Unit, based in the Fishery and Wildlife Sciences Department of New Mexico State University. Principal project investigators are the coauthors of this report. Project cooperators include Dr. J.B. Armstrong, NMSU Department of Animal Science; Dr. Rex Pieper, NMSU Department of Range Science; Dr. Manual Cardenas, NMSU Department of Experimental Statistics; the New Mexico Department of Game and Fish, the U. S. Fish and Wildlife Service, and the U.S. Department of Agriculture Jornada Experimental Range. Financial support for the research is provided by U.S. Army White Sands Missile Range.

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# RIPARIAN STRUCTURES AND WATERSHED TREATMENTS IN THE SOUTHWEST: HISTORY, STATUS, AND MANAGEMENT IMPLICATIONS - A PRELIMINARY REPORT

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## INTRODUCTION

Largely due to the arid and semi-arid climate of the Southwest, riparian areas and wetlands have always been limited. Even prior to settlement by European immigrants, less than 5 percent of the land could be so classified. Extensive changes in land use since the 1600s has reduced that figure even more. Recent estimates place the current extent of riparian areas and wetlands at less than 2 percent.

In an effort to halt destructive grazing, logging, mining, and similar practices common on western lands before the turn of the century, National Forests were designated to gain control of public lands. Since designation as National Forests, considerable activity has taken place to improve the condition of riparian areas and their contributing watersheds.

Literally millions of dollars have been spent over the decades to improve riparian and watershed conditions. Probably the most famous of these efforts was the Civilian Conservation Corps (CCC) in the 1930s. Individual Forests and Ranger Districts have done improvement work on their lands for years, often with mixed results. Unfortunately, however, monitoring and evaluation of the effectiveness of these projects has been sporadic. While individual Forests and Districts have performed management reviews and inspections to assess some project work, no focused effort has been made to assess this work and learn from decades of effort.

## HISTORICAL PERSPECTIVE

Early Forest Service (FS) efforts until World War II mostly dealt with conservation work and gaining control over land uses such as timber harvest, livestock grazing, and wildfire damages that had previously proceeded unchecked.

Management emphasis following World War II focused more heavily on commodity production to meet the needs of a growing nation. Timber, livestock, and minerals production increased with relatively minimal emphasis given to non-commodity outputs such as soil, water, and air resources. Riparian areas, which have always been a small percentage of the land base, were often overlooked or lumped with other resources, receiving little special management emphasis.

An awakening environmental awareness in the mid-1970s spawned legislation championing a broader mix of resource uses. The Multiple Use-Sustained Yield Act, Endangered Species Act, Wilderness Act, National Forest Management Act, and Clean Water Act are examples of this change in public emphasis.

National symposia in 1977, 1978, and 1985, highlighted riparian area values, recognized their disproportionate use relative to their size, and noted the loss of riparian acreage that had occurred over many decades. There was a growing realization of riparian areas as valuable resources in and of themselves. Additionally, two 1988 Government Accounting Office reports focused on problems with riparian areas in the West, especially related to livestock management. This provided even more incentive to speed rehabilitation of riparian areas and their contributing watersheds.

## CURRENT STATUS

Increased awareness of the need to improve riparian area management has generated considerable efforts recently to inventory and evaluate these areas, improve fish habitats, develop riparian pastures, plant riparian species, control erosion, close roads, and many similar activities. Funding and targets for these efforts increased, but widespread success remained elusive. This generated a number of key questions: How do we spend the available dollars more efficiently? What works best and why? What doesn't and why not? Are there common principles that are positive and negative to this effort? How does the "system" or day-to-day, month-to-month, year-to-year operation of the FS enhance or hamper efforts to maintain and enhance riparian areas? What is the extent and success of technology transfer?

To evaluate and learn from past improvement projects, a study was developed that would accomplish four key objectives:

- Evaluate a wide variety of projects aimed at improving riparian area conditions
- Determine project success or failure
- Determine common mechanisms of success or failure
- Use the results to educate personnel involved with riparian improvements so they can repeat successes and avoid failures

Study funds were allocated to the Forest Service Southwestern Regional Office in Albuquerque, which in turn transferred funding and responsibilities to researchers with the Rocky Mountain Forest and Range Experiment Station (RMFRES) unit located in Tempe, Arizona. RMFRES, in consultation with the Southwestern Regional Office, chose to accomplish the study via a contract due to limited personnel and time within the RMFRES unit and a desire to get an outside opinion, thus enhancing the study's credibility.

## STUDY SCOPE

The Southwestern Region of the USDA Forest Service encompasses over 22 million acres on 11 National Forests and 3 National Grasslands in Arizona, New Mexico, western Oklahoma and western Texas. Five National Forests are administered from New Mexico (Carson, Cibola, Gila, Lincoln, and Santa Fe) with the remaining units in Arizona (Apache-Sitgreaves, Coconino, Coronado, Kaibab, Prescott, and Tonto). The Cibola National Forest has administrative responsibility for the 3 National Grasslands. We designed the study to encompass projects in all National Forests as well as a wide variety of ecosystems, climates, soils, vegetation types, geologic types, and hydrologic responses. We needed to evaluate structural (fish habitat improvements, gully plugs, exclosures, etc.) and non-structural measures (management changes, prescribed fire, etc.), projects relating to a variety of land management activities (grazing, logging, recreation), and projects affecting both the riparian areas and their contributing watersheds.

The Watershed and Air Management (WSA) staff unit, Southwestern Regional Office, solicited proposals for possible project sites from all 11 National Forests in the region, using a series of criteria. The response from the Forests was very encouraging, with 116 potential projects identified across the region. Personnel from WSA and RMFRES reviewed the proposed sites and narrowed the scope to 25 representative sites that would meet the study criteria and time and funding constraints.

After reviewing proposals from several potential contractors, BioSystems, Inc. of Tiburon, California, was chosen to perform the study. Their team of scientists and sub-contractors included the following individuals and skills:

- Bill Platts - Team Leader, Fishery/Range interactions
- Sherman Jensen - Soils, geology, geomorphology
- Gary Alborn - Biology, range management
- Toby Hanes - Hydrology, watershed improvements, stream geomorphology

The authors of this report were the Contracting Officer's Technical Representatives for the Forest Service.

## STUDY METHODS

The study had three distinct phases:

- Pre-field
  - Pre-site visitation forms/questionnaire sent to Ranger District offices
  - Data gathering from Ranger Districts
- Field site visits
  - 13 sites in Arizona in June 1990
  - 12 sites in New Mexico in September 1990
  - Site measurements and evaluations
  - Photography - 35mm and video
  - Interview/discussion with field personnel from Forest and District
- Post-field and follow-up
  - Data analysis, interviews, etc.
  - Conclusions and recommendations
  - Report preparation and publication

## PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

Based upon site visits and data gathering efforts, the contractor developed the following conclusions and recommendations to improve riparian project success in the Southwestern Region.

- **Grazing Conflicts**

  Conclusion:
  Proper livestock management is essential to implementation of successful riparian treatments. Inappropriate livestock management poses the single most serious obstacle to riparian project success.

  Recommendations:
  - Develop riparian-compatible grazing strategies
  - Develop riparian-specific utilization standards
  - Fund structural treatments only where grazing management is compatible with riparian goals
  - Establish standards for riparian pasture and exclosure fences
  - Increase the size of projects and exclosures

- **Watershed Management Objectives Coordination**

  Conclusion:
  Riparian treatments and watershed management must share similar goals for riparian treatments to succeed. Many projects appeared to lack these shared goals.

  Recommendations:
  - Implement only projects that integrate watershed condition and riparian health
  - Assess watershed management activities with respect to effects on riparian area conditions
  - Use upland vegetation conversions to aid riparian areas only after intensive interdisciplinary planning

- **Monitoring and Evaluation Lacking**

  Conclusion:
  Few projects included monitoring and evaluation as part of the overall project design and implementation.

  Recommendations:
  - Develop and implement monitoring plan as integral part of project action plan
  - Establish evaluation criteria to measure success in monitoring plan
  - State project objectives carefully to drive inventories and monitoring
  - Link monitoring to maintenance and adjust maintenance to reflect monitoring findings

- **Coordinating Partnerships**

  Conclusion:

  Public and special interest group partnerships are increasing and provide valuable expertise and labor. Short-term efforts to take advantage of this interest sometimes conflicted with long-term rehabilitation strategies.

  Recommendations:

  - Maintain control of partnership projects, not letting projects control FS
  - Insist on quality construction and maintenance from all partners

- **Reliance on Instream Structures**

  Conclusion:

  In many cases the region relies on instream structural measures to restore riparian areas when the root cause of poor riparian health is unsatisfactory watershed condition. Efforts to restore the riparian area without addressing the overall watershed will likely have limited success.

  Recommendations:

  - Consider benefits of non-structural measures as the first alternative
  - Use formal engineering designs for more projects
  - Use bioengineering designs where possible
  - Use projects compatible with stream dynamics and watershed response
  - Use risk analysis in project design

- **Funding Imbalance Discourages Planning, Monitoring, and Maintenance**

  Conclusion:

  Funding for project implementation appears acceptable in most cases. Funding for project planning, monitoring, and maintenance, however, is under funded and under emphasized. This trend hampers long-term project success and seems to emphasize quantity rather than quality in project work.

  Recommendations:

  - Properly fund all phases of a treatment including analysis, planning, implementation, monitoring, and maintenance
  - Perform cost/benefit analyses on all projects and related land management activities
  - Approve only projects with monitoring and maintenance plan and budget
  - Develop procedures to budget all phases of projects

- **Site Potential Assessment Needs**

  Conclusion:

  Project implementation is seldom preceded with an inventory adequate to assess existing site condition or potential. This limited knowledge often leads to selection of inappropriate treatments, thus minimizing the likelihood of project success.

  Recommendations:

  - Conduct baseline inventories to assess current and potential assessment needs
  - Gather baseline data using methods compatible with future monitoring methods
  - Design projects specific to site needs. Avoid cookbook approaches where possible.

- **Interdisciplinary Approach Necessary**

  Conclusion:

  A true interdisciplinary approach on projects was found infrequently, thus limiting success.

  Recommendations:

  - Institute Integrated Resource Management (IRM) on all projects
  - Use true interdisciplinary approach in all projects
  - Increase hydrological input to most projects

- **Alternative Analysis Needed**

  Conclusion:

  Few projects include alternative analysis to determine the range of project alternatives and define consequences of actions.

  Recommendations:

  - Use Integrated Resource Management (IRM) process to develop full range of alternatives

- Address and treat underlying problems in the analysis, not just ways to treat symptoms

- **Maintenance Lacking**

  Conclusion:
  Lack of project maintenance was evident in many projects and contributed significantly to project failure.

  Recommendations:
  - Include maintenance plan and funding with overall project plan
  - Fund only projects that include maintenance in the project plan
  - Provide targets and rewards for project maintenance just as is done for new projects
  - Develop means to include maintenance funds at all levels of budget process
  - Insure links between monitoring and maintenance. Allow alteration of maintenance based on monitoring results

- **Commitment at All Levels**

  Conclusion:
  Successful project implementation seemed directly dependent upon the personal commitment of individuals on site rather than upon a commitment by the organization as a whole. Projects were, therefore, related to individual rather than organizational enthusiasm.

  Recommendations:
  - Develop means to increase commitment at all levels in organization
  - Increase training and awareness of watershed and riparian functions and values throughout the organization

## SUMMARY

The draft contract report containing the above recommendations and conclusions is undergoing final review by the Forest Service. The final report will be issued early in 1992. The Southwestern Regional Office and RMFRES will use this information to begin implementing changes aimed at increasing the success of riparian improvement projects on all southwestern National Forests. These efforts will include the publication of a General Technical Report from RMFRES, training for professional and technical personnel involved with riparian improvement projects, and development of handbooks, visual aids, and related materials to promote techniques with high success probabilities.

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# RESEARCH AND TRAINING NEEDS OF AGENCIES: A PANEL DISCUSSION

**In keeping with the conference's theme of agencies and science working together, a panel of agency representatives discussed how academic institutions could better meet their training and research needs. The following are remarks by the panelists prior to answering questions from the moderator and audience.**

*Jim Piatt*
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*Jim is a native New Mexican and most of his professional career has been spent in this state. He has been employed for the last seven years with the New Mexico Environment Department where currently he serves as chief of the Surface Water Quality Bureau. Prior to going to work for the Environment Department, Jim was employed as an environmental consultant.*

Yesterday you heard from Kathleen M. Sisneros, the director of the Water and Waste Management Division of the New Mexico Environment Department for whom I work. I agree with training needs that Kathy described, and see no reason to expand upon them. Let me emphasize again that one of the most important things the department desperately needs from academia is graduates with common sense—that which simply cannot be learned in university laboratories. They need to be able to function in the field.

Concerning water resources research, from my perspective, there are three areas of immediate concern. Most people are quite aware that New Mexico has been both blessed and unfortunately cursed with significant mineral deposits. While these deposits have helped fund this state during the course of its entire history, it has also left us with significant contamination problems. Several talks at this conference have described how we are now faced with attending to hundreds of thousands of tons of mineral waste products at many different sites. In situ bioremediation continues to be a priority area of needed research. To be honest about it, you are not going to be able to pick up and haul away these waste materials and try to dispose of them somewhere else. We need techniques that will work on-site on all the mineral types we have in New Mexico.

We are working cooperatively with several agencies, including the Forest Service, New Mexico Highway Department, and the New Mexico Department of Game and Fish, trying to remediate mine spoils present in significant quantities in the upper Pecos River. Many of you may have read of a massive fish kill in the state's fish hatchery on the Pecos early in the spring. This kill resulted from acidic leachate from mine wastes entering the river approximately eleven miles upstream of the hatchery. We are seeing that type of impact across the state due to historical mine waste products found on private and public lands. It is a problem that must be addressed. If we do not, we are going to be looking at federal legislation requiring us to deal with the problem in a manner which may not be suited to New Mexico. Most people do not want to be forced to work under EPA's oversight.

Another area of major concern is mercury contamination of our biota, including our fish, in many of the state's reservoirs and lakes. This is a problem that is not going to go away. Work conducted at Ute Reservoir in 1970 found the average concentration of mercury in walleye was 90 ppb. Today the average in walleye has risen to 670 ppb. The Water Resources Research Institute currently is reviewing several research proposals on mercury contamination. State and federal agencies are working cooperatively to identify those waters which contain contaminated fish, yet we need to go beyond that. My staff will never be able to identify the sources of mercury or other forms of biotic contamination in our lakes because the department does not have the money or the necessary resources. Unfortunately, mercury is just the tip of an iceberg.

We have good reason to believe that, for example, in the Pecos River we have high levels of lead in some fish. We also have indications of selenium problems in various waters as well as organic contaminants in the San Juan River Basin. We need to know what contaminants are present in biologically significant concentrations, how bad the contamination is and from what sources it is entering the waters. Once again, we desperately need your help in identifying and implementing mitigation measures for these problems. We need to start solving these biotic contaminant problems or we are going to see all 175 publicly owned and operated lakes listed as containing fish which should not be consumed by humans. If this occurs, there will be a major negative impact on the state's recreational facilities and an attendant economic impact. In that fishing currently is estimated to contribute almost $200 million dollars to the state's economy, a reduction in the fishing public could significantly affect the state's economic well-being. It should also be noted that other organisms are also eating these contaminated fish. Among those organisms are federally endangered species (e.g., American Bald Eagle), ducks (including several species which are consumed by humans), and several mammalian species. This is not just a human health issue, although human health is certainly of concern.

Finally, another research need concerns university assistance in the development of biological water quality criteria. The 1972 federal Clean Water Act required states to develop criteria for chemical contaminants in the state's waters. Those criteria have helped us to get a handle on some problems and we have applied the criteria fairly successfully. But the problem we are finding is one David Coss of my staff mentioned yesterday. Ninety-eight (98) percent of the state's surface water pollution is caused by non-point source runoff and the tricky thing is that it is episodic. If you are collecting water samples at the wrong time, the water may look perfectly appropriate, and yet in the stream you find no benthic macroinvertebrates, fish or the other critters that should be there. If we develop the biological criteria we believe are necessary—and certainly EPA is encouraging us to do so—we will finally have a means of integrating water quality across time. Those critters in the stream are exposed over long time spans to what's in the water. They are thus a direct measure of all pollutants in the aquatic system. They also are a direct measurement of the Clean Water Act's requirement that we "...maintain the chemical, physical, and biological integrity of the Nation's waters." No matter how much work biologist Jerry Jacobi of New Mexico Highlands University does, he is only one person. We must know the benthic population of all the state's waters. We need to know what a good "undisturbed" population looks like and which organisms are sensitive, that is, those which would indicate a healthy ecosystem.

We also do not have a good idea of the ichthyofauna in New Mexico. What should the fish populations look like in an unperturbed system? What are the effects of various perturbations on these populations? When a road is placed next to a stream, what is the biological effect of the sediment delivery? We need quantitative data on the biological health of aquatic systems.

We need to focus on the entire ecosystem. Historically, we have concentrated on water quality and that has given us some false positives and false negatives. We need to know more about the health of the entire ecosystem. Russ LaFayette and his colleagues at the Forest Service are contributing substantially in this area. However, the academic community can provide us with long-term studies that state and federal agencies simply are not going to be able to do.

I have been asked to comment on where, from my perspective, the department is going. It is nearly impossible to predict the Environment Department's future. The department has changed so much over the seven years I have been there that forecasting three months down the road, much less three years down the road, is a daunting task. Kathy Sisneros spoke of something yesterday that really does hold true. We are seeing many more multi-media concerns than we ever had in the past. Obviously, my being an ecosystems ecologist biases me a bit, but the department needs people trained to go beyond just biological concerns. We need biologists who know something about soil characteristics, stream morphologies, and lots of chemistry. Engineers who see beyond their plats are needed. We must look at the entire ecosystem if this department is to address environmental concerns. This is a daunting task in and of itself. For years the universities graduated highly skilled specialists, but from an environmental standpoint, we need more generalists than we did in the past.

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*Gary Eyster currently is the chief of planning for the US Army Corps of Engineers, Albuquerque District. He received his B.S. in Civil Engineering from the University of New Mexico in 1974 and earned an M.S. in Civil Engineering from Colorado State University.*

We find the engineers and scientists who join us at the entry level to be generally well prepared. On that basis, I feel that educators have done a good job of training natural resource professionals up to now. But we have seen enormous changes in the world in the last few years. Implementing worthwhile projects or public policy is far more complex than in the past. Many more voices clamor to be involved in decisions. So professionals need a better grounding in certain areas.

- First, they need education in the **systems** of the real world. Because our world is driven by laws, procedures, and public policy, technical education alone does not prepare natural resource professionals to be effective. For example, they need to be taught about the law (water law, water quality law, environmental law, and contracts). They need an understanding of interstate compacts. They need to be taught principles of public administration such as budgeting, legislation, and finance.
- Effective people need to understand the principles of sociology; how people work as groups, why they act as they do, how they make decisions.
- Effective people also learn to distinguish main issues from side issues; important issues from trivial issues. They need to set meaningful goals and achieve them through management of their time and effort. Later in their careers effective professionals can lead others using these same tools.
- To be effective, professionals need to communicate proficiently, both orally and in writing.

We can't afford tunnel vision in our natural resource professionals. They need to appreciate the many parts of the natural system and the many legitimate views of other professionals and the public. Mark Twain once said, "Concerning the difference between man and the jackass, some people say there isn't any.......This wrongs the jackass". We can be a pretty stubborn species, particularly when we are ignorant of other valid ways of looking at things.

I would like to give you some insight into the future of the Army Corps of Engineers and how that might impact on training needs. Someone once said that he who lives by the crystal ball is doomed to eat ground glass. Just the same, this may be useful to you.

The U.S. Army Corps of Engineers has been deeply involved helping local governments control their flooding problems for over 55 years. We will continue to do this for the foreseeable future; probably at least 15 years. In doing this we have developed expertise with applicability in related fields. We have biological and archeological expertise second to none. We have geotechnical capability that stands with the best anywhere.

Whenever our nation has emerging needs where these skills are applicable, such as in environmental planning and remediation, the Corps could become involved. We will pursue all our work from a broader perspective, incorporating fish and wildlife and recreation features into the work more fully.

Turning to research needs, we strongly support continued precipitation and stream-gaging data collection. These data are key to our water resource mission.

We see a growing need to understand the interaction of surface water and groundwater both from the perspective of groundwater recharge and the migration of hazardous and toxic pollutants.

We are assisting New Mexico acequia associations in rehabilitating many of their aging facilities. In some cases we may assist them by replacing a rock or brush diversion with a more substantial structure. Where we find that this would segment the stream in terms of the genetic pools of fish populations, we construct fish ladders as mitigation.

There is plenty of experience with fish like salmon but we have turned up very little on fish passage devices for trout or small non-game species.

A topic that might profit from some research would be Endangered Species law and policy. This topic is practically taboo with many and it has been highly divisive within the natural resource community. All of us might benefit from a candid examination of its impacts and application. This might also assist in applying the law better in the future and in its eventual reauthorization.

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*Kirk Koch is the Bureau of Land Management state hydrologist in New Mexico, with responsibilities in Texas, Oklahoma and Kansas. He spent ten years with the BLM as a hydrologist in southern Idaho and spent two years as a hydrotechnician on Roosevelt Dam. Program responsibilities include issues involved with soil, water, and air resources, including water rights, water quality, land-use planning and impact mitigation.*

The BLM has an internal education system devoted to training needs for staff career enhancement. This educational tool has been very successful and I encourage other entities to consider using it as a model. At the agency level, we think it would be beneficial if all instate agency training opportunities could be coordinated in an attempt to expand water educational opportunities.

New Mexico universities should provide their students with a solid, diversified resource background reinforced through practical experience. BLM can help in providing experience through the volunteer program, Co-op Education program, or seasonal employment program.

BLM is currently involved in two watershed research projects. The Global Change in the Chihuahuan Desert program is a cooperative effort with New Mexico State University's Department of Fisheries and Wildlife. Another program involves municipal sludge application for range improvement in the Rio Puerco watershed. This is a cooperative effort with the Forest Research Station, Environmental Protection Agency, and City of Albuquerque.

The BLM needs to improve the overall understanding of the following areas.

- Organizing New Mexico water research references into a database which will enhance literature search capabilities.
- Establishing a better understanding of ties between the uplands and the water column in terms of non-point source pollutants, both man caused and natural. Studies could include best management practices, and monitoring techniques to determine what works best and most efficiently.
- Studying playa biology and its benefits to humanity.
- Studying Colorado River salinity to improve methods to project, monitor, and verify salt movement on the watershed.
- Improving the Hazardous Materials Program's bioremediation techniques. The program offers other research topics and practical experience in site assessment, waste inventory, remote sensing, geophysical assessment, and HRS scoring.
- Developing an inventory of abandoned and orphaned wells associated with the oil and gas industry as well as creating methods to remote sense development impacts, assess cumulative impacts, and improve remediation of produced water spills.
- Assessing economic value of soil/water issues including the value of erosion, sediment costs, accumulation of trace elements in eroded material, loss in site productivity due to erosion, effects on vegetative vigor, and others.

To the organizers of this conference, I congratulate you on putting together a fine group of speakers. Water conferences have always been interesting and applicable to my job on the public lands. I welcome the chance to meet colleagues from across the state, and look forward to the 37th annual water conference. I also would like to become better acquainted with the capabilities of the various institutions represented here regarding the issues I have just discussed. Perhaps there are ways we could help each other. Feel free to call anytime at (505) 438-7429 or FTS 847-7429.

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*Jeanine is the deputy forest supervisor on the Lincoln National Forest in Alamogordo. Prior to that she was a district ranger on the Sequoia National Forest in California. She received her B.S. in Biology from the University of California, Riverside and her M.S. also in Biology from California State University.*

The Forest Service has a long tradition of research within the agency and through cooperative university research ventures. The Rocky Mountain Forest and Range Experiment Station provides research support for the Southwest Region of the Forest Service.

In preparing to discuss New Mexico watershed research needs, I contacted field people who implement our forest programs and those who manage the watershed program in Albuquerque for the entire Southwest Region. I also drew upon my own experience in the Forest Service supervisor's office in Alamogordo. The four subject areas presented do not represent all the Forest Service research needs in the Southwest, but provide examples of current research needs. There are opportunities for graduate student projects and long-term research programs that could be conducted by university researchers or scientists from the research branch of the Forest Service. Training needs for maintaining state-of-the-art knowledge in watershed management programs will also be discussed.

**Hydrologic Requirements for Threatened/Endangered Plant Habitat**

Many research questions must be addressed.

- How can we best manage watersheds to sustain habitat for riparian dependent, threatened or endangered plants?
- How does the natural hydrologic and geologic cycle interact with the dynamics of particular populations of threatened or endangered plants?
- What is the interaction between sediment movement into and through the stream channel and germination requirements for the plant species, both within populations and downstream from existing populations?

**Dynamics of Cave Hydrology**

- How does human activity affect the cave resource?
- What are the current natural growth rates of cave formations?
- What are the hydrologic processes that determine growth rates and active versus static cave systems?
- How is this related to climatic events, both past and present?
- How do levels of human use (frequency, intensity, season of use) impact dynamics of cave formations?
- What pollutants adversely affect cave development, and how does this relate to regional air quality (dust, smoke, chemical, etc.)?

**Dynamics of Woodland Ecosystems**

- How should the woodland resource be managed to reinstate and sustain healthy watersheds?
- Generally, how does the structural character of the vegetation and its arrangement on the landscape affect the groundwater potential within river basins?
- Specifically, do we know enough about the successional pathways and stages of plant community development within the pinyon-juniper vegetation type?
- What effect do the various successional stages of vegetation have on groundwater and surface water availability?
- What are the spatial and temporal arrangements of vegetation structure within a watershed that optimize water quantity in groundwater basins?
- What methods are most effective in achieving the desired ratio of woody/herbaceous cover and which are effective in maintaining that desired condition over time?

**Watershed Structures**

- When should structures be placed in channels to create or enhance fisheries habitat or to improve watershed conditions?

Training is needed to assist hydrologists and biologists in designing projects based on geomorphological characteristics of the watersheds. Training is also needed to assist specialists in designing projects to help the channel maintain itself and provide adequate habitat. This approach will ensure that entire watersheds are analyzed and treated whereas many current projects focus only on one small section of a stream and fail to account for the effects upstream and downstream. Research is needed to verify that this holistic approach will indeed maintain channel stability and watershed equilibrium over time.

**Future Trends**

We know that social values are changing, and rural areas are being populated with more urban-oriented residents. Demographic and social changes are producing different demands for national forest resources. Citizens have access to vast amounts of information and expect the Forest Service to provide them with immediate answers to complex questions. Our challenge is to help the more urban-oriented forest visitor understand the dynamics of forest ecosystems, both in context of the past and the future. Meeting public expectations for services and products, while anticipating the demands of our next generation of customers and beyond, is a greater challenge than any of us have experienced.

In response to this trend, the Forest Service is making strides toward emphasizing total ecosystem management as the basis for making decisions within our multiple-use mandate. This is true at both the national and local level. The need for objective research to be focused on today's challenging questions has never been greater. Our contacts with people who have a high level of interest in forest management indicate that the public also wants future forest management decisions supported by research. We will all benefit from advanced technology, both in gathering research data and applying research results for better managing our national forests.

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*Charles is a native of Mississippi and received his Civil Engineering degree from the University of Mississippi in 1961. He is currently the projects manager for the Albuquerque Projects Office, Upper Colorado Region, and his responsibilities include operation and maintenance of four storage dams, 26 miles of tunnels, 300 miles of floodway channelization, and 70 miles of conveyance channels.*

Reclamation was created to help reclaim arid lands through irrigation. As authorized by Congress in the 1902 Reclamation Act, our program was to stimulate further settlement and provide for economic development and stability. Because the Bureau of Reclamation program was successful in fostering settlement and economic development, new public needs for water arose. Eventually, the single purpose mandate of the bureau was expanded to include other beneficial purposes like hydroelectric power, flood control, municipal and industrial water, water quality, recreation, and fish and wildlife protection and enhancement.

During the last 20 years a number of social, economic, demographic and physical forces have quite literally reshaped the West and have caused the bureau's evolution to continue. We have seen major shifts in our population. People have moved in droves to the far West and Southwest, and at the same time there has been a tremendous shift off the farm and into town. We are not a rural population anymore. Population growth and shift has caused an ever increasing demand for water. This also has happened at a time when we have experienced some pretty dry years in most of the West.

Reclamation is now shifting from its traditional construction role, looking for research opportunities in water conservation and water quality, and using its technical expertise toward improved resources management, development, protection, and environmental awareness. Let me briefly describe how the Bureau of Reclamation is accomplishing additional goals in water management.

**RRA Water Conservation Plans**

The Reclamation Reform Act of 1982 (RRA) requires us to work closely with irrigation districts in water conservation. Section 210 of the act formalized the requirement for irrigation districts receiving Bureau of Reclamation water to develop and implement water conservation plans. We have found districts to be very supportive in this endeavor, and many are taking creative approaches. Many districts are installing measuring devices or are otherwise trying to increase their ability to measure water distribution.

Many districts have embarked on projects to repair linings, pipes, and gates, or to change from open to closed distribution systems. Some have implemented ambitious educational programs. Reclamation will continue to emphasize this requirement and will make expertise available, especially through the new water conservation advisory centers, to help in the effort. Research can help find economical ways for irrigation districts to make their systems and on-farm operations more efficient.

**Water Transfers Leases and Sales**

While there are policy and legal issues that must be sorted out, there is a tremendous opportunity around the West to get water where it is needed most through transfers, leases, or sales. Primacy in water allocation and management rests with the states; each state having its own water laws. Our policy is to be a facilitator in transfers that potentially affect federal projects or federally owned water rights. We see the opportunity for moving water around to its best use as a way to provide incentives for conserving water. If, for example, conservation creates water that is surplus to an irrigation district's needs, the Bureau of Reclamation can facilitate marketing between willing sellers and buyers.

Sometimes water is conserved because of a technical solution. Research will play a key role in identifying these technical solutions. Other times water conservation may occur through a creative management approach, or through a combination of both. We are seeing and participating in many creative endeavors to get water either temporarily or permanently shifted to its best use.

**High Plains States Groundwater Demonstration**

Another method for conserving water resources is through groundwater recharge. Considerable research has and will continue to be done on how to deal with declining groundwater supplies, particularly in the plains states overlying the Ogallala aquifer. Since 1986, the Bureau of Reclamation has been involved in a cooperative effort with the U.S. Geological Survey, Fish and Wildlife Service, Environmental Protection Agency, and state and local agencies in carrying out the High Plains States Groundwater Demonstration Program. This program is designed to demonstrate the effectiveness of various methods to recharge declining groundwater supplies.

The program's actual project phase got underway in 1989 with the first demonstration projects becoming operational this year. The 17 projects range from capturing snowmelt to recharging an aquifer with treated effluent from a municipal wastewater treatment facility. One project on the drawing board awaiting further program funding is in the Lubbock/Crosby County area of the Texas Panhandle. The project will demonstrate the potential for collecting precipitation runoff in playa basins and then economically clean the runoff of suspended particles so it can be stored in a near-surface geologic formation for future use. The partner in this effort is Texas Tech University.

**Water Quality Initiatives**

In addition to water quantity and conservation issues, another major area of concern is water quality research. There are already many cooperative efforts taking place, but more research opportunities exist. We are proud of the research underway at the Oakes Research Test Area in North Dakota. This cooperative effort among federal, state and local entities, and the state university system, will determine how various farm management practices affect the quality of groundwater and surface flows. Even more important than the agencies and universities involved, however, is the involvement of farmers who are assisting by incorporating best management practices on actual commercial farming operations.

In a cost-sharing project with the University of Nebraska, we are working on a research program to reduce nitrate concentrates in groundwater. Another joint effort is the Lake Andes-Wagner/ Marty II Project in South Dakota. This is a 45,000-acre irrigation development in the southeast corner of the state. Because of concerns about potential selenium contamination from irrigation return flows in the project area, in 1989 the Bureau of Reclamation cooperated with South Dakota and the U.S. Geological Survey in an evaluation which concluded that there is a likelihood of selenium contamination.

Such a discovery would normally be a death knell for a project like this, but is has evolved into a course of action to investigate further the selenium issue and how to deal with it. Legislation to authorize the project provides for an irrigation/drainage field demonstration on the project site to study return flows, best management practices, and wetlands effects.

The project has received broad support in Congress. It is included in an omnibus bill that was stalled in the last session and again this year by other controversies. This project suggests congressional interest in providing authorization and funding for projects that get at environmental, conservation, and water quality issues. These examples demonstrate that it is possible to put together cooperative research and demonstration efforts.

**Information and Education**

Education plays an important role in all of this in two ways. First, we can do all the research we want and yet, if we do not get the information and results to the people who need it and use it, it really does not do much good. Second, it is our youth who will inherit either the benefits of the research we do today or the results of our failures.

To promote more effective information dissemination about water conservation, each Bureau of Reclamation region and the Denver office is forming a water conservation advisory center. These centers are designed to get water conservation issues and information into the forefront. Each center will draw upon the expertise of their staff, state university systems, water users, and others to formulate strategies for more efficient water use and to develop methods of getting information to where it is needed.

We expect all centers to operate in much the same way while allowing for individuality to address particular local needs. All centers will be gathering and cataloging general and technical materials and will likely become regional clearinghouses of water conservation information. They will draw upon the technical skills and knowledge of a variety of disciplines to provide technical water conservation assistance to water users, and they will develop educational outreach efforts to disseminate this knowledge. In fact, I hope data generated from the research efforts identified during this conference is the kind of information that will be available to end users through the advisory centers.

The Bureau of Reclamation is taking the lead in an effort to develop a national program to teach youth about water conservation and water quality issues. The Great Plains and Pacific Northwest regions developed a pilot program in cooperation with Montana State University. Project WET, or "Water Education for Teachers," was implemented successfully in Montana and Idaho using materials and methods developed in North Dakota. The program is designed to get educational materials and ideas about water resources into the hands of public and private school teachers so they can adopt it into their curriculum. The Commissioner of Reclamation has endorsed bureau-wide implementation of Project WET, and funding will be provided to help this happen. Nationwide implementation will be accomplished through the western Regional Environmental Education Council, the organization responsible for the extremely successful Project WILD and Project Learning Tree environmental education efforts.

Individually, none of us has all the answers about water conservation and water quality. Collectively, however, we just might find some solutions. The bywords in this process must be creativity, cooperation, and adaptability. Most conflicts and challenges do not respect jurisdictional boundaries. They are not federal problems alone, nor are they solely state problems. Local agencies and individual irrigation districts need not be left to sort out problems themselves. We can pool our human, technical, and financial resources to address issues of mutual interest through long-term partnerships. I have touched on programs where the Bureau of Reclamation is involved in research and discussed some training needs which will involve further development. We look forward to working with this organization and others to achieve these goals.

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For the past 12 years, the Department of Game and Fish in cooperation with New Mexico Water Resources Research Institute and New Mexico State University have supported the research and development of a highly complex model of the state's fisheries called RIOFISH.

RIOFISH allows us to examine various management alternatives for the state's fisheries in terms of several biological, hydrological, recreational and economic variables. RIOFISH is also a system for tracking impacts on our fisheries due to variation in water supplies and water management within the state. The simulation model runs on an IBM-compatible microcomputer or personal computer.

While RIOFISH may be a bit ahead of its time in terms of our ability to use the system to its full potential, we are pleased with its success and convinced that the cooperative, long-term approach employed in its development is how future research and development should be approached. Staying a bit ahead is where we want to be.

How to continue building on the success of RIOFISH is the question at hand. To help answer this question, the Department of Game and Fish is asking the RIOFISH developers to study the feasibility of expanding the approach to the state's watersheds. This will necessarily tie the aquatic and terrestrial ecosystems together as a functional unit in a comprehensive model. Like RIOFISH itself, we envision expansion of the system into the watersheds to be a long-term, expensive endeavor requiring perhaps 10 to 15 year to complete.

One justification for this new effort—and there are several others—is that water in New Mexico is our most essential resource and its quantity, quality and usability is dependent in part on its management and the condition of its watershed. Strictly speaking, the Department of Game and Fish has little direct authority over water or watershed management, but working through the National Environmental Protection Act, and other laws, the department is required to be involved in the decision-making processes. Unfortunately, as yet, there is no comprehensive system in place for quantitatively assessing short- and long-term cumulative effects of the various land-use practices on the associated terrestrial and aquatic ecosystem. Yet any student of New Mexico knows these effects occur, and many of the more obvious ones have been detrimental to the state's fishery and wildlife resource interests as well as other resource interests including agriculture.

In the short-term, our interests include participation in land-use decisions that minimize detrimental impacts, and in the long-term, emphasize participation in land-management decisions that will eventually lead to some level of recovery. Without a comprehensive system for understanding consequences and for testing various alternatives, effective participation will be difficult at best. The research and development program we are asking RIOFISH modelers to explore is designed in part to address this problem.

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It is a pleasure to be here at the annual water conference to learn more about current water issues in New Mexico. The Soil Conservation Service primarily assists farmers and ranchers on private, state and Indian land in conserving the quantity and improving the quality of that precious resource we call water. We also assist public land users through Coordinated Resource Management Planning with other agencies upon request. The SCS assists federal land management agencies such as U.S. Forest Service, Bureau of Land Management, National Park Service and others in areas such as water conservation planning, soils information, and plant materials.

Water quality is the U.S. Department of Agriculture's major emphasis for the 1990s. Agriculture is being eyed by the public and various interest groups as a major non-point source of surface and groundwater pollution. The USDA is committed to helping farmers and ranchers reduce the potential for pollution from agriculture while still producing sufficient food and fiber economically for our great nation. It is in this area that the SCS has many research needs. This includes research to help determine how nutrients and pesticides move through different soil types. We need to inform farmers and ranchers on which chemicals to use on particular soils that would result in less pollution of surface and groundwater.

Methods of applying nutrients and pesticides to crops need further study to determine which methods are less likely to result in pollution of surface and groundwater. This includes the most cost effective ways to time applications.

Numerous models are being developed to predict pollution potential from use of various nutrients and pesticides. Models, such as NPURGE and NLEAP, will help a farmer or rancher plan to minimize potential harmful effects to water quality, but must be tested in the field to ensure their effectiveness.

Holders of agricultural water rights continue to be pressured to transfer their rights to meet in-state and out-of-state demands. Studies of water rights transfer strategies, potentials, and associated issues are needed so that New Mexico can respond to growing demands for its water resources. Research on the effects of increased urbanization on agricultural surface water quantity and quality in areas such as Taos, Chama, Santa Fe, Aztec, Bloomfield, Farmington, and Las Cruces must be undertaken.

The Soil Conservation Service has hired many new employees from New Mexico State University and sister institutions. Our personnel budget has been tight in recent years, but the situation looks better for Fiscal Year 1992. We look forward to hiring additional staff.

New employees should be prepared to work in many areas other than their primary discipline. In addition to strong technical backgrounds, they need to have excellent communications and personal relations skills. Interdisciplinary and interagency work are necessary to address New Mexico's complex water issues. A solid background in the use of computers and an understanding of software applications such as Geographic Information Systems (GIS) and Grazing Land Application (GLA) will be important in working with farmers and ranchers.

Employees must acquire strong leadership and management skills to be successful. Today, SCS's work force is diverse and will continue to be so as our population diversifies. Positive personal values and solid respect for the values of others will serve students well.

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*Donald currently serves as chief of the Technical Division of the SEO. He has been with the agency for the last 13 years and prior to that worked for both the U.S. Bureau of Reclamation and the Army Corps of Engineers. Donald received his B.S. in Civil Engineering from New Mexico State University and his M.S. in the same field from the University of New Mexico.*

I'm Donald T. Lopez, P.E., head of the State Engineer Office's (SEO) technical division. Basically, our training needs are twofold. The first is recruitment of engineers and other professional personnel. We look specifically for university graduates in groundwater and surface water hydrology with an emphasis in water resource engineering. Also, civil engineering graduates and civil engineering technology graduates with an emphasis either on geotechnical engineering or geology are needed. Job training is provided for many of our personnel who then work their way up through the agency. We look for training opportunities for our staff that allow personnel to advance their knowledge of the state-of-the-art in various areas like dam safety, groundwater and surface water hydrology, surveying, and other structural engineering applications.

Regarding research, we are involved actively with many federal and state agencies as well as New Mexico universities. Faculty from NMSU are assisting the SEO by collecting and analyzing hydrological data and creating a water conservation program for the Pecos River system. We are involved in developing new groundwater models that will advance significantly groundwater research and technology. Concerning geotechnical engineering, we are quite interested in working with other federal agencies on dam performance, in particular existing dams throughout the state. We would like to be involved in the geologic interpretation of site conditions to avoid some of the problems that we have had with dams.

We are becoming very actively involved with a global positioning system (GPS) and its surveying capabilities. The SEO's hydrographic survey section is involved in using this new surveying application and we would like to see more research in this area and the use of existing U.S. military information on this technology.

Our staff is becoming more adept in computer engineering and Geographic Information Systems (GIS) and would like to work more closely with other agencies and universities on GIS computer applications.

Finally, our agency would like to initiate a cooperative educational program with New Mexico universities. In 1968 I was a NMSU co-op student with the New Mexico State Highway Department. We have found that co-op graduates become very effective personnel at technical agencies like the SEO.

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