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As Chairperson of the WYOMING WATER '85 Symposium Organizing Committee, I would like to take this opportunity to express my great appreciation to each individual who helped make the symposium and these Proceedings possible.

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Steve A. Mizell, Chairman
WYOMING WATER '85
Organizing Committee

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WATER ISSUES AND PROBLEMS: AN INDUSTRIAL VIEWPOINT

Bill Budd
Wyoming Mining Association

My assignment is to define and list the important water resource issues and problems from industry's viewpoint. This is one of the easier assignments I have had since existing industry really has no immediate direct needs that are not being met. There is always an indirect need for water for domestic use by municipalities for industrial employees but since this is to be addressed by the next speaker, I will not dwell on it.

If and when synfuel plants become a reality in Wyoming, the demand for water will be substantial. A coal gasification plant that would produce 250 million cubic feet of gas per day would use between 5,000 and 14,000 acre feet of water per year. We believe the need would be closer to 5,000 acre feet than to the upper figure of 14,000 acre feet. A coal liquification plant that would produce 100,000 barrels of oil per day would need about 10,000 acre feet of water per year. It is likely that any liquification plants built in Wyoming would be smaller than 100,000 barrels per day.

The other major industrial user of water is coal-fired power plants. As long as the growth rate of electrical needs remains at or below 2 percent per year, the present plants can adequately handle our needs for several years. The present growth rate is about 1.5 percent per year and is unlikely to increase substantially in the short term. If the growth rate should accelerate to the point that additional power plants would be needed, a one thousand megawatt plant would consume about 7,000 acre feet of water per year.

Industry uses a very small percentage of the total water requirements in Wyoming. Agriculture uses over 90 percent of all the water consumptively used in Wyoming. I see no indication that this will change, in the short-range. Municipalities and industry use about the same amounts of water and again I see little change in the short-range. In terms of diverted water, agriculture accounts for 96 percent of all diverted water.

Industry supports the concept of water development. Even though we do not see any large demand in the near future, we realize that growth of any kind, short-range or long-range, will require adequate water. We are sure that in the long-range there will be demands for more energy and that will require additional water. Even if industry does not have a consumptive use for water, its employees will always need water for households, yards and recreational use.

It is impossible to determine in advance what future laws will dictate concerning the use of water that originates within Wyoming's boundaries. We feel that the sooner we can develop a beneficial use for the unallocated water in Wyoming, the stronger will be our position to maintain a legal right to that water when it is needed later on. It seems logical that any water that is developed and/or stored by the State of Wyoming could be sold to downstream users. It is certain that if downstream users are able to establish a legal right to water that is presently leaving Wyoming, we will never regain title to that resource. I believe that the mineral industry stands ready to do our part to help in this development of Wyoming water resources.

WATER RESOURCE PROBLEMS FOR MUNICIPAL WATER DEVELOPMENT WITHIN THE STATE OF WYOMING

Herman Noe
Cheyenne Board of Public Utilities

As I see it, the issues facing many Wyoming communities as they consider the development of municipal water supplies are:

1. Financial funding
2. Water availability (in the quantities needed)
3. Lack of preplanning or masterplanning
4. Environmental issues

As is true with most things, water resource development is becoming more expensive with each passing year. The easiest or less costly water resources are developed first, leaving the more difficult and more costly water development projects for subsequent development. As time passes, the influences of inflation and higher interest rates increase project costs.

For example: Cheyenne's first community water system began in about 1880 with direct diversions from Crow Creek and shallow wells. In 1910, as Cheyenne grew, dams and reservoirs were constructed about 20 miles west of town to impound the flows of Crow Creek. In the 1930's through the early 1950's, Cheyenne constructed well fields in the surrounding area to meet the City's growing need for water. By the early 1960's, Cheyenne found itself looking 75 miles to its west for water supply from the Snowy Range Mountains.

By 1964, Cheyenne was taking water from the Snowy Range Mountains to supplement its municipal water supply. However, due to prior appropriations of the flows of the North Platte River, Cheyenne had to replace the diversions made from the Snowy Range Mountains with water from the Little Snake Drainage (which lies on the west side of the Continental Divide). This Stage I water development project had a cost of $10 million in the early 1960's. By the 1980's, a Stage II expansion of the Stage I system is estimated to have a price tag of over $100 million.

Funding the costs associated with the development and construction of major water development projects is a major problem for many municipalities. The State of Wyoming offers significant financial assistance through the Farm Loan Board and the Water Development Commission. However, even with assistance from State grants and low interest loans, communities are finding it extremely difficult to fund multi-million dollar projects. Consumers are willing to bear only so much in increased utility rates. For example: Cheyenne's water rates have tripled from 50 cents per thousand gallons in 1960 to $1.50 per thousand gallons in 1985.

Failure to prepare for, that is failure to plan for, future water resource needs and the associated financial funding is a common mistake of many communities. As the development of water resources becomes more difficult and more costly, communities must learn to perform adequate advance planning. Not only should such preplanning (or masterplanning) address the physical components of a future water development program, but it should also set in motion the methods necessary to fund such projects. Planned water rate increases, capital facility connection fees, State grants and low interest loans, bond issues, 1 percent sales tax options and capital account sinking funds are some of the tools that deserve consideration in the financial planning process.

Masterplanning for the physical components of a water supply project should consider the rate of growth the community is expected to experience, what water supply needs will exist over the next 20-year planning period, what water development options or alternatives are available, what is the reliability or dependability of the water supply in terms of uniform annual yield and carry-over supply in years of drought, what is the potential for systematic expansion of the system as future water needs increase, what is the initial development or construction cost, what is the annual operating cost, what is the expected water quality of the supply, what environmental issues will have to be resolved and what water project can be envisioned to meet the 40- and 50-year needs of the community (the water supply needs beyond the immediate 20 year planning period).

There are a number of environmental laws and environmental groups that generate issues that must be resolved before construction of a project can begin.

A few examples are:

1. The 404 permit needed from the U.S. Army Corps of Engineers.
2. Permits needed from the Wyoming Department of Environmental Quality.
3. The National Environmental Protection Act.
4. The Endangered Species Act.
5. Potentials for legal actions by any number of environmental groups.

As with inflation and higher interest rates, environmental concerns escalate the costs of certain water development projects. I am not suggesting that development be given a free hand to bring about careless disruption of the environment, nor am I saying that environmental extremists be allowed to demand unrealistic blackmail. I am saying that today's world of environmental awareness creates certain impacts on water development projects creating higher costs and reduced water yield potentials. Consideration must be given to the impacts of environmental issues.

Again, I offer an example of the Cheyenne Stage II water development project. In 1976, the Board approached the Forest Service for an easement to allow the construction of the Stage II water project. At that point in time, Stage II was estimated to cost about $66 million. The project would have developed and delivered 21,000 acre feet of water per year. In 1982, (after six years, six major government studies and two environmental oriented lawsuits) the Stage II project had been reduced in yield by 25 percent, to an annual water yield of 15,800 acre feet. Yet the costs had escalated by 50 percent to an estimated $100 million. The planning process for water development projects must take into consideration that environmental concerns can delay construction of a project, increase project costs and reduce potential water yields. Consideration of these factors can affect which project will be the best and most desirable.

One item that deserves further discussion is water availability. As exampled earlier, it is not unusual for communities to have to look further and further from their boundaries to find adequate water supplies. Even though we have vast arid regions, there exists a condition in Wyoming whereby hundreds of thousands of acre feet of surplus water, from high mountain runoff, exit our borders every year.

Even though excess water supply is available on a state-wide basis, the water supply is not always available where it is needed most. Thusly, the concepts of transporting water considerable distances is being discussed more and more with each passing year. However, even if the logistics of water supply and water need are worked out, what is the probability that our current water surpluses will still be available in 10, 20 or even 50 years when it will be needed? I contend that if left undeveloped, there is a high probability that the downstream states will systematically lay claim to our surplus waters and prevent our future use. The Congress of the United States can establish the law of the land and Wyoming has only three votes out of over 500 total votes.

I support the philosophy that the best way to protect our temporarily excess water supplies is to develop them as soon as possible.

In summary, the major problems facing water development for Wyoming communities are:

1. Financial funding.
2. Water availability.
3. Lack of preplanning.
4. Environmental issues.

In conclusion, the best approach for resolving the problems facing water development is to be prepared by planning ahead. The preplanning process should give consideration to:

1. Future population growth projections and associated water need (a 20-year planning period is not uncommon).
2. The development of project alternatives.
3. The evaluation of project alternatives.
    a. Reliability and dependability of the supply (average years and drought years).
    b. Potential for systematic expansion.
    c. Development and construction costs.
    d. Operating costs.
    e. Water quality.

f. The impacts of environmental issues.

g. What project is envisioned to meet the 40- or 50-year water needs.

4. Methods for funding project costs.

Take the time to plan ahead and keep such masterplans updated by annual review.

WATER ISSUES AND PROBLEMS: AGRICULTURAL PERSPECTIVE

Larry J. Bourret
Wyoming Farm Bureau Federation

We, in Wyoming, find ourselves in a unique situation with water. We have a great deal of water in some years and in other years we do not have enough water. We have large amounts during some parts of the year and during other parts of the year we do not have enough. The State Engineer tells us we produce an average of 17 million acre feet, and that an average of 14 million acre feet leaves the state each year. We use about 3 million acre feet of the 6 million acre feet we are entitled to under the compacts and decrees. The question really is "What are we going to do during the low water years and during the low water seasons of the year?".

Everyone is concerned about the low water years or months. A farm or ranch, municipality, industry or recreation cannot do with averages--the low flows or lack of flows are what each entity worries about. The debate of today will determine the future--just where are we going? Nebraska, Arizona and other downstream states have a tremendous stake in what we do <u>and</u> in what we do not do.

There are those who say build now because the demand will come and others say don't build until the demand comes. Interstate 80 would still be a two- or three-lane highway if we didn't plan and build ahead of demand. We suspect that more irrigated lands will be taken out of production if other supplies are not provided.

The 1970's will probably come again. How do we prepare? The law says some of the coal taxes should go to renewable resource development.

Problems which we see are:

1. Identification of amounts of water and the amount of appropriation already approved. We often do not know how much is available, how much is appropriated and how much is therefore still available.

2. Federal government claims such as the "reserved water doctrine". The U.S. Forest Service says they can reserve water for "favorable conditions of water flow" and that they want those flows in the spring. We also hear that we need water for instream flow during the low flow part of the year. Can we develop projects that will be feasible given these conflicting demands? Can we store the high flows if the U.S. Forest Service says they want the water during the high flow season?

3. Mitigation demands on storage projects may make some infeasible. Is mitigation the same as instream flow? If not then what are we dealing with?

4. Planning - we must dovetail known and often unknown needs and obtain answers on unknowns so that we can plan. We must obtain as many answers as possible.

It is best that we let our water continue to leave the state or will the future show us (or our heirs) that we should have made added investment even if we looked a bit silly at the time?

Agriculture cannot now show much, if any, ability to pay for water. We need to look at the long-term however. We certainly could have given a different answer in 1973-75; in 1978-79. Who knows what the future will bring. Over the long haul the picture is different than it looks today.

We need to determine who should own the projects. Should the State own them? If not the State, then who?

Research is needed in several areas as follows:

1. Irrigation costs
   a. Flood meadow
   b. Flood intensive cropland
   c. Sprinklers
      1. Side-roll
      2. Circular

   This information needs to be constantly updated because costs change all the time.

2. Cost of doubling the capacity of delivery facilities for March 2, 1945 through March 1, 1984 irrigation rights. Benefits data is also needed. The 1985

Legislature enacted a new law providing an additional one cubic foot per second of water per 70 acres of land and water right holders need to know what the economics are of making use of this water.

3. Mitigation check list for landowners. A check list is needed so that landowners do not neglect to check on items in cases involving mitigation.

4. Computerized analysis of water right amounts analyzed by average flow, average high flow and average low flow considering pre-March 2, 1945 rights and March 2, 1945 through March 1, 1985 rights. This would tell irrigators something of the possibilities of water during average, high and low water years and allow them to plan better. This information is needed by stream segment so each water right can be analyzed under average, low and high water conditions.

WATER ISSUES AND PROBLEMS: ENVIRONMENTAL-FISHERY PERSPECTIVE

Robert W. Wiley
Wyoming Game and Fish Department

The Wyoming Game and Fish Department is statutorily empowered, to manage wildlife (and fisheries) in Wyoming. Section 23-1-103 of the Wyoming statutes provides in part that..."It is the purpose of this act and the policy of the State to provide an adequate and flexible system for control, propagation, management, protection, and regulation of all Wyoming wildlife."

WATER FISHERY RELATED ISSUES

Relative to water-fishery related issues, generally, the Department feels that the public must be as well informed on water related issues as possible in order that informed decisions about these issues can be made. Water issues are becoming increasingly controversial as the demand for water increases. As we have all come to know, decisions on water issues are no longer made by a single agency, user group or even the Legislature.

Portions of several public and private groups are involved in all major water development issues. We have only to consider one or two of the water projects espoused by the Water Development Commission to see the extent of the interest. Questions are raised over a broad range of issues including, but not limited to, perceived need for water, financing of projects, and instream flows. More and more of these questions are being, and will be addressed by the courts if not otherwise resolved to the satisfaction of everyone. We all need to work together to understand the issues.

ACID DEPOSITION

Acid deposition is a topic relatively new to the West. Its more familiar name is Acid Rain and I am reasonably certain many have heard about the problems in the eastern United States and Europe. There, fisheries and forest resources have been drastically affected by acid rain. We are interested in the problem in Wyoming because there is a need to obtain background data on potentially affected waters before the problem is upon us. High mountain (above 7,500 feet elevation) lakes are more susceptible to the effects of acid rain because those waters are only lightly buffered and could not withstand the addition of even small amounts of acidic substances without loss of aquatic life. There are about 1,900 alpine lakes in Wyoming though not all may be susceptible to acidification.

FISHERY RESOURCE VALUATION

There is a need to establish representative values for fisheries and other water-based recreation forms. Such information is important in consideration of water use issues. Economists have wrestled with this knotty problem for many years and information shows that the value of fishery resources and associated water-based recreation is inversely proportional to its abundance.

STREAM CHANNEL ALTERATION

There is a great need for recognition of the effects of stream channel alteration in Wyoming and there is need to control such alteration or at least assure that where it is necessary it is accomplished in the best possible way.

Nationally, streams are being altered at a rate of 6,000 miles per year. Even in Wyoming over 10 miles a year are altered. Without some modification or control of this activity, the following losses will mount;

1. Property will continue to be lost from flooding and erosion.
2. Property values will be reduced.
3. Tax dollars will be wasted to correct avoidable problems.
4. Esthetic values will be depressed.
5. Fishing opportunity will be lost.
6. Wildlife diversity will be reduced.

The Federal 404 permitting program has offered some assistance in this regard. The program is however, unpopular with individuals and does represent federal control.

Most channel work that is flood and erosion related can be corrected without drastically altering stream channels which usually leads to greater problems.

It is time, in Wyoming, to adopt some sort of review or permit system pertaining to stream channel alteration. While this carries some governmental overview requirements, the benefits to landowners, water users, and stream resources are of far greater importance.

RECOGNITION OF INSTREAM FLOWS

This issue has occupied much space in the past few years and it seems only logical to recognize an instream use of water to support fish in stream segments as beneficial uses of water. The goal of the Game and Fish Department, relative to instream flows, is to preserve and maintain the current resource. An instream use of water should and would be subject to the same legal constraints as any other use of water.

The Department's position has always been that instream uses should be able to compete on equal grounds with other water uses and that they should not enjoy privileges over other kinds of water rights. The State Engineer, as chief administrator of Wyoming's water, has always considered legally recognized uses of water effectively and has indicated that instream flow rights can be considered as well.

SEDIMENTATION AND CHANNEL MAINTENANCE

Sedimentation and sediment transportation are natural processes in streams. Activities that modify stream drainages (logging road building and so on) all have an effect on the amount of sediment reaching a stream. If sediment reaching a stream is in excess of the ability to move through the system changes in stream pattern can be expected.

Flushing flows are important in maintaining stream integrity. Such flows typify spring runoff but duration of flows necessary to "clean" (move natural sediment) channel are not yet well understood. The Wyoming Water Research Center is currently working on a project to determine flushing flow requirements for channel maintenance purposes.

There is also need to recognize the relationships between sediment generation and impact on fisheries. Once this is understood, it must be incorporated in land management planning to minimize the effects of land practices on the stream environment.

SUMMARY

Several important concerns have been highlighted; awareness of water issues, acid rain, economic valuation of fisheries, stream channel alteration, instream flows, and sedimentation. I believe that all water use interests can work together towards addressing these issues and accomplish water development and fishery resource protection.

WATER ECONOMICS

WATER INFORMATION MANAGEMENT FOR ECONOMIC RESEARCH

John W. Green
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ABSTRACT

The Water Branch, Natural Resource Economic Division, Economic Research Service, U.S. Department of Agriculture, has the mission to anticipate and conduct a program of national research on issues related to water of importance to agriculture and rural communities. In order to perform this mission, analysts must be aware of and have access to data and models describing water supply, quality and demand and the interactions between them and the society in which they are measured. The Water Information Management System (WIMS) is designed to meet that need.

More than 300 databases and models have been identified and entered into the Directory of Water Information System. Digital documentation is available for the system and I will be demonstrating it on a Compaq at the Symposium.

The WIMS also classifies databases and models according to access frequency and outlines a system for organizing, documenting and maintaining the information in each category. Micro computer hardware complements and software packages are identified and their integration discussed and demonstrated using data from the 1978 and 1982 Census of Agriculture.

INTRODUCTION AND PURPOSE

The Federal Government's water data acquisition activities support scores of missions involving the Nation's water resources. Federal agencies are responsible for planning, designing, constructing and operating water projects; river and flood forecasting and warning services; water-supply planning; emergency response to critical water problems such as floods, droughts and hazardous-waste spills; water pollution control;

international treaties and interstate compacts relating to water resources; and numerous other water resources functions. Federal expenditures associated with these water-related responsibilities are difficult to quantify accurately, but have probably exceeded $6 billion annually in recent years.

The need for water data continues to increase as it has for the past 10-12 years. Since 1972, approximately two dozen major pieces of legislation have been enacted that require water data for implementation. Most of this legislation required new types of data because it called for the protection of the water resources and other elements of the environment rather than the more traditional functions of planning and managing for water supply purposes. The trend of decreasing Federal outlays for water data acquisition evident in the early 80's appears to have reversed in response to the ever-increasing need for water data throughout the nation.

Water Data Coordination

A "Federal Plan for Water-Data Acquisition" is prepared each year as required by Office of Management and Budget (OMB) Circular A-67. Circular A-67 requires the Department of the Interior (DOI) to coordinate water-data acquisition activities of the Federal Government. Also, as part of the implementation of Circular A-67, the Secretary of the Interior established the Interagency Advisory Committee on Water Data (IACWD). The IACWD members represent Federal agencies that collect or use water data. The "Federal Plan for Water-Data Acquisition" is prepared by the Office of Water Data Coordination within the U.S. Geological Survey (USGS) in cooperation with the IACWD.

Federal agencies cooperate to collect water data by requesting hydrologic data collection and investigations on a reimbursable basis from the USGS and each other. Data collected under federal arrangements are normally stored for future use by the entire water resources community. This large data-user service is made possible through the cooperative efforts of federal and non-federal organizations that help maintain a national data system. Some federal agencies can obtain needed data entirely through other sources, i.e., the Federal Emergency Management Agency (FEMA). Many agencies can operate smaller in-house data acquisition programs because the bulk of their requirements are met through cooperative programs and data sharing through the national data system. In-house programs are established when special requirements cannot be effectively or economically met using existing sources.

Hydrologic data activities are indexed by the National Water Data Exchange (NAWDEX) so they can be shared. NAWDEX is a consortium of over 250 water data users and collectors--federal, state and local governments and the private sector. The program is managed by the USGS in support of data sharing and user services. NAWDEX is a directory and catalog of water data exchange information, not a data source.

Almost all federal water resources responsibilities are performed in coordination with state and local governments. For example, the Cooperative State Research Service serves to facilitate coordination and provide linkage between federal programs and state components such as state agricultural experiment stations, the 1890 land grant institutions and the forestry schools. Some responsibilities also involve coordination with organizations in the private sector having water-related interests, such as hydropower and water supply utilities. In many instances, data to support federal aspects of water programs are provided or funded by the private sector.

The district offices of the USGS serve as a focal point for coordination with state and local agencies and the field offices of federal agencies. For years, the USGS's Federal-State Cooperative Program has provided the basis for close coordination of programs at the state level. This is especially true for the stream-gaging program, which has long been conducted by the USGS with strong local financial support. In short, water information collection and use is a joint federal, state, local and private effort. Increased automation and demand for water information are influencing the direction of water data programs.

<u>Trends Affecting Water Data Programs</u>

Several factors seem to be affecting water data activities of more than one federal agency. They are:

1. Increased use of automation.
2. Increased use of satellite telemetry.
3. New data management systems.
4. Increased river basin studies.
5. More dependence on historical data.
6. More environmental legislation.
7. Increased need for hydrologic information in small basins.
8. New federal policies.

The first three trends mentioned relate to an important class of current water data acquisition activities. These immediate-need, current conditions data systems support critical operational missions. Agencies involved in water control and forecasting work closely together to obtain and exchange information. This is because their missions are interdependent. For example, water control managers use forecasts of precipitation, temperature, streamflow, snowmelt, and other data to decide how water should be stored or released in reservoirs. Forecasters use reservoir release information to estimate flows downstream. All the agencies need measurements of river stage, discharge, temperature, rainfall, snowdepth, snow water equivalent in the pack, and other data to trace current water quality conditions.

Minicomputers are an important new breakthrough in handling current conditions water data. Data are fed automatically into powerful, but small computers. The computers then perform data reduction tasks, simulation and analysis, graphics display, and data distribution to other offices.

Hardware is not the major concern. Software is, and agencies are working together on this problem. Several important interagency coordination initiatives occurred in FY1984. Over several years, the National Weather Service (NWS) developed a Standard Hydrometeorological Exchange Format (SHEF) for computer-to-computer data exchange. The NWS and Corps of Engineers (COE) are using SHEF under an interagency agreement called TRADE (Test Reliability and Data Exchange). At the request of NWS, a technical working group (TWG) was established under the Circular A-67 water data program to coordinate standard formats and procedures for current conditions data exchange for all agencies.

The key concerns for the late 80's appear to be groundwater quality, toxic pollutants, toxic waste management, groundwater quality research, nonpoint source pollution, and other environmental quality issues.

The Environmental Protection Agency (EPA) is planning a major activity to protect the Nation's groundwater resources. In August 1984, they published their Groundwater Protection Strategy which describes planned activities and identifies groundwater contamination as a major environmental issue of the 80's. They have already begun to implement the protection strategies which contain the following core elements:

1. Strengthen state groundwater programs.

2. Cope with currently unaddressed groundwater problems.

3. Create a policy framework for guiding EPA programs.

4. Strengthen internal groundwater organization.

Water Data Needs for Economic Analysis

The mission of the Economic Research Service (ERS) is to conduct a national program of research and policy analysis on economic and environmental factors relating to the use, conservation, development, management and control of land and water resources in agriculture.

Data are needed to assess the adequacy and efficiency of water use, competition by agriculture for limited water supplies, cost effectiveness of production practices, and policy measures to improve water quality in rural areas. Water quantity and quality data available from federal and state agencies are used in economic analyses. Investments, costs and other economic data related to water resources are obtained from the Agricultural Census and the ERS Resource Economic Survey (RES). These data are used to evaluate emerging trends in farm uses for water supplies, alternative policies for managing water resources, impacts of water quality protection measures, and public and private resource development and conservation expenditures.

ERS does not collect physical data on water quantity or quality. However, the Natural Resource Economics Division (NRED) conducts economic studies on the extent and impacts of groundwater mining and on alternative irrigation systems for water conservation. The NRED also conducts studies to identify the linkage between agricultural nonpoint source pollutants and impaired water uses and to assess the extent of damage attributable to agricultural sources.

Plans have been developed to initiate a RES to obtain national and regional data. A 5-year rotating schedule will be followed to obtain economic information about soil conservation and water quality improvement practices; landownership; land use; conversions and improvements; and water use, sources and irrigation practices.

The ERS plans to develop a national database of socioeconomic information about agricultural land and water resources. The data system will be designed to compile economic data from RES and other sources and relate it to physical data collected by other agencies.

The Natural Resources and Environmental Committee (NRE) has charged the Water Issues Working Group (WIWG) and the Resource Assessment Appraisal and Program Development Working Group (RAAPD) to scope and prepare a data collection effort to obtain water information needed by the U.S. Department of Agriculture. The information needed by the U.S. Department of Agriculture. The information collection effort will be accomplished by cooperative activities of several departmental and other government agencies. The NRED economic data activity is centered in the Water Economics Branch in the Water Use and Trends Project.

The Water Information Management System (WIMS) being developed in the Water Use and Trends Project has as its general objectives to:

1. make available water information to assess water resource status, conditions and trends;
2. provide initial training and continuing technical assistance to Water Economics Branch researchers on the use and continuing development of WIMS; and
3. develop effective means of communicating the availability of water data.

The Water Information Management System being developed for the Water Branch first locates and briefly outlines 300 data files which describe groundwater, surface water, water quality, water models, agricultural water use or socioeconomic data supporting water research. This process and the resulting Directory is described below where the types of water data files are summarized and discussed in general terms. Most of the data files which have currently been identified are listed under one or more of several headings. A more complete description and access information on each data file is maintained in an IBM PC XT database. Twenty-four fields describing each data file are stored using Rbase 4000, a relational database management program.

The organization and structure of WIMS, sources of water information and accessibility to information resident in the water data files identified in the Directory of Water Information will also be discussed. This paper also briefly discusses hardware and software requirements for Water Branch access to and use of water data.

AN INVENTORY OF WATER DATA SOURCES

Sources of information describing water inventories, use and modeling were investigated to develop an inventory which researchers could access to identify data to support research projects and policy evaluations. Preliminary examination suggested that the data files and models identified should be classified into similar groups corresponding to keywords which could then be used to sort the water data files and models. The following groups were used to classify the data files and models.

- Surface Water
- Groundwater
- Water Quality
- Socioeconomic
- Agricultural
- Water Rights and Institutions
- Miscellaneous

Within each group, data files and models were identified from several different sources. The source is useful in assessing the general accessibility of the data or model, its geographical coverage and its quality. Definitive statements must be reserved until after each data file or model is used.

The possible sources of data are listed below. Each source may not apply to all of the above classifications.

- Federal Government
- State Government
- Commercial Vendors
- International Sources
- Models

A total of 292 data files or models have now been entered into the Directory. A general division of data files and models, by category, is described below.

<u>Surface Water Data Sources</u>

At least 129 data files or models have been identified from federal, state and commercial sources. At least 25 surface water models are described in the Directory.

<u>Groundwater Data Sources</u>

At least 81 data files or models have been identified from federal, state and commercial sources. In addition, four groundwater models were identified.

<u>Water Quality Data Sources</u>

More than 105 data files or models have been identified from federal and state governments and commercial and international sources. In addition, 29 water quality models are described in the WIMS Directory.

Socieoeconomic Data Sources

Only 7 data files or models have currently been identified. This area needs to be substantially expanded by identifying additional data files, systems and models available to complement water information, models and resulting analyses. Most sources of economic data which have currently been identified are available from commercial vendors.

Agricultural Data Sources

At least 26 data files or models have been identified in the WIMS Directory from federal, state and commercial sources. In addition, 8 agricultural water models were identified. This area should also be strengthened through the identification and description of large and smaller models available in ERS, Forest Service, Soil Conservation Service and at land-grant universities.

Water Rights and Institutions Data Sources

There are 12 data files describing water rights currently identified in the WIMS Directory and 11 data files which provide legal information about water issues; only 1 of the 23 data files overlap. Proprietary data problems are more likely to be encountered with these data files than any other category.

Miscellaneous Data Sources

There are a number of data files which could not be neatly categorized; these were included in this miscellaneous category.

Use of these data files or information systems may suggest that they should be included in one of the above categories.

Commercial and International References

The WIMS Directory currently lists 13 data files dealing with water or water issues available through DIALOG, a commercial vendor. Another commercial vendor, NEWSNET, is listed 13 times for news-related services dealing with water issues. There are also other commercial vendors represented in the WIMS Directory. The WIMS Directory lists 19 international sources of water data or information.

Data Source Description and Access: The WIMS Directory

The Water Economics Branch, Natural Resource Economics Division, Economic Research Service, U.S. Department of Agriculture is currently developing a Water Information Management System (WIMS) to help water researchers locate water information, access it and use it in their research projects. The first step in that process was to develop a directory of water information, including brief descriptions of each data or text file or model and access information.

The Directory of Water Information is an IBM PC XT based bibliography which uses Rbase 4000 as a database management system, i.e., the Directory runs on an IBM PC XT using Rbase 4000, a relational database management program. The Directory requires a hard disk because the database itself currently exceeds 450K (more than 1 floppy diskett just for the data, excluding the Rbase 4000 program).

The Directory contains 24 fields totaling 887 characters. Each field is described below. Additional fields can be created, or existing fields expanded, up to the Rbase record size limit of 1,530 characters. Every record contains the following information on each data file or model.

1. NAME — DATA FILE NAME — TEXT — 90

   This field is the name of the data file or model described in the rest of the record. TEXT indicates the designation of the field within the relation WIMS. All fields are currently defined as TEXT (textual information). The number 90 indicates the currently defined length of the field, i.e., the field can contain a maximum of 90 characters.

2. ACRONYM — DATA FILE ACRONYM — TEXT — 10

   In most cases, an acronym is commonly used and presented in the literature. If one was not presented, I selected one which seemed reasonable.

3. NUMBER — DATA FILE NUMBER — TEXT — 4

   This is a sequential number assigned to each record.

4. UPDATE — ENTRY/UPDATE DATE — TEXT — 8

   This is the date on which the record was entered into the Directory. This date should be changed when updates are made to the Directory.

5. KEYWORDS — KEYWORDS — TEXT — 75

   This field contains a list of keywords I selected based on my knowledge of the data file and the written abstract. Each keyword is separated by a comma; the Directory can be searched using textual strings, i.e., "groundwater."

6. ABSTRACT ABSTRACT TEXT 350

This field contains a description of the data file. In many cases, the size of this field was inadequate to accommodate the entire description. This field should be lengthened to handle a more complete description of the data file described by each record.

7. AGENCY AGENCY/VENDOR TEXT 10

This is the government agency or commercial vendor which collected and/or maintains the data, i.e., USGS or DIALOG. In the case of data files accessed through DIALOG and other commercial vendors, the data is maintained by some other entity; this Directory should be updated to reflect this fact so that researchers with specific questions about the data can go right to the source of the information.

8. CONTACT CONTACT NAME TEXT 30

This is the name of the person in the agency or at the vendor who is responsible for the data file or who can provide information on how to gain access to the data.

9. COM-TEL COMMERCIAL TELEPHONE TEXT 25

This is the commercial telephone number of the person at the agency or vendor who can provide information about the data file or information about how to access the data.

10. FTS-TEL FTS TELEPHONE TEXT 10

This is the FTS telephone number of the person at the federal agency who can provide information about the data file or information about how to access the data.

11. COST CHARGE FOR USE TEXT 15

This field presents the cost of accessing the data file, if known. In many of the records, this will be general information, i.e., that the data file is free or that an access fee is charged.

12. GEO-COV GEOGRAPHICAL COVERAGE TEXT 15

This field describes the geographic coverage of the data file, i.e., "US" or "NATIONAL" or "INTERNATIONAL".

13. INFO-TYP INFORMATION TYPE TEXT 10

This describes the kind of information contained in the data file, i.e., data, model, biblio, text, etc. If model is listed in this filed, the record describes a model, not a data file. Biblio is an abbreviation for bibliography, i.e., a database such as this Directory.

14. STATUS DATA FILE STATUS TEXT 15

This field lists the status of the data file described by this record. In most cases, the files are currently operational or available, although some have been archived or are inactive.

15. ACCESS ACCESS TEXT 15

This field states whether access to the data file is limited. Access to many files is restricted because they may contain some proprietary data.

16. ACES-MTH ACCESS METHOD TEXT 20

This field indicates how the data file may be accessed. Most files are accessible on-line using a telephone and modem, others can only be accessed via batch requests. Some are available only on a tape obtained from the agency maintaining the information.

17. NO-RECRD NUMBER OF RECORDS TEXT 15

This is the number of records contained in the data file. This number is not known for many files or is constantly changing as information is added.

18. COM-MOD COMPUTER MODEL(S) TEXT 15

This is the name and model of the computer on which the data file resides or on which the model was programmed. Computer model is not very restrictive in terms of whether the data file or model is transportable; the language is more important.

19. DOC DOCUMENTATION TEXT 15

This field indicates whether documentation is available describing the contents of the data file or model.

20. LANGUAGE LANGUAGE(S) TEXT 15

This is the language or languages in which the data file or model has been programmed or which control its access. This may be a limiting factor when transporting the data file or model to USDA computers.

21. RELIABIL RELIABILITY TEXT 15

This field gives some indication of the reliability of the data file. In many cases, it is a subjective estimate by someone knowledgeable about the data. This field is not relevant if the record describes a model.

22. UPDAT-FQ UPDATE FREQUENCY TEXT 15

This field indicates how often the data file is updated or how frequently a model is modified.

23. TIME-PER DATA TIME PERIOD TEXT 20

This field presents the beginning of the data collection effort represented by the data file and whether data is still being collected.

24. COMMENTS COMMENTS TEXT 75

This field presents comments relevant to accessing or using the data file or model. In many cases, this is information which could not be included in the abstract field because of limited space.

As mentioned earlier, the size of each record can be expanded to 1,530 characters by expanding existing fields, i.e., the ABSTRACT or COMMENTS fields, or by adding new fields. It must be kept in mind, however, that the amount of information which can be displayed on a single page of computer printout may be substantially less than the maximum of 1,530 characters.

WIMS Organization, Structure and Accessibility

The organization, structure and accessibility of data for water economics research is determined by the importance of the information. Some data, like Census of Agriculture irrigation data, is used frequently by Water Branch researchers while other data, for example, municipal water systems, will be needed very infrequently. In addition, some data is located and maintained on-line by other agencies, like USGS, and it makes little sense for ERS to install and maintain it in-house.

Because of the varying importance of and accessibility to data, the following categories are part of the WIMS organizational structure. Each data file or model in the Directory will be identified with one of these categories and its contents handled accordingly. In some cases it is conceivable that a data file could be divided between more than one category. Obviously, this is a system which will evolve over time and shifts between categories will occur. WIMS is a Directory and organizational system of water information. Water information will be stored and accessible via personal computers, on-line access, in-house storage, extent on-line access or through the administering agency depending on ERS information demands. The structure of the water information system is based on data file size, accessibility and frequency of use.

PC-Based Information

Some data files are used so frequently that the Water Branch will want them immediately accessible for research. These files will be copied from mainframe compatible 9-track tapes onto floppy diskettes which can be organized and manipulated using off-the-shelf software packages. I will briefly discuss those software programs and the way they fit together later in this paper.

On-Line Access

There are two on-line access categories recommended for water information. The first is on-line access to data files and models maintained by other agencies. The second is the Agricultural Research Information Economic Studies System (ARIES), the database management system used by USDA on its mainframe in Washington, D.C.

Extant, On-Line Systems. There are several database systems maintained by other agencies which ERS should access to efficiently perform economic research on water issues. The largest and best known of these systems is maintained by the USGS. The Water Branch has established an account on NAWDEX, the National Water Data Exchange, the gateway to the many data files maintained by the USGS. The ERS also has a computer access account with DIALOG, thus gaining access to information about many commercial data files. It is probable that some data accessed on-line, especially from USGS, will be downloaded to IBM PC hard disk because of its frequency of use. Other agencies with on-line data systems will be contacted in the future as the WIMS grows.

Agricultural Research Information Economic Studies (ARIES) System. The ERS has its own database management system, called ARIES. Some data files containing water information valuable to researchers, which does not currently reside in an accessible on-line system, will be obtained from its source and entered into ARIES by ERS systems analysts. This information will then be available on ERS's own in-house, on-line system. An example of a data file in this category is the information maintained by the Bureau of Reclamation. They have a substantial amount of information describing annual characteristics of water use and cropping patterns on irrigation and water use projects throughout the West. They have agreed to share that information with ERS but it cannot be accessed on-line. In this case, ERS will obtain tapes containing several years of information, enter it into ARIES and analyze it using the mainframe computer. Some of this information will also be downloaded to the PC.

Infrequently Used Information and Models

Many data files and most models will be of little use to researchers in the Water Branch. Most of these will not be obtained for in-house storage or use. Some data files and models, however, although not immediately useful to water researchers, will be important enough to obtain and store at Water Branch Headquarters or at the Washington Computer Center. These data files and models will be of significant potential interest to researchers and therefore will be obtained to quickly service staff requests or short-term research projects. Any costs involved in obtaining, cataloging and maintaining these infrequently used data files and models will be balanced against the probability of their use.

Directory of Water Information Systems

The data files and models which are not likely to be used by Water Branch researchers will still be maintained for reference in the Directory of Water Information. All references to water and socioeconomic data files and models will be maintained in the Directory, even those brought in-house and used on mainframe and microcomputers. The Directory can then be used by management and researchers to locate information and models needed to address a staff request or research project. If the needed data or model has not been obtained, the manager or researcher can then use information in the Directory to initiate a request for the information. If it has already been obtained, he/she will know where to go to gain access to it. The Directory of Water Information will be the most important resource available to Water Branch researchers and must be kept current.

HARDWARE AND SOFTWARE CONFIGURATIONS

This section will concentrate on the minicomputer hardware and software necessary for Water Branch managers and researchers to use information and models deemed important enough to be installed on the IBM PCs in the Water Branch.

Personal Computer Hardware

The personal computer hardware needed in the Water Branch must be capable of using and storing large data files and accessing them from spreadsheet and statistics software packages. This hardware must be standardized enough so that the data software and digital output can be passed between machines and used to demonstrate capabilities at conferences and symposiums, much like I am doing today. This dictates that the hardware be IBM or IBM compatible. The following list outlines what I consider to be minimum hardware configuration necessary to develop and maintain this WIMS Project.

- IBM PC with 2 floppy drives and 135 watt power supply
- 20 megabyte or larger hard disk, preferably internal streaming tape backup device, external for portability (extra boards?)
- Memory board to 640K with clock, parallel and serial ports, etc.
- Color graphics board--not IBM or Hercules
- High resolution color monitor, at least 680 x 400
- Model--1200 baud, 2400 as soon as feasible
- Wide carriage, fast printer with graphics capability
- Plotter, 6-pen preferred
- 8087 chip
- Portable computer with 10MB, parallel and serial ports and RGB plug

An AT with the above capabilities would be desirable because of its increased speed. The goal is to provide an IBM compatible environment that has storage, display, output, demonstration and communication capabilities to allow the manager and researcher to perform efficiently and look professional when demonstrating his/her products. This enhances agency interaction and cooperation and interoffice data compatibility.

Personal Computer Software

There are many software packages available to organize and manipulate large data files, perform statistical analysis, do geographical mapping, build spreadsheets, create reports, do business graphics, etc. The list I present below includes the packages that have demonstrated to me they can do the job. I think they do the job better than most packages on the market, although they may not be the "best" package available of their type.

- Rbase 4000, Rbase 5000 or dBase III. I personally use Rbase 4000 and think it does an excellent job. I am looking forward to getting Rbase 5000 because it has additional, useful features. Our Washington office uses dBase III, as do other agencies I have worked with.

- Statgraphics. I like this package because it integrates a comprehensive set of statistical routines with graphics display. It performs several time series routines, but not simultaneous equations, although I would bet that will shortly be added. It also does linear programming, has comprehensive data file management and is completely menu-driven. It is a little slow and probably too complex for the casual user.

- Lotus 1-2-3, Symphony and/or Framework. Lotus is widely used and almost indispensable. Symphony probably does a better job than Framework, although it is much more complex to learn and use. However, if an analyst knows Lotus very well, Symphony should not be too difficult to learn. In addition, Framework's new copy protection method means the program does not work on all hard disks, including mine, and

I have had trouble getting much satisfaction out of Ashton-Tate. Framework is also limited by the memory of your machine, i.e., some things it does must fit in memory, thus causing problems when working with large data files.

- WordStar, WordPerfect, Leading Edge or whatever. I use WordStar, am used to it and like its power; WordPerfect has been getting good reviews and others speak highly of it. Our Washington office uses Leading Edge.

- Atlas Microcomputer Mapping Software. I have done an extensive review of these packages and this one is the cheapest and, in my opinion, the most flexible. This package is indispensable for presenting, geographically, the results of your analyses.

- GraphWriter, EnerGraphics, etc. I am not very familiar with these packages but other faculty at Colorado State University like GraphWriter. EnerGraphics does not work very well with non-IBM cards and the company has a reputation for not being very responsive.

- CrossTalk, SmartCom, PCTalk III, etc. Most of these seem to work very well.

The essential packages of this group are: (1) the database management system, (2) a word processing package, and (3) a geographical and business graphics package. Spreadsheet and statistics packages are essential once you begin to use the data to build a model or analyze a problem. In the report I am writing for ERS, I use a selected set of these packages on a sample agriculture data set to demonstrate how they can be fit together to perform a specific analysis.

DATA SERVICES CENTER SUPPORT

ERS has a large Data Services Center. It is my feeling that the Center can contribute to this Water Information Management System by doing all the mainframe related work, setting up accounts and access instructions to on-line systems, obtaining necessary documentation for on-line systems, obtaining and storing data tapes and entering data into and maintaining data in the ARIES system.

The Water Branch must be responsible for identifying the personal computer equipment they require, acquiring the necessary software packages, learning those packages, entering and maintaining the data on the personal computer, doing the required analyses and preparing the output for demonstrations and reports.

DEMONSTRATION DIRECTORY

I have brought a portion of the Directory of Water Information with me today and will be demonstrating its use on my Compaq. The Directory I have with me today contains only 193 records because of diskette storage limitations. The data files I have eliminated from the Directory were Eastern and Midwestern state references.

The demonstration Directory contains 193 records. The water information records for Wyoming are included in the national data files; there are no records of data files or models specifically for the State of Wyoming. There are 17 records containing "agricultur" in the keywords field, indicating that those records describe files containing agricultural water data. There are 43 records describing models. There are 5 records describing agricultural models, i.e., where the keywords field contains "agricultur" and the information type field contains "model". There are 11 records where the keywords field contains the word "legal". There are no records where the keywords field contains both "legal" and "agricultur". There are 104 records which are national in scope, i.e., they cover the entire United States. There are 19 records which are international in scope.

SUMMARY

The Water Branch of the Natural Resource Economics Division, Economic Research Service is developing a Water Information Management System to assist managers and researchers in responding to staff requests and to complete research projects. This System consists of a Directory of Water Information which lists, in an automated, microcomputer-based database management system, 300 data files and models relevant to water and economic research.

Data files and models in the Directory are categorized into groups depending on the immediacy of need for Water Branch researchers, accessibility of the data and frequency of access. Frequently used data files and models will be obtained and installed on IBM-compatible microcomputers. On-line systems will be accessed in their host agencies. Other data files and models will be installed on USDA's computer in Washington, D.C. and the data accessed using ARIES. Some files and models will be obtained and stored while the availability of others will only be noted in the Directory.

Researchers in the Water Branch will access frequently used information using an IBM-compatible complement of equipment and software which will perform comprehensive management, analysis and presentation functions.

Data Service Center support staff will assist in the installation of the data on the mainframe, in gaining access to and using on-line systems and in storing infrequently used data on tapes.

WATER CONSERVATION - RELIEF FOR THE TAXPAYER

Frank B. Odasz
Consulting Chemical Engineer
Larry Harms
Casper Parks and Recreation

ABSTRACT

Although Wyoming has surplus water, specific new consumptive uses are increasingly expensive. Using the City of Casper as a non-typical example, the authors show how a potential of over $371,000 per year might be saved by recycling cleaned, nutrient-rich municipal wastewater onto a City park. Problems and potential are examined.

INTRODUCTION

As will be in evidence today and tomorrow, debates on Wyoming's water supply flip-flop on two paradoxical facts: Wyoming is water-rich; Wyoming is water-poor. Its richness originates in the high mountain snow packs feeding major rivers that flow out of Wyoming across each of the four borders of the State. Its poorness is embedded in the natural frustration that water responds physically to gravity; it flows to low points, forming the exiting rivers that cut through dry plains.

As an extreme quirk of nature, the copious Green River channels about 1.5 to 3.0 million acre-feet per year to Colorado. Yet ironically, less than 40 miles to the east lies the 3,000 square-mile Great Basin Desert, and about 50 miles to the north of the Green's headwaters is lush, green Yellowstone Park.

Succinctly, Wyoming is water-poor because the water is not where we want it when we want it, bringing to mind the poet Coleridge's words, "Water, water everywhere, and not a drop to drink."

Compounding Wyoming's problems of water development is the occasional amendment of the physical rule of gravity by the financial rule that water flows toward the magnet of money. Wyoming's experience in water development confirms both rules.

For example, since 1900 significant progress has been made through our engineers' ability to tame and contain the raging torrents of the North Platte River, which has been identified as the epitome of a controlled river. Until this century, it cycled annually from destructive floods in early summer to a meandering stream in late winter. Now the flow is monitored, used multiplicatively, and harnessed within much narrower, useful, and safer limits.

Simultaneously, with physical control of the North Platte, legal control was established by the North Platte Decree in 1945. This is a legal, rechargeable time bomb. The fuse is obvious in its Article XIII. Proposed changes in the decreed physical control of the North Platte trigger new legal questions for resolution before the changes can be perfected. The bomb went off only once since its assembly. This was resolved by the Stipulation and Decree of 1952.

And, of course, in addition to these legal and technical problems, changes in water use, however noble, actuate financial, political, and environmental questions, too.

Casper, the largest Wyoming city on the North Platte, has grown in both population and land area. It has four (1926, 1963, 1970, 1977) surface water rights which, for practical purposes, are considered to be junior rights. In that future, statistically inevitable, dry year when senior right holders need to exercise their rights to the limited available water, Casper could legally be cut off from its North Platte supply "cold turkey". Casper management accordingly has diligently searched for new supplies to ameliorate this foreseen, but unscheduled, eventuality.

The major water use of water in Casper is for summertime lawn irrigation and, as you might anticipate, the major single user is the Casper Department of Parks and Recreation. This paper describes how the Parks Department has analyzed its present and future needs for water, and found a solution that has the rare and delightful potential of actually reducing several important, direct costs paid by the taxpayers of the City. Some are current costs; some are future costs. You should be aware that these savings are site-specific. They should not be generalized for other sites or other cities. Instead, we hope that the principles to be described will stimulate similar creative solutions for other cities.

In essence, this paper analyzes water needs for Casper parks, and concludes that recycling cleaned, nutrient-rich municipal wastewater is the most cost-effective way of providing water for the expanding park system.

BACKGROUND

The historical values in the pie chart of Figure 1 show that, by far, most of Wyoming's water flows to downstream states. We use only 2.6 million acre-feet, or 15 percent, of the 17.3 million acre-feet that are physically available. Unfortunately, 10.9 million acre-feet, of Wyoming's physically available water has been already committed to Mexico and certain states by one treaty, seven interstate compacts, and three court decrees such as the North Platte Decree. Potentially still available for Wyoming's use is 3.8 million acre-feet. Figure 2 shows where the outflows occur. The green color represents Wyoming's share of the flow.

Shifting our focus from this big Wyoming water picture to our specific site, Figure 3 illustrates Casper's historical water usage in contrast with natural precipitation. Since 1950, Casper's demands have increased, on the average, by 70 million gallons per year. The figure shows that precipitation has a temporary inverse relationship with demand, as for example in 1980 - a fairly dry year, although not the driest. But, the population expansion from 23,673 to 51,016 over this period is the primary factor in the growth in demand from 1,228 million gallons per year to 4,501 million gallons per year.

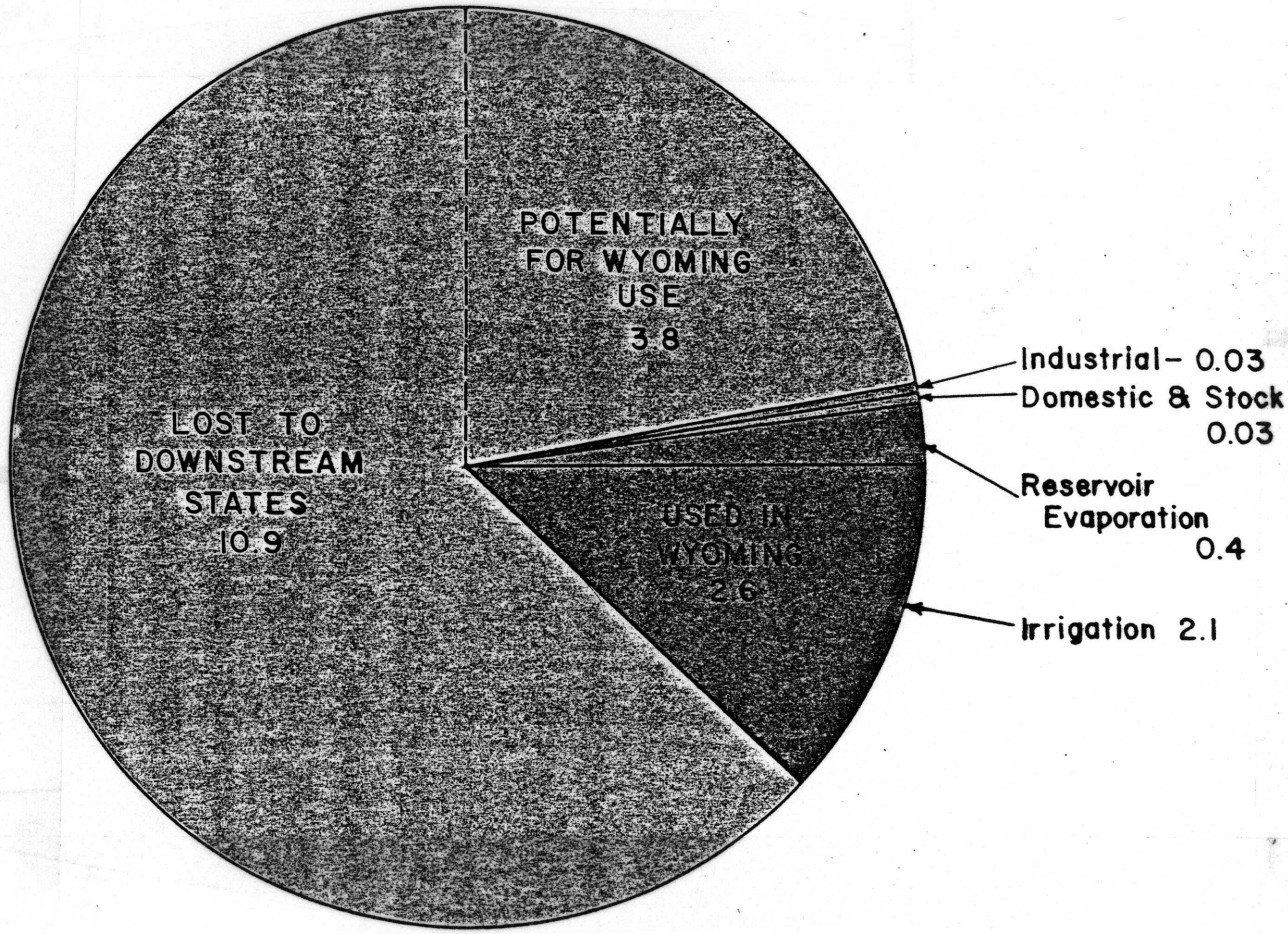

Figure 1. Wyoming's "Use It or Lose It" Water Status (Millions of AF/Yr).

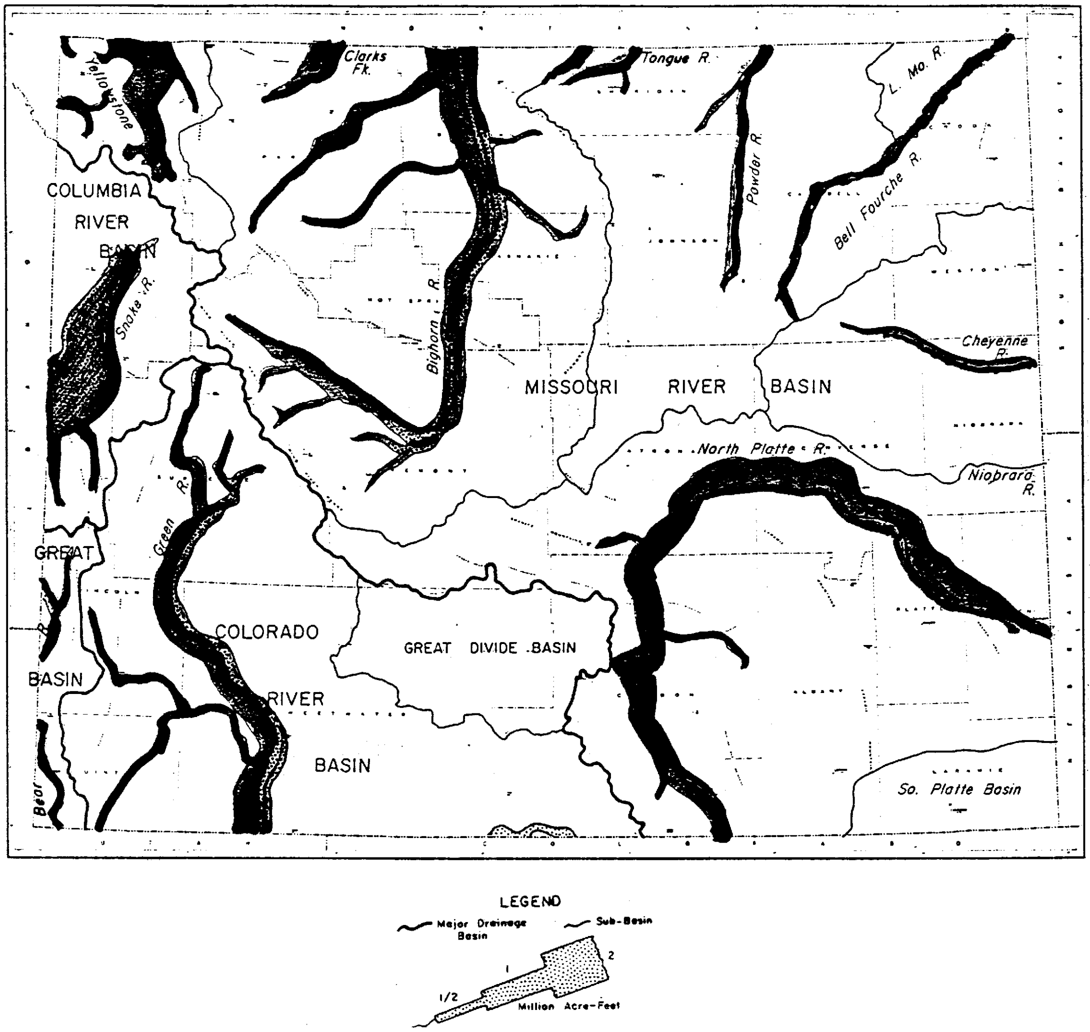

Figure 2. Average Annual Streamflow in Wyoming.

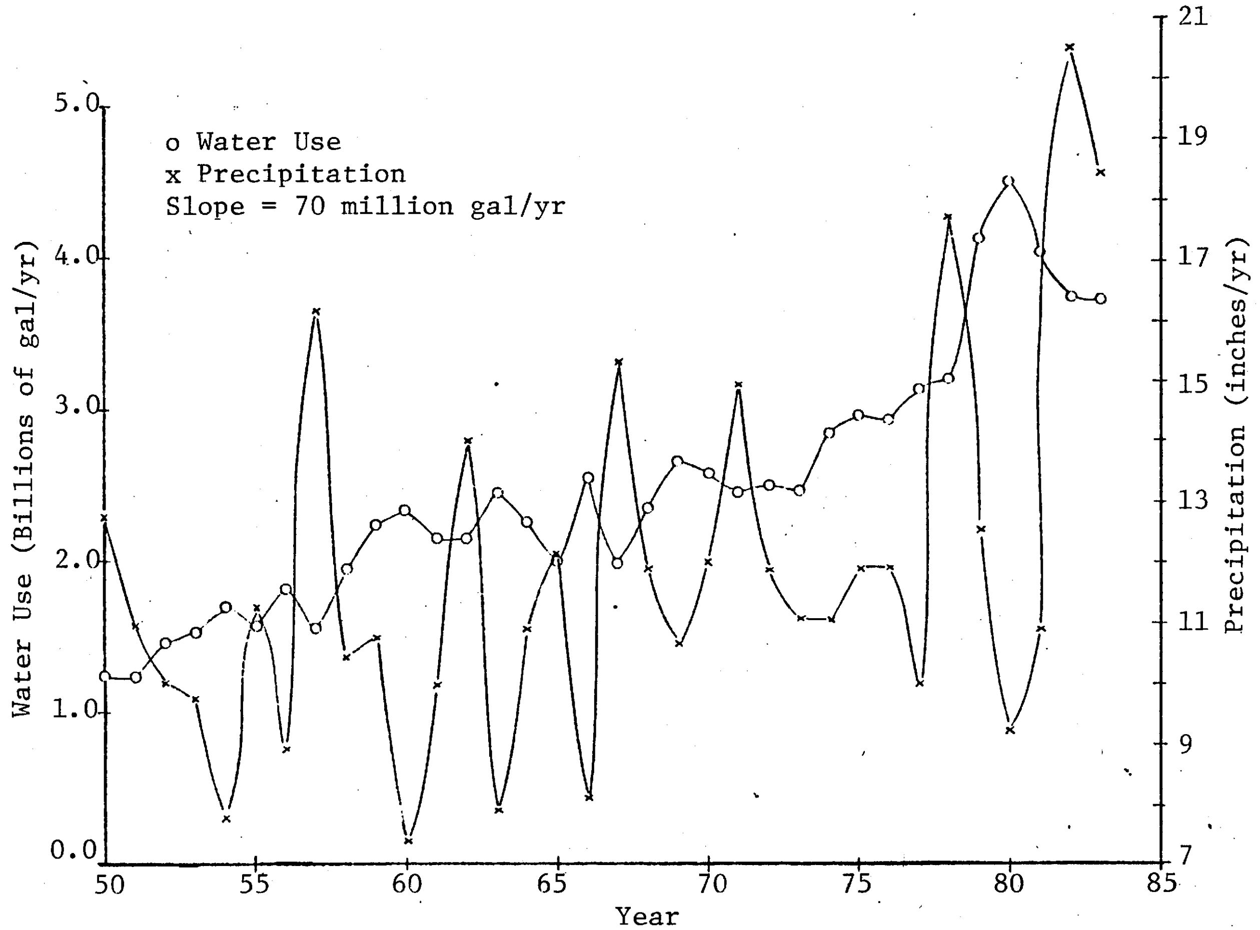

Figure 3. Precipitation and Water Use for Casper, Wyoming.

Figure 4 is most revealing; it shows the monthly demand for treated water during recent years in contrast to the City's four water rights to North Platte River water.

As expected, peak summertime use is three to four times the October to May use. The four permits fit the demand quite well, with the sole exception of 1980 - the driest year in this period. As long as the snowpack and annual precipitation are sufficient to avoid regulation, Casper has no problem. However, the priority dates for all four permits are relatively new. The May 1970, May 1977 and January 1963 priority dates would be among the first to be shut off. The April 1926 priority date is not much better. Note that in five of the seven illustrated years, the April 1926 permit was insufficient to provide enough water for the basic domestic needs which in this analysis are assumed to equal the minimum wintertime use. This is indeed a serious situation.

How does this relate to Casper's parks? Figure 5 is specific for 1983. It zooms in on Casper's total water demand, water consumption, wastewater discharge into the North Platte River, and the water used on Casper's parks. Thus, in the actual perspective, the Parks Department peak summertime demand of 39 million gallons in July would probably be the first to be cut off under regulation, quickly transforming 220 City acres from lush green recreation areas to brown, dry fire hazards.

Ironically, Casper's 46 parks received national recognition for cities between fifty and one-hundred thousand population. The

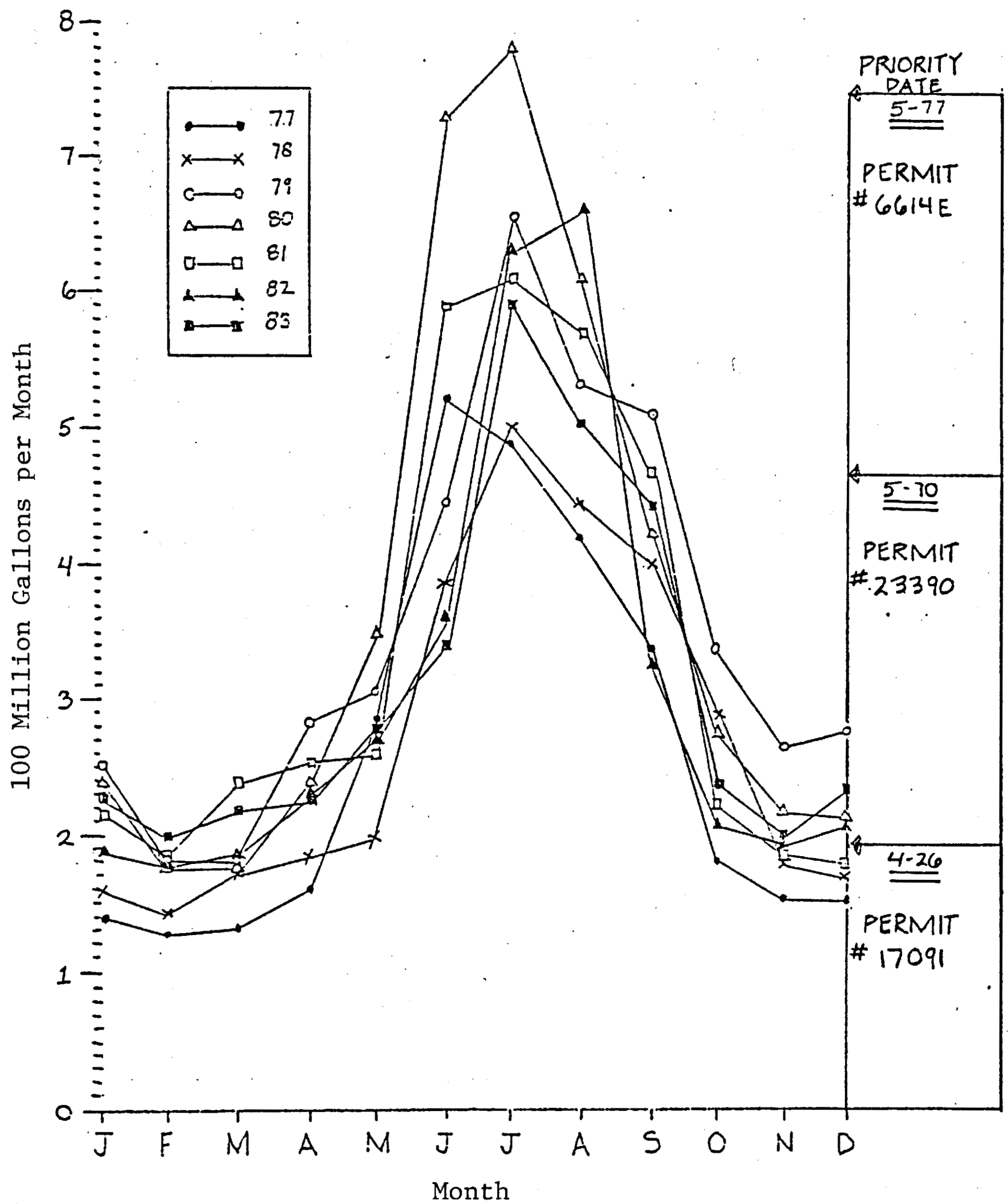

Figure 4. Monthly Production of Treated Water

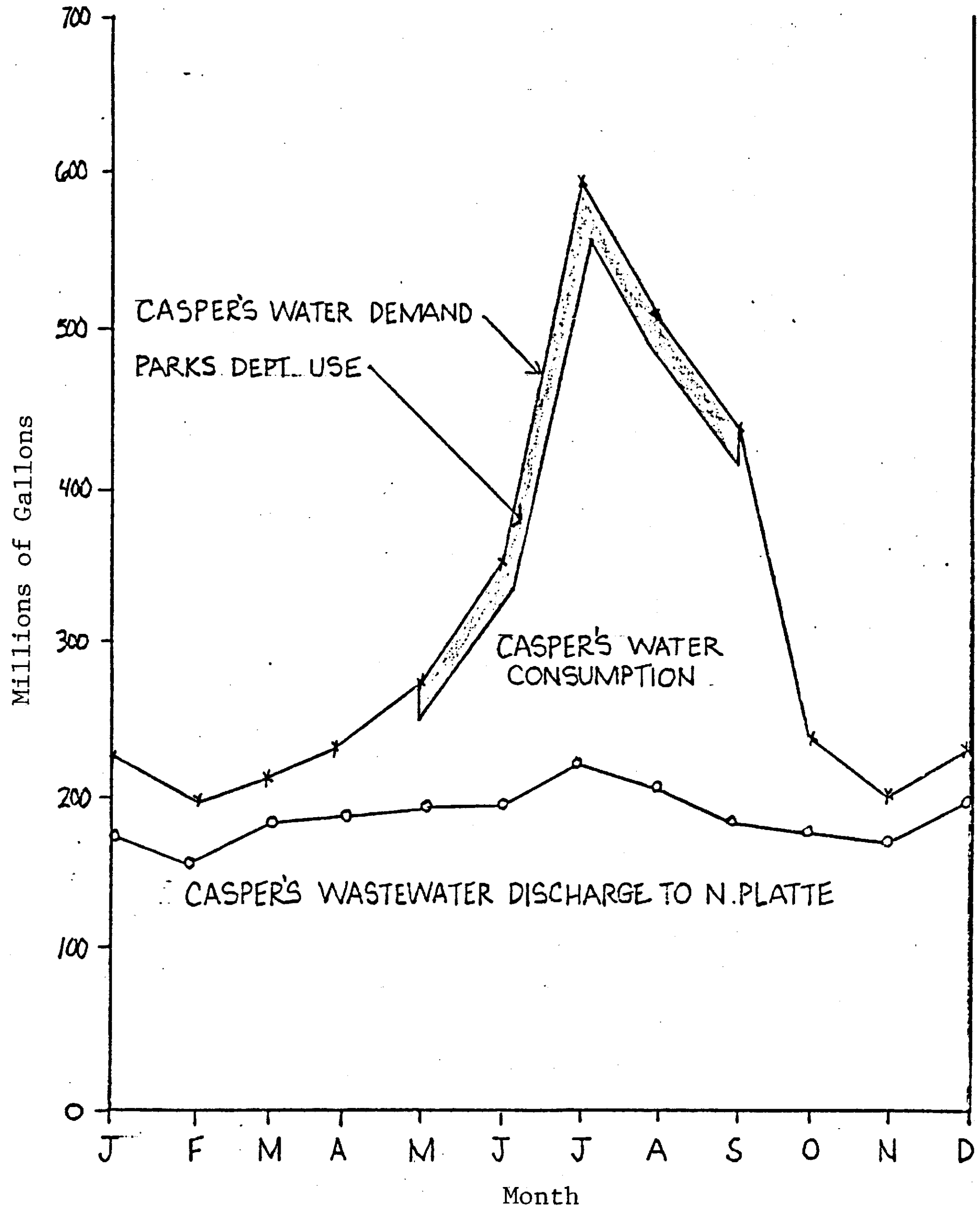

Figure 5. Casper Parks Department 1983 Water Use.

existing 220-acre system is the keystone of one developing plan that will ultimately encompasses 457 acres, and require an additional 180 million gallons of water a year, of which 42 additional million gallons will be needed in each peak summer month. Under this scenario, the parks will need twice as much as they currently use.

Obviously, this doubled demand further strains the available permitted water supply from the North Platte, and proportionally jeopardizes the investment the City has already made in its nationally recognized park system.

Another developing plan deals with the 1100-acre North Platte Park for which water is needed to irrigate 500 acres. This will be addressed in detail later in the presentation.

Therein lies a problem. Therein also lies a challenge for a creative solution.

SOURCES OF NEW WATER

Traditionally, when water supplies fall short of demand, management has edicted "find new supplies." Casper has energetically sought firm, "drought-resistant" supplies, as shown on Table 1.

TABLE 1: ESTIMATED CAPITAL COST OF NEW SUPPLIES

	Project	Millions of Dollars
1.	Stage III	232.0
2.	Deer Creek	45.0
3.	Seminoe Enlargement	12.0
4.	Rock River Ranch	4.0
5.	Casper-Alcova Project	2.6
6.	Wells	0.2
7.	Surface Waters Within Casper	0.02

The first five surface waters all require treatment prior to distribution for Casper's use. The last two may not, depending upon the water analysis and use. The capital investments are significant just for the supply system. Additional capital investment is required for the distribution infrastructure.

Breaking with tradition, the Parks Department posed a probing core question: "What unique features of our needs differentiate our demand from the domestic demand?", and the corrollary: "What supplies can the parks use that domestic users might not consider?"

The answer evolved through considerations of water quality. People require water that meets drinking water standards. However, the trees, shrubs, flowers, and lawns of the parks respond to different qualities. For example, there are limits on the amount of ammonia nitrogen permitted in water for people. Plants, on the other hand, are periodically and purposely fed ammonia nitrogen in the form of purchased fertilizer. Significant quantities of ammonia nitrogen have been measured in the cleaned, nutrient-rich municipal wastewater. So have phosphorus and potassium which are also vital plant nutrients.

So, what kind of problems and incentives exist for recycling clean wastewater onto green acreage in Casper? Five problem areas were considered:

1. Legal. The City owns the wastewater until it is discharged into the river. Recycling *per se* provokes no new legal obstacles. On the contrary, the concept is viable even if the City's irrigation water wells are shut down first under regulation. And, of course, a useful legal precedent is established by recycling. Continued discharge to the river is also permitted under the terms of Casper's NPDES permit. No legal problems are foreseen.

2. Environmental. Conservation of nutrients for feeding terrestrial plants makes better environmental sense than feeding aquatic plants that eutrophy, die, and compete for oxygen with fish and other aquatic species. The miniscule incremental amount of the topical "acid rain" seems to sweeten Casper's alkaline soil. No environmental problems are foreseen. Indeed, cities downstream of Casper will have better drinking water quality by this action. Even the underground seepage from the park will be cleaner.

3. Political. There is no apparent competition for this water; its planned use would not interfere with any other water

user. However, as many in this audience know from personal observation, changes in water use that require legislative or administrative action inevitably evoke political posturing. The ensuring problems are eventually resolved in the conventional democratic manner. Adequate time must be scheduled for this process. There should be no confusion over this fact: recycling wastewater is not an alternative to any other plans or projects that improve Casper's drinking supplies or its water rights.

At this time no political problems are foreseen, but they are harder to forecast than non-political problems. Therefore, it is prudent to be prepared for some sort of political problem.

4. Technical. Thorough investigation of the constituents in the wastewater is necessary. For example, there is an indication that sulfates increase significantly by the use of water in Casper. Raw water has about 225 ppm of sulfate. Discharge from the wastewater treatment plant often has over 1000 ppm, which is assumed to be due to infiltration of groundwater.

Other molecular components might also be of concern. When Casper's new wastewater treatment plant is commissioned, it will receive wastes from several neighboring communities that are not now on the Casper system. Chemical analyses of these sources of future feed to the wastewater treatment plant is strongly advised over a reasonable period of time.

On the optimistic side, however, the state-of-the-art for solution of technical problems is so well advanced that optional solutions exist for most technical problems. For example, a sulfate problem could be resolved by either reverse osmosis, ion exchange, electrodialysis, or desalinazation. These are extremely expensive. Fortunately, the state-of-the-art is improving. Perhaps sulfates could be isolated by either of several techniques. Alternatively, the landscaping could be designed to accommodate the constituents of the water, including sulfates. These are routine technical problems that must be resolved prior to major capital commitments. However, no new technical breakthroughs seem required.

5. Financial. Water projects must be financed by citizen taxpayers either directly through their tax bills, or indirectly, through higher prices for goods and raw materials to pay for the taxes imposed on corporate taxpayers. Rarely does a case arise which might provide economic relief for citizen taxpayers. Recycling clean municipal wastewater is in this rare category, and Casper's situation presents a special opportunity to provide such relief. Now is the opportune time to act. Both the park system and the wastewater treatment plant are in development stages. This financial opportunity will be examined in detail.

RECYCLING CASPER'S CLEAN WASTEWATER

Examination of this opportunity for taxpayer relief focuses on the anticipated expansion of the park system, with emphasis on one particular large park which surrounds Casper's Events Center. This is the North Platte Park, shown in Figure 6. It consists of 1,100 sandy acres and now features a runway for flying model airplanes, a skeet shooting area, an auto speedway, extensive landscaped grounds surrounding the Events Center, several athletic fields, and future plans for a 27-hole golf course. The entire area is exposed to the famous Casper gale which limits the fun of these outdoor sports, even though it provides more fresh air per capita than other places.

For this analysis, we assume that only 500 acres will be irrigated. This will require 385 million additional gallons of water per year, with a summertime monthly peak of 88 million gallons, or 2.25 times the prevailing use for all other existing parks.

We also assume for convenience in this analysis, that technical problems are solvable by technical acumen. We recognize that they are not solved yet, and that perhaps they have not all even been identified yet. Instead, using the process of limitations, let us proceed to a logical judgment to learn if the order of magnitude of economic incentive is sufficiently encouraging to identify, address, and solve the technical problems.

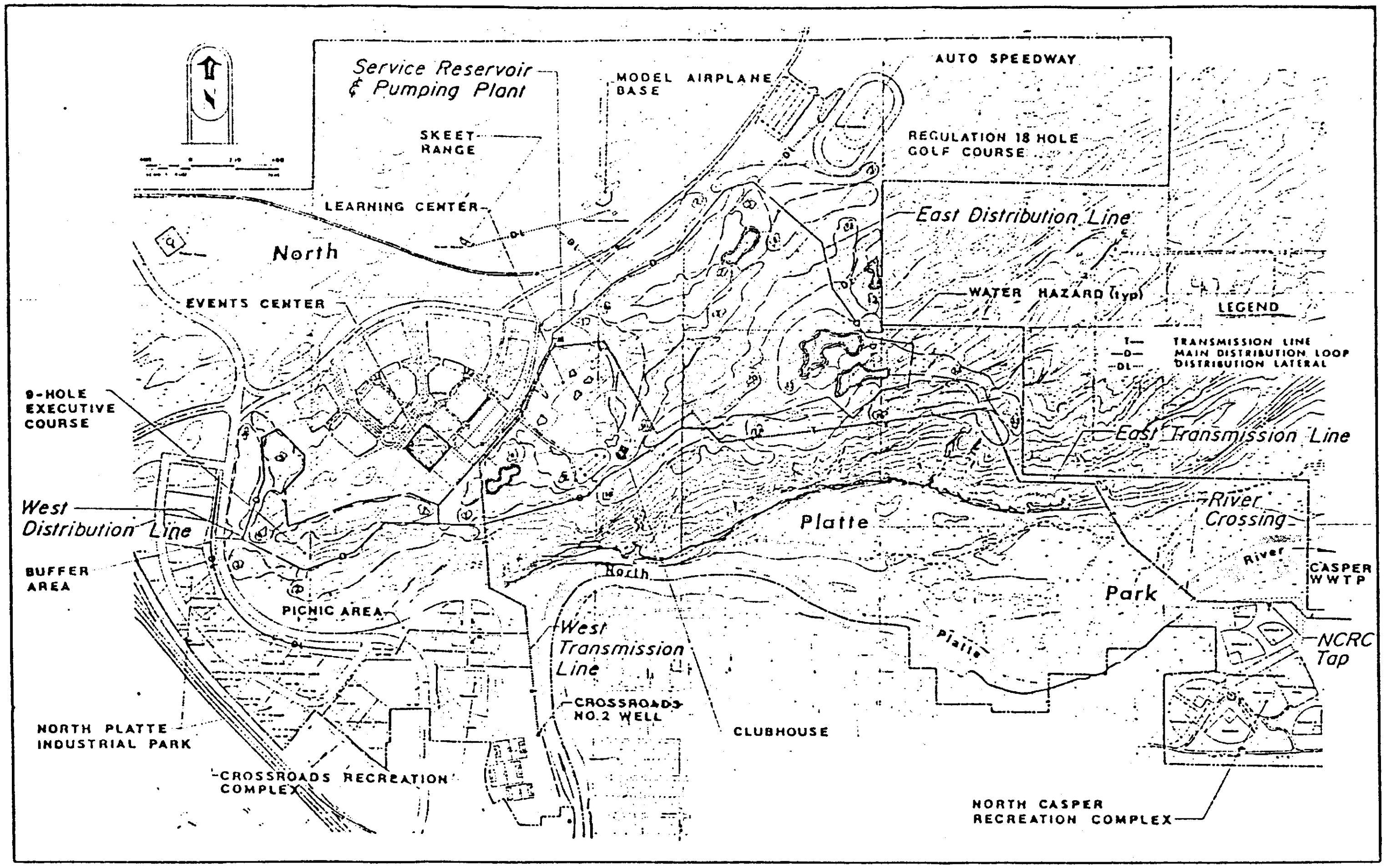

Figure 6. Draft Water Development Plan for Casper's North Platte Park.

Several facts have been gleaned from various reports that will be presented as goals for defining the following opportunity statement.

OPPORTUNITY STATEMENT

In 1984, the Parks Department initiated a program to reduce the cost of water for the City's parks. Now, a unique and timely opportunity exists to implement one of the program activities; that is, to converse and recycle cleaned nutrient-rich water from the expanded wastewater treatment plant to nourish and irrigate selected green areas in Casper.

The goals for implementing this opportunity are to:

1. Ameliorate Casper's need for new fresh-water supplies during the peak watering summer season.
2. Reduce the amount of treated drinking quality water from the river water treatment plant. Chemicals, power, and maintenance costs would be reduced, and the need for taxpayer's money to expand this plant could be postponed.
3. Conserve and recycle valuable fertilizer in the form of dissolved nitrogen, potassium, and phosphorus that have been found and measured in the wastewater.
4. Reduce the amount of ammonia being discharged to the North Platte, and thereby postpone or completely obviate the need for the estimated $7,000,000 tertiary treatment addition to the wastewater treatment plant.

5. Continue to develop Casper's green acres without depending on more expensive water from the existing system or on much more expensive water from the alternative plans now being considered.
6. Demonstrate active leadership in water conservation that will save taxpayer money.
7. Build an expandable operating system to establish precedence and rights to the enriched conserved water, and to demonstrate the concept of applying the lowest cost water to the lowest value use.
8. Position Casper to support a hydroponics or greenhouse industry by supplying heated nutrient-rich water from the $30,000,000 expanded wastewater treatment plant. (Effluent water is at about 40°F during January, warmer in summer.)
9. Prepare to supply industrial quality water for future projects as Casper grows.
10. Reduce eutrophication in the North Platte River, thereby enhancing fish habitat and possibly fish flavor.
11. Reduce the amount of Casper's wastewater entering the drinking water system at Evansville.
12. Reduce Casper's exposure to regulation in terms of its junior water rights.

An example of the economic incentive for implementing the concept is shown in Table II. It is based on providing four feet of water per year to 500 acres of the sandy soils in the 1,100-acre undeveloped North Platte River. The quantity of water conserved would be 2,000 AF, or an average of 163 million gallons per month (167 cfs, 3,700 gpm) for the four-month watering season. The projected annual savings for Casper taxpayers is impressive.

TABLE II. ANNUAL SAVINGS FOR CASPER TAXPAYERS

	Savings	$/Yr
1.	Value of water per David Engels, Director, Casper BPU ($135)(2,000AF)	$270,000
2.	Savings to electorate for chemicals, labor, and maintenance reductions	60,000
3.	Value of nutrients (NPK) in solution	41,000
4.	Postpone or eliminate $7,000,000 tertiary treatment plant	+
5.	Labor savings in eliminating manual application of fertilizer	+
6.	Improve fish habitat	+
	TOTAL ANNUAL SAVINGS	$371,000+++

Of course the system will require capital investment for a separate system to store and transport the clean wastewater from the wastewater treatment plant to the park -- a distance of about one mile. However, the latter system would be required for alternative sources of water.

The judgmental question to be answered is:

"On balance, is the potential economic value of over $371,000 per year sufficient to justify moving forward on the conservation of freely available wastewater as a means of providing some refreshing economic relief for our taxpayer citizens."

We think so. A proposal for implementation has been prepared to achieve these savings for Casper.

We appreciate this opportunity to share our experience with you, and welcome your insight so that these economic advantages of water conservation might be enjoyed by other communities in Wyoming.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the review and guidance provided by Mr. David Engels, Director of the Casper Board of Public Utilities.

REFERENCES

Much of the basic data used for this paper were adapted from the May 1984 report, "Minimizing the Cost of Water for Recreation Arenas in the City of Casper," by Frank B. Odasz, P.E.

AN ANALYSIS OF ALTERNATIVE MANAGEMENT STRATEGIES OF IRRIGATORS FACING RISING ELECTRICITY RATES AND DECLINING GROUNDWATER TABLES

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ABSTRACT

Irrigators using center pivot irrigation systems in southeastern Wyoming face a difficult combination of factors. Rising electricity costs, a declining groundwater table and the cost-price squeeze have combined to reduce the profitability of producing crops under center pivot systems. Some strategies irrigators may consider to improve the economic returns with center pivot irrigation systems are:

1) converting high pressure to low pressure systems
2) improving pumping plant and/or applications efficiencies
3) change cropping patterns
4) reduce the application of water where the loss in revenue from decreased yields are less than the savings in power cost.

This study analyzed the economic impact of selected management strategies on irrigators in Southeastern Wyoming. In analyzing the economic impact, a model farm using center pivot irrigation was developed. The economic analysis was conducted using a crop evapotranspiration and yield model, a pump cost simulation model and a linear programming model. Results from the two simulation models are used as inputs to the linear programming model which determines the optimal crop mix under alternative irrigation strategies.

Results of this analysis suggest that the most promising management strategies for maintaining the profitability of center-pivot irrigation seem to be improving pump and/or application efficiencies, conversion to low-pressure pivots and load control programs. It must be emphasized, however, that these short-run adjustments to maintain net returns cannot be extended into the

future indefinitely. As long as recharge rates are less than extraction rates, electricity costs continue to rise and crop prices remain constant, the long-term forecast is for some abandonment of center-pivot irrigation from groundwater.

It should also be pointed out that any attempt to predict the future involves a great deal of uncertainty. In particular, any change in crop prices or in technology that would affect pumping costs and/or crop yields could change the results substantially. However, the results of this analysis suggest continued economic pressures on center pivot irrigation. Only the most efficient operators may be able to survive to that time when groundwater pumping will approximately equal natural recharge rates.

INTRODUCTION

Irrigators using center pivot irrigation systems in southeastern Wyoming have faced a difficult situation in recent years. The combination of increased electricity costs, low crop prices, and a declining groundwater table has reduced the profitability of crops produced using center pivot irrigation systems and is threatening the viability of irrigated farming in the area. Such pressure provides an incentive for irrigators to consider alternative management strategies which may improve the economic returns from crops produced under center pivot irrigation systems.

The study uses a model of a typical farm using center pivot irrigation in Laramie County, Wyoming to assess the impact of alternative strategies. An evapotranspiration/yield model and a pump-cost model simulate yields and pumping costs for the representative farm. The results from these two simulation models provide input for a linear programming model which determines the optimal crop mix under alternative irrigation strategies. The alternative strategies considered in this study are:

1) Converting from high to low pressure center pivot systems;
2) Improving pump and application efficiencies;
3) Reducing the water applied to crops;
4) Alternative electricity rate structures and load control programs; and
5) Adding a livestock feeding operation.

Results of the analysis indicate that the most promising strategies for maintaining the profitability of center pivot irrigation are:

1) Conversion of center pivot systems from high pressure to low pressure;
2) Improving pump and/or application efficiencies; and
3) Participation in the direct load program.

This paper includes a brief review of previous work on the Wyoming Ogallala Aquifer as well as a methodology section outlining the mathematical models used in the analysis. Results for the three management strategies listed above are also discussed.

REVIEW OF PREVIOUS WORK

Lindemer (1983) performed an economic analysis of high and low pressure center pivots with a declining groundwater table and increasing electricity costs. The study was performed for a representative farm in Laramie County, Wyoming through the year 2002. Linear program models for high and low pressure center pivot systems were used to estimate optimal cropping patterns under constant water application rates and constant pump and application efficiencies. An average groundwater table decline of 1.5 feet per year was assumed. The effects of increasing electricity prices and a declining groundwater table were assessed under three crop price scenarios.

Results from Lindemer's study indicate that, only under optimistic assumptions, i.e. 2-4 percent increases in the real price of electricity and higher than expected crop prices, does all irrigated crop land continue to be irrigated through 2002. Also with these assumptions, projected profitability remains sufficient to cover land and management costs. However, with a 4 percent increase in the price of electricity, returns decline by 40 percent. If electricity prices increase by more than 4 percent, the optimal crop mix changes such that land is gradually converted to dryland wheat production. The study concluded that conversion to low pressure pivots would only slow this trend.

Studies have been done for other regions of the Ogallala Aquifer. The conclusions reached about the future of irrigated agriculture vary from study to study depending on the assumptions made concerning future crop and energy prices. For example, one of the assumptions in the Ogallala Aquifer Regional Study (1981) was that future advances in technology and increases in demand for farm production due to exports will cause real crop prices to increase faster than all costs of production, including energy costs, between 1977 and 2020. In light of this assumption, the

Oklahoma portion of the regional study (Warren, Mapp, Kletke, Ray and Want, 1981) estimated irrigated acreage in the Oklahoma High Plains would increase 19 percent and dryland acreage would decline 6.5 percent from 1977 to 2020. Also, despite projected increases in real natural gas prices of 336 percent and an expected annual decline of 2 feet in groundwater levels, net returns to a typical producer in this area were estimated to increase 139 percent from 1977 to 2020.

On the other hand, in a study done by Mapp and Dobbins (1977), production costs, technologies, and crop prices based on 1969 to 1973 averages were held constant throughout the analysis. It was also assumed that there would be a 567 percent increase in natural gas prices between 1976 and 2025 and an estimated annual decline of 2 feet in groundwater levels. With these assumptions, Mapp and Dobbins estimated irrigation in the High Plains of Oklahoma would cease by 2025 and dryland acreage would increase 98 percent. Net returns to agriculture in this area were estimated to decline by 67 percent by 2025.

Thus, results from various studies assessing the economic impact on farming of a declining water level in the Ogallala Aquifer are contingent on the assumptions made about future circumstances. In turn, the credibility of the results are determined by one's view of the reality of the assumptions.

METHODOLOGY

The economic analysis of irrigation strategies on a typical farm using center pivots in Laramie County, Wyoming was conducted using 2 simulation models and a linear programming model. Alternative irrigation strategies and resulting crop yields are considered in a simulation model of crop evapotranspiration and yield. Results from this model provide estimates of the amount of water applied through irrigation and are fed into a pump-cost simulation. The pump-cost model considers depth to water, price of electricity, pump and application efficiency, and other pump characteristics in computing pumping costs. Yields and costs from these two simulation models are then used in a linear programming model (L.P.) which determines the optimal crop mix and calculates net returns to land and management.

In the evapotranspiration/yield model, potential evapotranspiration (ETP) is estimated using the "Blaney-Criddle" method. ETP is a function of daily mean temperature, daily proportion of annual daylight hours and a crop coefficient. The model estimates evapotranspiration on a daily basis and subtracts it from estimated soil moisture. Soil moisture is increased through effective irrigation and effective precipitation. If soil moisture is depleted below an allowable fraction of field capacity, actual evapotranspiration (ETA) falls below potential evapotranspiration, and yields are decreased. Daily historical average precipitation and temperature from Pine Bluffs, Wyoming were used to estimate potential evapotranspiration.

Two versions of the model allow for substantially different irrigation strategies. In the first model, an irrigation is made to field capacity the day soil moisture is depleted below the allowable fraction of field capacity for the crop root depth. ETA is maintained at ETP over the season and maximum yields are attained. In this version, the model determines irrigation timing and quantities needed to produce maximum yields. In the second version, the timing and quantity of irrigation are input under control of the model user. ETA may fall below ETP and yields are decreased according to the evapotranspiration deficit.

The pump-cost simulation is based entirely on the pump cost program on AGNET (1984). The pump cost calculates fixed and operating costs of center pivot irrigation. The pump-cost calculation allows for varying the type of system (high versus low pressure), depth to water, application and pump efficiencies, and amount of water applied. Irrigation costs include fixed costs, variable non-electrical costs, electricity costs, and a demand charge. Required inputs to calculate pumping costs are gallons per minute, pressure in pounds per square inch, depth to water in feet, pump and application efficiencies, inches of water applied, price of electricity (¢/KWH), and the demand charge per horsepower. The change in variable costs associated with different pump and application efficiencies is incorporated into the analysis through the pump-cost program. An average groundwater table decline of 1.5 feet is assumed throughout the analysis unless otherwise specified.

Finally, using output from the pump-cost and evapotranspiration/yield simulations, the linear program model determines the optimal crop mix and calculates net returns to land and management. An objective function expresses net returns from all crops as a function of crop prices, quantity of crop sold, production costs per acre, acres in production, and irrigation expenses. The model determines the maximum net returns under a set of linear constraints on cropping patterns and acreages. The constraints are on total acreage available, total acreage for individual crops, and crop rotations. Prices used in the analysis are provided in Table 1 along with some other price scenarios for crops grown in Southeastern Wyoming. The 1973-82 adjusted average prices were used for all crops except alfalfa and corn silage. The prices used for alfalfa and corn silage are the 1979-83 average prices for these crops. Results using the last two price scenarios in Table 1 will be discussed.[1]

RESULTS

Results of the simulation and L.P. analysis for high pressure and low pressure center pivots are provided in Tables 2 and 3.

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[1]Potatoes were excluded from this analysis. This was done because the structure and size of potato farms differ substantially from the grain-forage farm.

Table 1. Various Estimated Prices for Crops Grown in Southeastern Wyoming.

	Used by Lindemer (1983)[1]	1973-82 Average[2]	1982 Actual[2]	L.P. Brkeven[3]	1973-82 Adjusted Average[4]	Price Used
Alfalfa (ton)	67.26	53.45	53.50[5]	58.86[5]	54.36	61.00
Feed Barley (bushel)	2.64	2.60	3.30[5]	3.89[5]	2.64	2.64
Dry Beans (cwt)	24.20	19.60	11.00	18.74	20.42	20.42
Corn Silage (ton)	20.29	16.04	16.05	17.48	16.31	18.30
Irrig. Wheat (bushel)	3.77	3.29	3.25	3.60	3.29	3.29
Dryland Wheat (bushel)	3.77	3.29	3.25	3.28	3.29	3.29

[1]Lindemer expected price scenario.

[2]Data from Wyoming Agricultural Statistics.

[3]For the high pressure base scenario with 1984 irrigation costs; management and land costs are not included.

[4]1982 price received index (PRI) divided by mean 1973 to 1982 PRI, times 1973 to 1982 mean actual price received. PRI from U.S. Ag. Statistics, 1983, p. 592 for food grains, feed and hay, and beans.

[5]Alfalfa and barley breakeven prices assume 1973 to 1982 adjusted average price for barley and alfalfa, respectively.

Table 2. Results of Linear Programming Model for High and Low Pressure Center Pivots Assuming Constant Electricity Prices.*

Scenario Number	Year	Depth to Water	Electricity Costs ¢ per kwh	Electricity Costs $ per hp	$ Max. Return	Acres in Crops Bean	Acres in Crops Alfalfa	Acres in Crops Feed Barley	Acres in Crops Corn Silage	Acres in Crops Dryland Wheat
HIGH PRESSURE										
1	1984	110	4.5	18.00**	5,128.46	94	319	78	8	0
2	1994	125	4.5	18.00	3,334.23	94	319	78	8	0
3	2004	140	4.5	18.00	2,740.08	94			47	460
LOW PRESSURE										
4	1984	110	4.5	18.00	13,236.11	94	319	78	8	0
5	1994	125	4.5	18.00	11,441.87	94	319	78	8	0
6	2004	140	4.5	18.00	9,647.74	94	319	78	8	0
LOW PRESSURE - 2.5 FT DECLINE										
7	1994	135	4.5	18.00	10,245.22	94	319	78	8	0
8	2004	160	4.5	18.00	7,256.02	94	319	78	8	0

* Application efficiency = .85, pump efficiency = .65

** Participation in direct land control assumed (seed Direct Land Control Section)

Table 3. Results of Linear Programming Model for High and Low Pressure Center Pivots Assuming Two and Four Percent Increases in Electricity Costs.*

Scenario Number	Year	Depth to Water	Electricity Costs ¢ per kwh	Electricity Costs $ per hp	$ Max. Return	Acres in Crops Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat
HIGH PRESSURE										
9	1984	110	4.5	18.00	5128.46	94	319	78	8	0
			2% Increase							
10	1994	125	5.49	21.94	1572.96	83			42	480
11	2004	140	6.69	26.74	83.20					640
			4% Increase							
12	1994	125	6.66	26.64	137.81	83			42	480
13	2004	140	9.86	39.44	83.20					640
LOW PRESSURE										
14	1984	110	4.5	18.00	13,236.11	94	319	78	8	0
			2% Increase							
15	1994	125	5.49	21.94	6848.99	94	319	78	8	0
16	2004	140	6.69	26.74	1946.92	83			42	480
			4% Increase							
17	1994	125	6.66	26.74	2538.13	83			42	480
18	2004	140	9.86	39.44	83.20					640

* Applications Efficiency = .85

Pump Efficiency = .65

Table 2 presents a comparison of high and low pressure pivots for successive years under the optimistic assumption of constant electricity prices.

Scenarios 1-8 show the economic desirability of low pressure pivots in the face of higher electricity costs due to a declining groundwater table. Returns for the low pressure scenarios are more than double those for the high pressure system. Also, results suggest that a low-pressure pivot maintains the life of irrigated farming through at least the year 2004 while a majority of acreage converts to dryland wheat production by that same year using a high pressure system. The difference in future income between high and low pressure returns, if discounted to obtain present values, would indicate how much money could be invested today to finance the conversion to low pressure pivots.

Table 2 also displays results from the model assuming a 2.5 foot decline in the groundwater table. Even at this rate of decline, the crop mix remains the same for a low pressure pivot. If electricity prices remain constant, results suggest that increasing costs of pumping due to decreasing water levels in wells should not, to any large degree, adversely affect irrigated agriculture by 2004.

Scenarios 9-18 (see Table 3) also indicate the economic advantage of a low pressure pivot with increasing electricity prices, although increases in electricity costs threaten the viability of irrigated farming for both high and low pressure systems. The results show that even with a 2 percent annual increase in electricity costs, by 1994 most of the acreage converts to dryland wheat production and returns decline substantially with the use of high pressure pivots. Increased profitability through the use of low pressure center pivot systems is better able to absorb the higher electricity costs. However, even with low pressure, the the results indicate that irrigated farming would almost cease by 2004 with a 2 percent annual increase in electricity costs.[2]

These results lend support to the findings of Lindemer (1983). While his analysis used a higher crop price scenario and therefore indicated a longer life for irrigated farming with a 4 percent increase in electricity costs, the same general trend for irrigated farming is found in both analyses. Only under optimistic assumptions regarding electricity and crop prices can irrigators in southeastern Wyoming tolerate declining groundwater levels. If

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[2]Conversion to dryland crop production necessarily results in less water pumped and thus a lower average rate of decline in groundwater levels. Analysis of this factor indicates that the impact on pumping costs in future years is not significant and thus can be ignored. For example, although not presented in Table 3, the same analysis shows that in 1999 50 percent of irrigated crop production converts to dryland production using a low pressure pivot. As a consequence, the rate of decline of the groundwater table may be reduced to .8 instead of 1.5 feet per year. Using .8 as a rate of decline the depth to water in 2004 would be 136.5 rather than 140. However, results show that the crop mix is the same as for that predicted with a 140 ft depth to water and returns increase by only 6 percent, from $1946.92 to $2069.92. Thus, reduced rates of decline due to dryland conversion do not appear to be a significant factor in determining the fate of irrigated agriculture.

more severe conditions are assumed, cessation of irrigated farming appears inevitable. Nonetheless, increased profitability through use of low pressure center pivot systems is able to extend the life of irrigated farming beyond the time predicted with use of high pressure systems.[3]

IMPROVING PUMP AND APPLICATION EFFICIENCIES

The impacts on net returns from improvements in pump and/or application efficiencies are shown in Table 4. An increase in application efficiency decreases the amount of water pumped which, in turn, affects pumping costs. As a consequence, variable costs are reduced via a decrease in the amount of time required to run the system. Similarly, an increase in pumping efficiency reduces variable pumping costs through the horsepower requirement and subsequent kilowatt hours required per acre inch applied.

Scenarios 19-22 show the effects of increasing pump and application efficiencies at a constant groundwater table level. The economic advantage of such improvements is clearly indicated through the increase in net returns. Of more interest, however, is the benefit from improved pump and application efficiencies in the face of declining groundwater levels and increasing electricity

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[3]It should be noted here that results of the analysis appear to be fairly sensitive to changes in crop prices. The same analysis using the 1973-1982 adjusted average price scenario in Table 1 indicated that even with no increase in electricity prices, and as early as 1984, most of the acreage on an average farm should be in dryland wheat production.

Table 4. Results of Linear Programming Model for Low Pressure Pivots With Changes in Pump and Application Efficiencies.

Scenario Number	Year	Depth to Water	Electricity Costs		Efficiencies		$ Max. Return	Acres in Crops				
			¢ per kwh	$ per hp	Pump	Application		Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat
19	1984	110	4.5	18.00	.60	.80	10,265.30	94	319	78	8	0
20	1984	110	4.5	18.00	.65	.80	11,898.01	94	319	78	8	0
21	1984	110	4.5	18.00	.70	.80	13,797.23	94	319	78	8	0
22	1984	110	4.5	18.00	.70	.85	14,575.11	94	319	78	8	0
2% Increase in Electricity Prices												
23	1994	125	5.49	21.94	.60	.80	3,194.48	94	97	24	34	320
24	1994	125	5.49	21.94	.70	.80	7,097.57	94	319	78	8	0
25	1994	125	5.49	21.94	.70	.85	8,627.56	94	319	78	8	0
26	2004	140	6.69	26.74	.60	.80	1,000.47	83	0	0	42	480
27	2004	140	6.69	26.74	.70	.80	2,063.08	83	0	0	42	480
28	2004	140	6.69	26.74	.70	.85	2,437.77	83	0	0	42	480
4% Increase in Electricity Prices												
29	1994	125	6.69	26.74	.60	.80	1,576.95	83	0	0	42	480
30	1994	125	6.69	26.74	.70	.80	2,574.29	83	0	0	42	480
31	1994	125	6.69	26.74	.70	.85	3,569.44	94	319	78	8	0
32	2004	140	9.86	39.44	.60	.80	83.20	0	0	0	0	640
33	2004	140	9.86	39.44	.70	.80	83.20	0	0	0	0	640
34	2004	140	9.86	39.44	.70	.85	83.20	0	0	0	0	640

costs. Consideration of these factors are displayed in Scenarios 23-34. The cases considered are for a 2 percent and 4 percent annual increase in electricity prices.

A comparison of Scenarios 23-25 shows the economic benefit in 1994 of improving pump and application efficiencies with a two percent increase in electricity prices. Scenario 23 displays the outcome of the L.P. assuming no change in pump and application efficiencies from 1984. If the pump and application efficiencies were .60 and .80 in 1984 and remained so in 1994, net returns would decline by 69 percent due to increases in electricity costs. Increasing the pump and application efficiencies by 10 percent and 5 percent respectively, mitigates this reduction resulting in only a 16 percent decline in net returns. Scenarios 26-28 show results for the same type analysis for the year 2004.

In the case where electricity prices were increased 4 percent annually, the most significant affect can be seen in Scenarios 29-31 for the year 1994. Improving pump and application efficiencies results in the farm remaining in full irrigated crop production and in turn, net returns increase 56 percent from what they would have been if efficiency levels remained the same as in 1984. By 2004, changes in pump and application efficiencies become irrelevant with a 4 percent increase in electricity prices as this increase, coupled with a 140 ft depth to water, causes complete conversion to dryland wheat production.

Of course, increased returns from improvements in pump and application efficiencies would have to be compared with the cost of attaining the improved efficiencies. Improvements in application efficiency might be attained by use of drop hoses or by less irrigation during peak evaporation periods.

DIRECT LOAD CONTROL

Load control refers to a program where irrigators allow utilities to turn off irrigation pumps so as to receive a reduction in demand charges. Direct load control allows the utility to turn off irrigation pumps, often by some form of remote control. The irrigator normally saves under this system via a decrease in the per horsepower (hp) demand charge paid and occasionally through a reduced price per kilowatt-hour. In 1984, the Rural Electric Company opted for a one-day voluntary turn-off system which allows participating farmers to pay an $18.00 per rated hp demand charge while non-participants paid $18 per hp for the first 25 hp and then $33.29 for each hp used in excess of 25 hp.

For the individual irrigator, the economic aspect of load control is composed of two components. The first component is the value of reductions in yield that may follow from timing and/or reduced amount of water applications because of load control. The second component is the savings in energy costs associated with the load control program. A load control program would reduce yields when the time between irrigation dates is limited such that the quantity of water needed to obtain maximum yield cannot be applied.

Table 5 presents results from an analysis of a load control program in which the irrigator voluntarily shuts off his irrigation system for one day a week. The "Inches Applied" column is the amount of irrigation which resulted in maximum yields as estimated by the evapotranspiration model initially.

The number of days available to apply water without a load control program is the difference between the "Dates Applied" in the first column. As long as this number of days exceeds the "Number of Days Needed To Apply Water," the irrigator is able to keep up with crop water needs, and yields are not affected. Table 5 indicates that all crops would be able to tolerate a one-day off load control program with no yield reduction in a year of average precipitation. If a soil water deficit did occur under a load control program and yields were reduced, the decision to participate in a load control program would depend on the value of reduced yield versus cost savings due to a reduction in the demand charge.

Table 6 presents results from the L.P. for both participation and non-participation in a load control program. For the non-participant the demand charge for his irrigation system is \$18.00 per rated hp for the first 25 hp used and \$33.29 per rated hp for any amount used in excess of 25 hp. The demand charge for a participant is \$18.00 per rated hp for all hp used.[4]

[4] The 1985 rate is \$19.26.

Table 5. Analysis of Load Control and Available Irrigation Times.

Date Application Started	Inches Applied	No. Days[1] Needed to apply	No. Days Available to Apply: No Load Control	No. Days Available to Apply: 1-day off
Maximum Yield Strategy				
Winter Wheat				
4/30	4.45	12.36	28	24
5/28	2.98	8.28	53	45
Alfalfa				
6/11	7.88	21.89	45	39
6/16	.91	2.53	33	28
7/19	5.30	14.72	65	56
Barley				
5/19	2.37	6.58	12	9
5/31	2.48	6.89	11	10
6/11	2.77	7.69	12	10
6/23	3.27	9.08	19	16
7/12	.35	.97	28	24
Bean				
6/14	1.23	3.42	8	7
6/22	1.47	4.08	5	4
6/27	1.59	4.42	9	8
7/ 6	1.81	5.03	7	6
7/13	1.96	5.44	8	7
7/21	2.31	6.42	10	8
7/31	2.05	5.69	32	28
Corn				
6/13	3.31	9.19	18	16
7/ 2	4.11	11.42	17	14
7/19	4.71	13.08	21	17
8/ 9	3.62	10.06	30	26

[1] A pivot operating at 850 gallons per minute on 125 acres could apply .36 acre inches per day.

Table 6. Results of Linear Programming Model for Participation and Non-Participation in Voluntary Loan Control Program.*

Scenario Number	Year	Depth to Water	Demand Charge		$ Max. Return	Acres in crops				
			1st 25 hp	Excess 25hp		Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat
PARTICIPATION										
25	1984	110	18.00	18.00	13,236.11	94	319	78	8	0
26	1994	125	18.00	18.00	11,441.87	94	319	78	8	0
27	2004	140	18.00	18.00	9,647.74	94	319	78	8	0
NON-PARTICIPATION										
28	1984	110	18.00	33.29	10,460.11	94	319	78	8	0
29	1994	125	18.00	33.29	8,472.27	94	319	78	8	0
30	2004	140	18,00	33.29	6,482.94	94	319	78	8	0

*For a low pressure center pivot system

A comparison of the results indicates the economic advantage of the load control program. While the crop mix remains the same in both cases, returns decline at a faster rate for farmers not participating in the load control program. By 2004 returns are \$6,482.94 for non-participants compared to \$9,647.74 for participants, a 34 percent savings. In 1984, the savings are \$2,776 or 21 percent.

CONCLUSION

The results of this study have indicated some ways in which the profitability of center pivot irrigation might be improved. These are: conversion to low-pressure pivots, improvements in pump and application efficiencies, and load control programs. It must be emphasized, however, that strategies proposed to maintain or improve net returns may not be able to be extended into the future indefinitely. As the results of this study suggest, as long as recharge rates for groundwater are less than extraction rates, electricity costs continue to rise and relative prices of crops and inputs remain constant, the long-term forecast is for some abandonment of center pivot irrigation. On the other hand, any attempt to predict the future involves a great deal of uncertainty. Individual operators might find their circumstances to vary substantially from those modeled here and thus, not every farm in the area may behave as predicted. Also, any improvement in technology that would affect pumping and/or crop yields could change the results substantially. However, at this point, this analysis indicates that only the most efficient operators may be able to survive to that time when groundwater pumping will approximately equal natural recharge rates.

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WATER
MANAGEMENT

SNOWPACK ESTIMATES FROM SATELLITE IMAGERY AND RELATIONSHIPS TO SPRING MELT PATTERNS

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ABSTRACT

Snowpack has traditionally been monitored by selected, onsite recording stations and periodic sampling for water content. These procedures are proven effective, but may be improved by augmenting them with new techniques that employ satellite imagery for obtaining regional estimates of the snowpack. Landsat imagery obtained during the late winter, spring, and summer each year records the depletion of snowpack during the spring and summer melt. The area of snowpack can be efficiently estimated using an electronic planimeter coupled with a video density-analysis system. The laboratory measurements of snowcover for each watershed can be plotted together with data from selected stream gages to derive an empirical relationship between snowcover and discharge. With several years' data, the empirical relationships can be refined to the extent that it can be used as a tool for forecasting runoff.

Over the past two years we have made a concerted effort to establish an image database from which to define the critical snowmelt patterns in each Wyoming drainage area where snowmelt contributes significantly to the water supply. Snowcover measurements have been made and the data evaluated relative to appropriate streamflow data. In most cases, three or four year's satellite data have been used to establish a predictor relationship that allows estimates to be made of expected annual runoff, volume of peak runoff, and duration of the snowmelt season. Most of these predictor equations can now be employed in runoff estimation that can supplement the runoff projections derived by more conventional means. As each year's satellite data are evaluated and discharge volumes are measured, the new data can be incorporated into the forecasting system to improve the definition of the predictor equations and the accuracy of future water-supply forecasts.

INTRODUCTION

The first ERTS (Landsat) satellite was launched in July of 1972, and with it, a new era of earth resources remote sensing began. The broad-scale, repetitive, multispectral coverage of Landsat provided a new perspective on the earth that was immediately recognized as an asset in early resources assessments. One of the potential applications was that of monitoring snowcover. Just one year after the launch of the first Landsat system, the first results of applications tests were published detailing the use of Landsat as a tool for periodically mapping snowcover. In October, 1973 Barnes et al. reported:

> "...snow extent can be mapped from ERTS imagery in more detail than is depicted on aerial survey snow charts. For the areas tested, the agreement between the percentage snow cover as determined from ERTS data and from aerial survey snow charts is of the order of 5 percent for most cases. Moreover, it appears that although small details in the snowline can be mapped better from higher-resolution aircraft photographs, boundaries of the areas of significant snow cover can be mapped as accurately from the ERTS imagery as from the aircraft photography. Moreover, the costs involved in deriving snow maps from ERTS imagery appear to be very reasonable in comparison with existing data collection methods."
>
> (from Barnes et al., 1973)

The work continued, and in 1975 a symposium was held (Rango, 1975, ed.) discussing results of a number of studies in which the utility of satellite data for mapping snowcover and for predicting runoff had been demonstrated in various areas (Aul and Ffolliatt, 1975; Katibah, 1975; Leaf, 1975; Rango and Salomonson, 1975; and Thompson, 1976) demonstrated the application of snowcover mapping to runoff forecasting in Wyoming watersheds. Even so, the techniques were not immediately accepted as operational procedures, although the test studies indicated potential for efficient and cost-effective application.

Four years later, another conference was held to discuss "Operational Applications of Satellite Snowcover Observations" (Rango and Peterson, 1979, eds.). Several newly tested procedures for estimating runoff from satellite snowcover measurements were presented (Schumann et al., 1979, Shafer and Leaf, 1979; Moravec and Danielson, 1979; Brown et al., 1979; Hannaford and Hall, 1979; Martinec and Rango, 1979). These studies generally supported the conclusion that Landsat could be used effectively to forecast runoff and could be expected to improve timeliness and accuracy of runoff forecasting. Several investigators reported results of their efforts to improve on the basic techniques for predicting runoff from snowcover. Some used Landsat data together with data from meteorological satellites (Schumann and others, 1979), others correlated the snowcover data with more sophisticated models for runoff prediction (Dillard and Orwig, 1979; Moravec and Danielson, 1979; Hannaford and Hall, 1979). Rango and Martinec (1982) incorporated daily temperature data into a prediction model. Most studies emphasized the necessity for defining specially tailored snowcover/runoff relationships for each drainage area in order to accommodate variations in pattern due to topography, slope aspect, vegetation cover, elevation and other local conditions.

Although Wyoming drainage basins were used as test areas in a number of studies that demonstrated the utility of these techniques, no major effort was made to implement the procedures on a regional scale. As one of the few workers in Wyoming involved in multidisciplinary applications of remote sensing, I determined, in 1982, to try to develop a statewide system for using snowcover estimates from Landsat to monitor the depletion of snowpack during spring snowmelt and forecast runoff. A proposal was made to the Wyoming Water Research Center with the following goals in mind:

1. To accumulate a statewide, multi-date image database suitable for establishing a permanent record of snowcover depletion for several seasons and for each Wyoming watershed in which annual snowpack provides a significant component of annual discharge.
2. To derive snowcover estimates from the Landsat images and relate these to appropriate streamflow measurements in order to define relationships between snowcover and runoff in each watershed.
3. To assist in establishing a system using satellite imagery as a tool to monitor snowpack and improve runoff forecasts.

The project was considered ambitious at the outset. It has since proven even more demanding than originally supposed. Yet the technique has proven effective in most drainage areas, and success is certainly within reach.

APPROACH

The approach taken in this work was one largely pioneered by Rango and Salomonson (1975), Thompson (1976), and Moravec and Danielson (1979). Every effort has been made to keep interpretation and analysis procedures as simple and cost-effective as possible without unduly jeopardizing accuracy of results. In this context, the methods used by early investigators have been applied with only minor modification and without embellishments that could produce slightly improved forecasts but at considerable cost in terms of manpower and data analysis time.

Inventory was first made of the Landsat data in the image library of the University of Wyoming, Remote Sensing Laboratory; and determination was made from the available data of the dates and type of imagery best suited to this effort. Bulk-processed Landsat image transparencies of spectral band 5 (red band) were selected because they provided strong contrast between snow and vegetation even during the late spring snowmelt period. Single-band scenes were preferred to color-composite scenes because of greater availability and lower cost. Transparencies are more readily input to video analysis and provide better image detail than prints.

Computer listings of available Landsat coverage were obtained from the USGS/EROS Data Center in Sioux Falls, South Dakota; and supplementary coverage was ordered for selected seasons on the basis of minimal cloud cover and availability of streamflow data.

Streamflow data from selected gage stations were obtained from the Wyoming Water Research Center in the form of computer listings of daily discharge values and monthly discharge totals. Drainage sub-areas were selected to allow for single-scene coverage of individual regions with consideration made for availability of appropriate streamflow data (Figure 1). Discharge from most sub-areas is represented by measurements from a single gage station.

An image mask was constructed for each sub-area so that the region of interest could be isolated on each 1:1,000,000-scale Landsat scene (Figure 2). Use of the image mask assures that the same area is evaluated on each successive Landsat scene. It also enables the interpreter to easily separate the sub-area to be evaluated from the surrounding areas with the electronic image analyzer used to estimate snowcover. The Spatial Data Systems model 70 image analyzer was used to make estimation of snowcovered areas more efficient (Figure 3). This device allows the interpreter to color slice the image of the selected drainage area according to image gray tones (Figure 4). The density analyzer is adjusted so that an arbitrarily chosen color boundary corresponds to the snowline displayed on the image. An electronic planimeter then allows the interpreter to estimate the area of basin and the area of snowcover almost instantaneously. The percent snowcover computed as the ratio of these two estimates can be very quickly derived for each image in a multi-date sequence.

AREAS COMPLETE APRIL, 1985

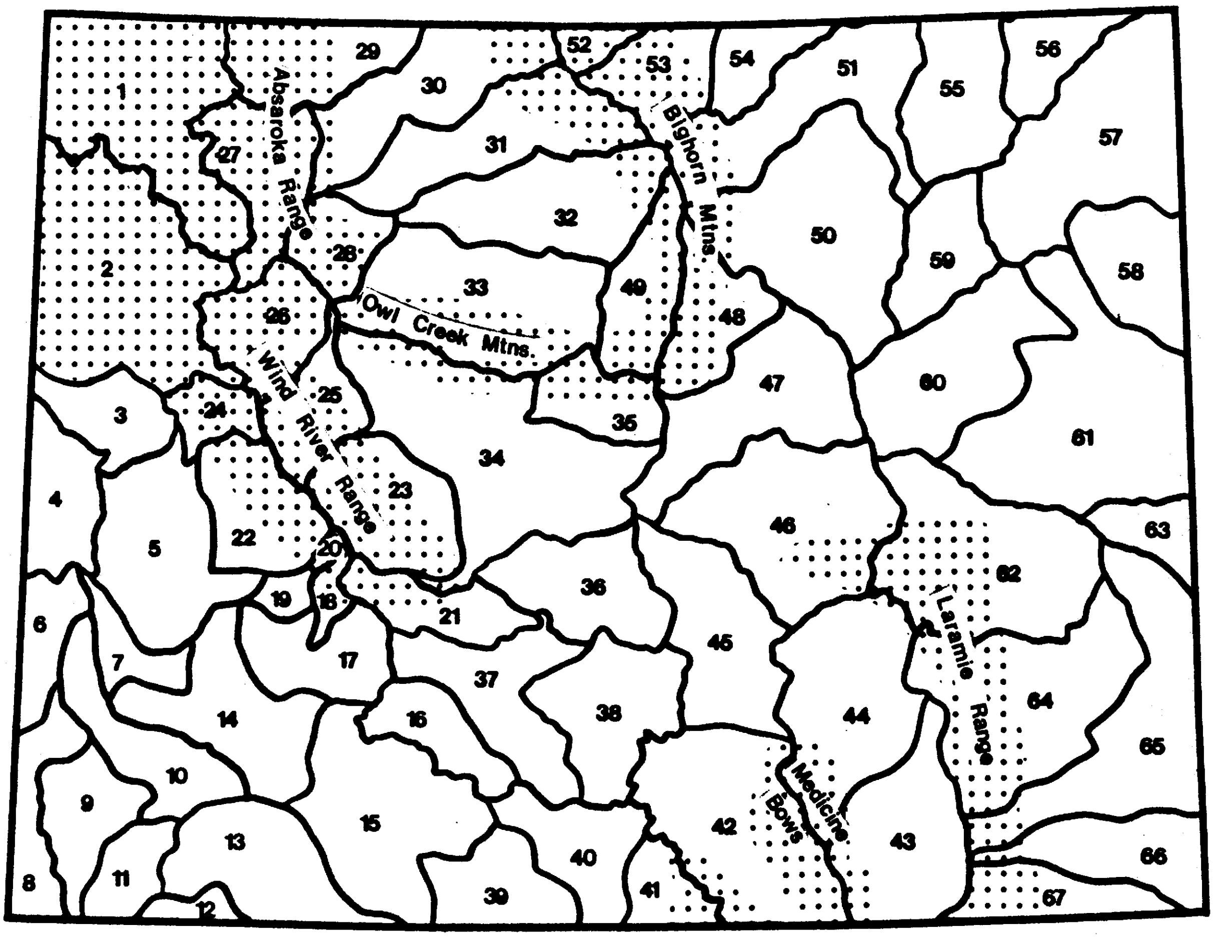

Figure 1. Index map showing drainage sub-areas selected for snowcover runoff analysis. Analysis of shaded areas have been completed.

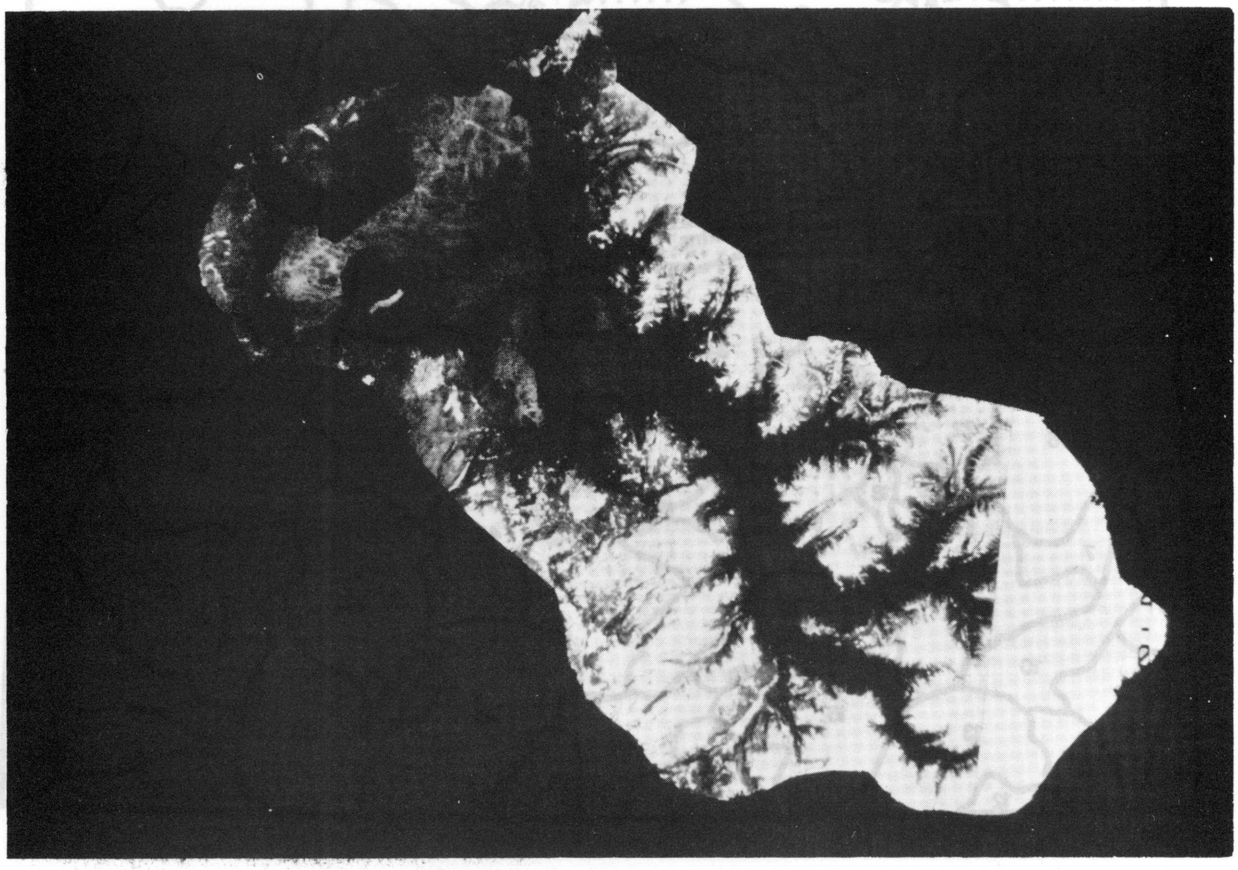

Figure 2. Example of a Landsat scene with a selected drainage sub-area isolated by an image mask. The small portion of the drainage not covered (right) will be analyzed on adjacent scene and added in.

Figure 3. Photograph of the Spectral Data model 70 image analyzer used to estimate snowcover for each sub-area.

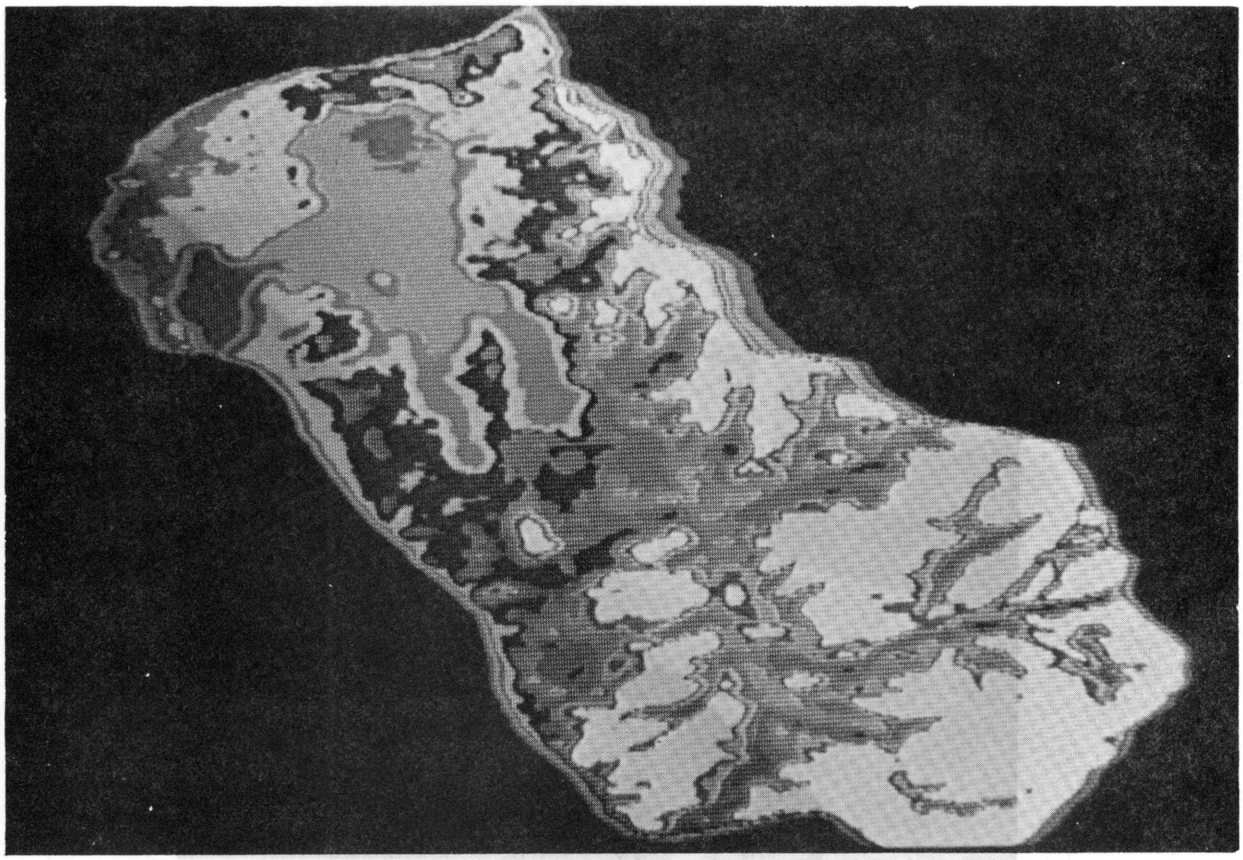

Figure 4. Black and white photo of a color-density-slice of a drainage area illustrating the technique used to isolate snowcovered area. The video planimeter will automatically estimate area of each shaded zone.

Daily discharge volumes measured at appropriate gage stations (obtained from the digital database of the Wyoming Water Research Center) are summed to produce cumulative runoff values for dates corresponding to the dates of the Landsat imagery. The cumulative runoff values are plotted against snowcover and against time to yield curves representing the snowmelt/runoff relationships of the drainage area (Figure 5). Runoff versus time data are derived entirely from streamflow measurements and serve only as a guide to help define the snowcover/runoff relationship more accurately. Using the two curves together allows the interpreter to more accurately interpolate snowcover values between the widely spaced samples provided by Landsat images. Separate curves are generated for each season's data; then the curves are combined to produce a composite snowcover/runoff relationship for each drainage area. The composite curve is constructed by weighing each season's data relative to the long-term average runoff. As a result, the composite curve presents the snowcover/runoff relationship expected for an average year. The composite curve is presented along with curves representing individual seasons so that runoff predictions can be made using the composite curve as a standard and using the individual season curves to adjust for observed conditions indicating unusually heavy or unusually light snowpack or other abnormal conditions.

For each drainage area, a brief discussion is prepared detailing the quality of the data used in constructing the standard

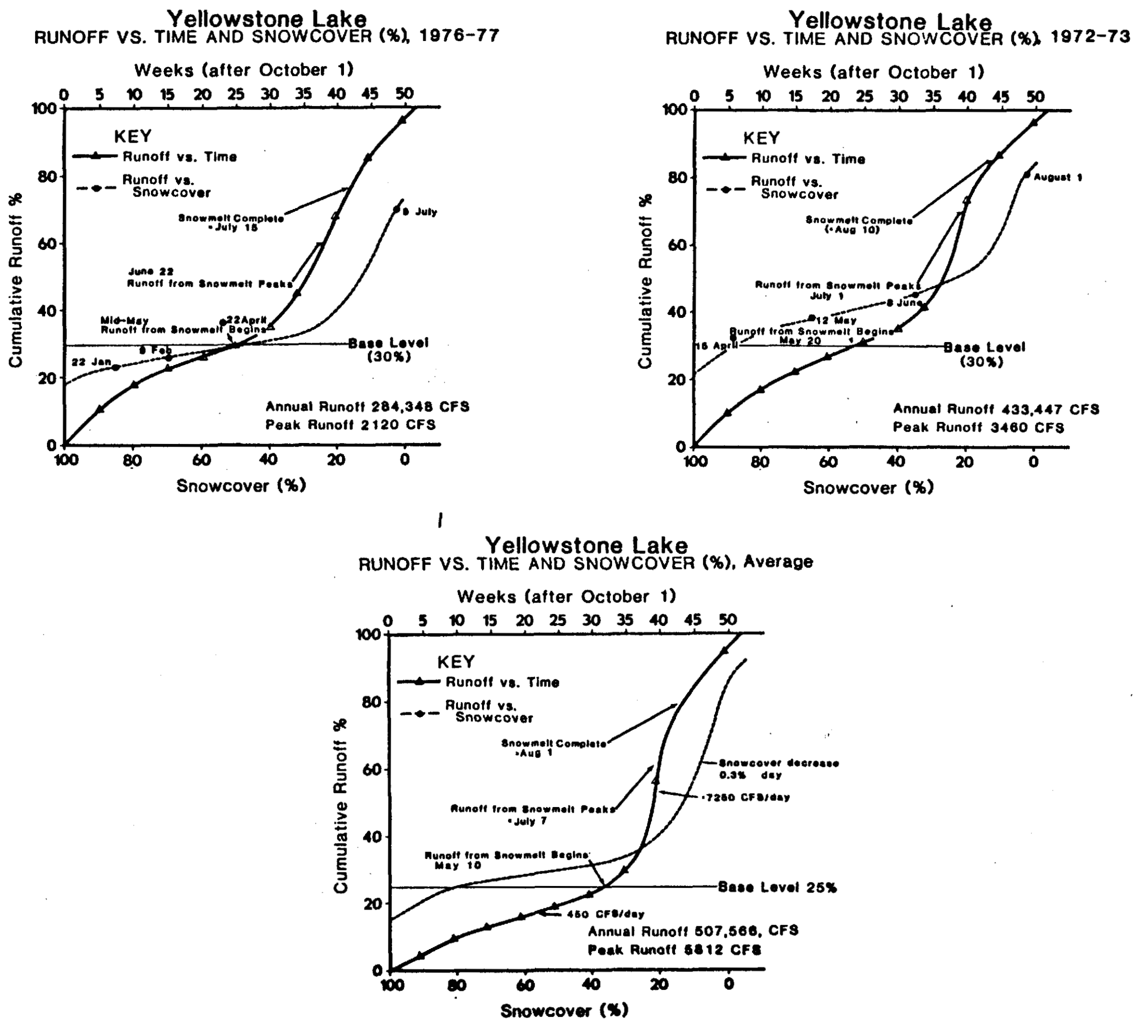

Figure 5. Snowcover vs. runoff and runoff vs. time curves showing the typical relationships between cumulative runoff and snowcover as it is depleted during spring snowmelt.

curves, critical values determined in the analysis, and other important considerations with regard to interpretation of the relationships presented. Together, the graphs of snowcover versus runoff, and duration of the snowmelt season.

PROGRESS

Sixty-seven drainage sub-areas were initially defined in Wyoming. Some were later combined or split to better accommodate available streamflow data. Forty-five drainage sub-areas in Wyoming accumulate a winter snowpack that contributes significantly to the annual discharge. Both streamflow and satellite data are available for forty areas; and we have made very effort to define a useable snowcover/runoff relationship for each of these areas. Image analyses have been completed and snowcover/runoff plots constructed for each area. We are presently making evaluations of each data set and compiling discussions to aid users in the application of these data to runoff forecasting. We have also selected a few areas to make an initial test of the predictive capability of this system using the most recent Landsat imagery to estimate depletion of the 1985 snowpack.

No arrangement has yet been made for actually incorporating satellite snowcover-estimation procedures into an operational program or for continuing to maintain and upgrade the image database. We are confident that the groundwork is sufficiently complete and the database is minimally adequate for operational application of these techniques to water management. However, the manpower and financial resources necessary for continued image acquisition and analysis have not been identified. The techniques have been demonstrated to be both effective and practical. The essential groundwork for statewide application of the technique is nearing completion. We are now at the point where we must make the decision whether or not to implement the technique as part of the State's water management program.

Arrangement was made for the USGS/EROS data center to notify us of each useable image acquired during the snowmelt season. Images can be obtained within 7-10 days of their acquisition by satellite, and evaluation can be made within one additional day to enable timely forecasting of expected streamflow.

Evaluations and discussions at each of the forty areas should be completed in July, 1985 and will be incorporated into the final project report.

DISCUSSION

The procedure works well in most Wyoming watersheds and produces snowcover/runoff curves that show a consistent pattern and are readily interpretable. The typical curve shows that runoff is reasonably constant or diminishes slightly until the onset of spring snowmelt. As snowmelt progresses, the runoff increases steadily to a peak value and then wanes as the snowpack is depleted. For a given drainage the curve tends to shift laterally to earlier dates for seasons of light snowpack and toward later dates for seasons of heavy snowpack. Also, the runoff versus snowcover curve tends to steepen (percent snowcover diminishes rapidly) when snowpack is below normal. These typical relationships hold true for most areas, but considerable variability is apparent in comparing relationships from one drainage area to another, demonstrating the necessity for defining a separate set of reference curves for each area.

One problem that critically affects analysis in a few areas is that of availability of streamflow data. Gage stations have not been installed on some drainages; and, for few others, the streamflow data are available only for a few years or only during certain parts of the year. If no streamflow data are available, the snowcover information can provide only a relative estimate of expected runoff. Snowcover/runoff relationships can only be constructed by inferring relative flow rates from adjacent areas. In areas where partial data are available, the relationships can be constructed to produce semi-quantitative predictions, but the results are only as good as the data from which the relationships are derived. If runoff forecasting from satellite data is to be applied successfully in a statewide program, gage stations should be maintained to monitor discharge from each mountain watershed, and, if possible, data should be collected continuously for the entire year.

Another problem is that of limited satellite coverage due to cloud cover. The 18-day cycle of Landsat satellites 1, 2, and 3 and the 16-day cycle of Landsats 4 and 5 are marginally adequate for runoff forecasts, even if every image acquired during the snowmelt season is cloud-free. Unfortunately, at least half of the imagery acquired over Wyoming during the snowmelt season is not useable because of cloud cover. The cloud cover is not a critical limitation in constructing snowcover/runoff reference curves because periods of good, cloud-free coverage can be selected and used to define the reference relationships. But, if timely forecasts are to be made, the availability of cloud-free images is critical. No solution to this problem is possible with the present Landsat system, but several eventual solutions are possible:

1. The frequency of satellite imaging could be increased to provide greater opportunity to image on cloud-free days. This could be accomplished by using more than one satellite in alternating orbit cycles or by using a pointable satellite system (such as the planned SPOT system to be launched by the French in late 1985).

2. Landsat data might be supplemented by images from the geostationary weather satellites. The daily coverage provided by these systems has been used successfully for broad, regional snow surveys; and previous research suggests that it might be possible to effectively combine the data from the geosynchronous satellites with the less frequent, but higher resolution, data from Landsat.

3. Cloud-penetrating radar systems could be used instead of the visible and near-IR bands of the current systems. Such a system would allow imaging at night and through cloud cover. Seasat and the Shuttle Imaging Radar experiments may be precursors to an operational radar system to be launched at some future time.

Whatever solution to the problem, a system that provides more frequent coverage could be easily integrated into the current procedures to produce better and more timely results.

One other problem is that of distortion of normal runoff patterns by water management. In some areas, water management practices strongly affect the measurements at critical gage stations. Management practices change from year to year and they can severely distort the snowcover/runoff patterns. Adjustments can be made for these effects if the changes in runoff due to management can be isolated, but this is often difficult or impossible. Water management practices are usually a problem only in areas where large storage facilities are maintained or in areas of heavy water use by agriculture or industry.

One final consideration is that snowcover measurements can not be used to forecast runoff until the snowmelt season has begun and the snowpack has begun to diminish. This prevents very early projections of expected runoff and necessitates continued use of snow course measurements or other methods to obtain early assessments of snowpack.

CONCLUSIONS

The practicality of using Landsat data as a tool for monitoring snowpack and forecasting runoff has been demonstrated in several areas. Work in the past two years has provided a basic data set and a set of snowcover/runoff relationships that can be used to forecast runoff from most Wyoming watersheds. Limitations of the technique require that it be used to supplement and improve current forecasting procedures rather than supplant them.

ACKNOWLEDGEMENTS

This project was made possible with support provided by the Wyoming Water Research Center and the U.S. Geological Survey. Equipment and imagery available through the Remote Sensing Laboratory of the Department of Geology and Geophysics was used extensively. The image analyses and most other work was accomplished through the efforts of Cheryl Jaworowski, Janet Marks and Bill Small, graduate students. Their assistance is greatly appreciated.

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RANGE MANAGEMENT'S WILDLAND WATERSHED RESEARCH EFFORT: ANTIDESERTIFICATION OF RIPARIAN ZONES AND CONTROL OF NONPOINT SOURCE POLLUTION

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ABSTRACT

Overgrazing by domestic livestock and periodic flooding are often cited causing increased nonpoint source pollution in streams within semi-arid rangelands. Riparian zones along streams my help decrease nonpoint pollution if maintained in a healthy ecological condition. This paper will address two research programs designed to reverse desertification of stream-side zones along cold desert streams in Wyoming by: 1) manipulating livestock grazing, 2) promoting regrowth of desirable vegetation, 3) willow planting, 4) using instream flow structures to store water in channel banks and trap sediment and 5) encouraging beaver damming. Research hypotheses as well as monitoring protocol will be discussed and related to ease of technique used by management agencies and producer groups affiliated with western rangelands.

RIPARIAN ZONES

Riparian zones are areas supported by a high water table because of proximity to surface or subsurface water. They are characterized by distinct soils and more highly productive and diverse plant communities and animal species than adjacent more zeric areas. They normally occur as an ectone between xeric and aquatic ecosystems (Brown et al., 1978).

Importance

Riparian zones are used by a wide variety of interest groups (Busby 1978, Johnson 1978, Tubbs 1980, and Kauffman and Krueger

1984). Apparent causes for concentration of multiple uses in riparian zones are the vegetation species diversity, productivity, and proximity to open water. High species diversity in the riparian zones is reported by Campbell and Green (1968), Brown et al. (1978), Ewel (1978) and Kauffman et al. (1983a). The vegetation of this zone stabilizes stream channels by creating a rough surface thereby reducing stream flow velocity and roots hold bank material together (Li and Shen 1973, Heede 1977, Platts 1979, and Andrews 1982). Because stream flow velocity is reduced and vegetation traps sediment on banks, water quality is improved (Schumm 1963 and Andrews 1982). Lowrance et al. (1985) show how interflow between bank waters and streams in riparian zones further improves water quality. Increase in water quality promotes diverse aquatic habitat and thus improves fisheries (Cummings 1974, Duff 1979, and Platts 1981). As well, riparian habitat value to wildlife is well documented (Crothers et al. 1974, Johnson et al. 1977, and Thomas et al. 1979). Increased edge effect for area occupied (Odum 1978) and vegetation structural diversity compared to surrounding plant communities are often characteristic of riparian zones (Anderson et al. 1983). Both edge effect and structural diversity are important for habitat to maintain diverse wildlife species composition (Ohmart and Anderson 1978). In addition, high vegetation production, free flowing water, flat terrain and shade are cited as reasons livestock use riparian habitat (Kauffman and Krueger 1984).

User Impacts

Users of riparian zones may cause soil compaction, slough off undercut stream banks, and denude vegetation along channels. These actions can increase erosion which often causes stream channel widening, downcutting, or both (Peterson 1950, Schmidly and Ditton 1978, Meehan and Platts 1978, and Thomas et al. 1979). This erosive action may result in loss of: 1) floodplain water tables, 2) floodplain soil moisture, 3) aquatic habitat quality, 4) fisheries, 5) plant vigor, and 6) plant species diversity (Jahn 1978, Campbell 1970, McCall and Knox 1978, and Platts 1981). Examples of stream degradation and channelization with impact as above are noted by Busby (1978), Meehan and Platts (1978), Roath and Krueger (1982), and Kauffman et al. (1983b). Recovery of stream channels, aquatic habitat, fisheries, and riparian vegetation after livestock have been removed has been demonstrated by Keller et al. (1979), Duff (1979), Bowers et al. (1979), Platts (1981), and Kauffman et al. (1983a). These researchers have used exclosures to eliminate grazing along stream reaches within different grazing management strategies to hopefully document which strategy best conserves riparian and aquatic habitat. Little research has been initiated to look at reclamation of streams and riparian zones to promote water storage and control nonpoint source pollution. This contrasts with studies to evaluate removing riparian vegetation to increase water downstream.

A loss of water through evapotranspiration cannot be denied. In areas like the southwest United States, much research has been conducted to measure water yield following riparian vegetation removal from floodplains. Large savings of transpired water predicted by Gatewood et al. (1950) and Robinson (1965) were found to be less by Culler (1970) and even smaller by Horton and Campbell (1974) when salt cedar was removed. Interest in removing riparian plants to increase water yield during the last decade has been minimal (Graf 1980). This perhaps is because short-term increased water yields decline when riparian plants reinvade riparian zones (Horton and Campbell 1974), high cost to benefit ratios (Graf 1980), other user demands for riparian zones (Campbell 1970), and downstream loss of recovered water to deep aquifers (Davenport et al. 1982). Certainly conflicts between interests exist as how to best manage riparian zones. Graf (1980) points out that saving water by reducing transpiration is not currently as popular as habitat management for other uses. However, managers must determine how to reduce floods when riparian vegetation reduces stream channel conveyance of flow to and through downstream areas. Conversely, if developed riparian zones cause flooding, why not use this phenomenon to repair degraded stream channels, store ground water, and control nonpoint source pollution.

Hypothesized Mechanisms for Reclaiming Streams and Riparian Zones

Invading riparian plants stabilize stream bars, islands, and floodplains. Often bars become islands and channels around islands close to form floodplains bordering one channel. This occurs when flushing flows are not able to remove established vegetation and overbank flooding deposits sediment to further advance channel filling. This normally occurs in low rather than steep gradient stream reaches. When flow regime is in equilibrium with channel size and bank resistivity, developed riparian zones may indicate geomorphological character of the stream system (Leopold et al. 1966, Graf 1978, and Heede 1981). This process may begin in a wide, degraded stream channel when surface flow decreases. Low flow across low gradient channel bottoms meanders, thereby increasing stream sinuosity and length. Permanent aggradation occurs when sediment deposits from flow and is stabilized by vegetation. Andrews (1982) shows aggradation occurs bank first during overbank flooding and through accumulation of bedload during lower flows. Accumulated bedload may persist until the channel narrows to meet the annual flow regime. Narrowing of the channel causes increased flow velocity and accumulated bedload is then transported downstream causing the channel to deepen. Andrews (1982) also indicates that although a developed stream maintains an average width and depth in equilibrium with the flow regime, it will move laterally from year to year thus fitting Leopold and Lanbein's (1966) description of meandering streams. The presence of undercut banks along stable streams are evidence of lateral movement of meanders and should not be construed as showing stream channel instability.

Reclaiming degraded streams to support mature riparian zones depends on deposition and stabilization of deposited sediment by vegetation. Stream channel transmission loss of water downstream during a high flow event to surrounding alluvium occurs as shown by Lane et al. (1970). Loss in flow downstream should cause aggradation of sediment. Glymph and Holton (1969) show loss of stream flow from any one runoff event in semi-arid regions should be maximum near the mouth of a drainage basin or in large basins if channel transmission loss occurs. Location of manipulative practices to reclaim degraded streams based on loss of flow and aggradation of sediment should therefore be placed at locations of maximum water travel time.

Damming by instream flow structures, like check dams or trash collectors; and biological damming by beaver or constrictive channel dams caused by encroaching banks and riparian zones cause: 1) reduced flow velocity, 2) stable bedload and, 3) storage of water in banks proximal to the dam. Heede (1978 and 1982) discusses reclamation of gullies by raising a local base level of ephemeral stream reaches to decrease gradient slope upstream using check dams. The lower gradient reduces sediment transport. Deposition occurs upstream in a wedge shape. Following Heede's 1978 and 1982 research, dams should be placed downstream just above a tributary junction. Additionally, to achieve restoration of riparian habitat the dam should also be located on a stream reach having a low gradient where meandering occurs and a stable floodplain exists. The dam should then cause bank deposition of sediment and maximum filling within the upstream drainage network. Established riparian vegetation and narrowing of the channel may then eventually cause water to spread over banks during flood producing runoff events (Graf 1980).

Study Approach: Reclamation of Cold Desert Steppe Streams

Funding and Administration

Antidesertification of cold desert steppe streams through reclaiming degraded channels and promoting riparian habitat is a joint research effort being conducted by the Range Management, Civil Engineering, and Zoology departments, and the Wyoming Water Research Center (WWRC), University of Wyoming; the Bureau of Land Management (BLM); the Department of Environmental Quality (DEQ), State of Wyoming; industry and ranchers. Funding has been, and is being, provided by the U.S. Department of Agriculture; Science and Education Administration and the Environmental Protection Agency. Funding has been requested from the U.S. Geological Survey to document hydrologic response associated with reclaiming degraded streams and associated riparian zones. WWRC provides the administrative umbrella for various research efforts being conducted by the University. Individual departments account for budgets, data sets, and report obligations. Land and water management agency personnel, industry and ranchers work with individual University departments when: a) research is being planned, b) research sites are selected, c) livestock are used in experimental designs, d) facilities are developed, e) funds are requested and f) data is gathered.

Integration of a multidisciplinary team effort as described above is a second step in developing best management practices for abatement of nonpoint source pollution to streams from semi-arid western rangelands. The first step in Wyoming's research effort did not start with research requests from the University to the land and water management agencies at the state or national level. Quite contrary, the University was contacted and urged to become involved by field personnel of management agencies and by local ranchers. Only after much deliberation between potentially involved interest groups and being convinced there was a need for research which could solve local, state, national, and international problems did University researchers make a commitment. By following this philosophy, a strong bond has developed between multiple users and managers of rangeland and water. Responsibility and accountability is distributed to those who need questions answered and the University is a third party in helping to answer them. This process has now materialized so that state support for field level agency personnel is present and research facilities are, or are being, constructed by the BLM, WWRC, and ranchers to conduct long-term research.

Facilities

The importance of riparian zones and impacts caused by multiple users are well documented. These problems may exist on almost any stream. Because personnel, funds, and time are limited under current economic constraints to develop management strategies for abatement of nonpoint pollution, research facilities and experimental designs must be developed to answer questions pertinent to any drainage basin or within different stream reaches within any one basin. Wyoming has tried to do this by limiting research efforts to selected facilities within geographic areas and vegetation zonations for answering riparian zone questions. Examples of these facilities are: 1) The Snowy Range Hydrologic Observatory; an instrumented watershed located from alpine down to and within montane vegetation, 2) a valley without a developed channel to be used beginning in 1985 for diversion of water for municipal supply and which will become a perennial stream located above reservoir storage within the montane to foothill vegetation zones, 3) an instrumented flood irrigated meadow complex to document return flow to tributaries of the Green-Colorado River system located within foothill rangeland, 4) an ephemeral stream exclosure to document using sediment, livestock grazing, and vegetation enhancement to reclaim degraded streams and riparian zones located within a cold desert steppe basin, 5) a perennial stream exclosure and pasture system to document using sediment, livestock grazing, vegetation, instream flow structures, and beaver to reclaim degraded streams and riparian zones within a cold desert steppe basin and 6) the wildland watershed laboratory located on the University of Wyoming campus within the College of Agriculture to interface with field site data for modeling functions of riparian ecosystems. Hopefully because research efforts are: 1) concentrated within select and well developed facilities, 2) located within representative areas of vast western rangelands, 3) located on streams characteristic of those flowing through semi-arid region drainage basins and, 4) concentrated on streams where flow regime is typical of mountain to basin conveyance of water, reclamation procedures for reversing desertification of riparian zones can be accomplished in a timely and cost effective manner.

15 Mile Creek

The research facility for 15 Mile Creek is located above the confluence of a downstream tributary. This allows maximum transmission loss of stream flow thus reducing velocity from any one runoff event. The stream reach within the facility is meandering, has a low channel gradient, and loses water to supporting alluvium. These characteristics plus manipulation of livestock grazing to leave vegetation on channel bank slopes minimize stream flow velocity. Reduced velocity should cause bank-first deposition of sediment. Stabilization of this sediment by vegetation and encroachment of plants into the channel should further reduce stream flow velocity and thus create channel filling.

As the channel fills peak flow events can be forced over floodplains left dry because of past downcutting. Floodplain vegetation again traps sediment and slows flow velocity, and terrain depressions create surface storage. Depression storage, after evapotranspiration, should percolate into alluvium thereby increasing soil and ground water. Further spreading of water over floodplains can be increased by rounding of banks through hoof action by livestock trampling. Rounding promotes vegetation establishment on former straight wall stream banks and decreases channelization by flood producing flow events. Depressions left because of hoof imprinting should cause surface storage of water, increase infiltration, promote bank plant production, lower bank profile and will help curb bank rill erosion. As the process of channel filling progresses through encroachment of stream banks, root biomass should cross the narrow interim channel. If grasses and other vegetation along the stream edges are rhizomatous, plants should establish across channel. This vegetation should filter sediment during flows and roots should stabilize bed load. The channel bottom should rise and as a result, 15 Mile Creek could have a natural dam two miles long. This dam should cause channel filling upstream and the described hypothesized process should repeat itself upstream.

Reclaiming this ephemeral stream channel depends on management of vegetation along banks. Livestock and wildlife have, and are, grazing this channel. The challenges for this research effort are to determine how: 1) grazing affects ephemeral stream channel vegetation, 2) grazing affects stream channel stability and, 3) to develop ways to graze degraded and reclaimed ephemeral streams while maintaining desired vegetation and channel stability and promote channel filling. Answers to these questions should help control nonpoint source pollution from wildlands of semi-arid regions of the world in a cost effective manner over extended periods of time. This can be accomplished, however, only after technical information is conveyed to land and water management agencies as well as to other user groups. University Extension has participated in planning and is a member of this research team to insure technology transfer.

Muddy Creek

Muddy Creek was selected as a study site because: 1) the stream is located next to a highway and access will allow extension to transfer technical information easily through research demonstration techniques, 2) different stream reaches within the 65 km study area depict different degrees of channel stability and degradation and, 3) the study area meets all geomorphological requirements used for selecting the 15 Mile Creek site, although Muddy Creek is perennial. The Muddy Creek site study area is divided into six hydraulic response units each with a different degree of channel degradation. Reversing desertification of this area is being accomplished using instream flow structures (trash collectors), willow and other vegetation planting, and beaver dams to create riparian zones. Riparian zones trap sediment on banks during overbank flooding. Trash collectors and beaver dams pond stream flow, trap sediment, stabilize bedload, raise water tables, store ground water, and promote increased riparian vegetation thereby narrowing the channel. When dynamic equilibrium of flow regime with bank resistivity is obtained, riparian zones will act as a constrictive dam during peak flows thereby causing further sediment deposition upstream.

The three mile downstream stream reach has been ponded during low flow with 32 (45 cm high) trash collectors placed on straight channel sections along the reach. The trash collectors have withstood summer high flow events and winter ice. Many are full of sediment and the channel bottom between catchers is aggrading. Beaver are using three of them as a base for constructing dams out of willow and sagebrush. New sets of 32 (45 cm high) trash collectors will be constructed this summer and in future summers over those filled until high flows flood adjoining areas left dry because of past channel downcutting. This 5 km constrictive dam will back sediment upstream creating riparian zones to be further enhanced with more trash collectors. The upstream 5 km stream reach is degraded because of sediment being filtered by a 16 km stream reach of good riparian habitat above it. Above the 16 km stream reach 5 km of flood flats exist. This area will be planted with vegetation and grazing management will be altered to cause aggradation for an additional 10 km upstream.

Pertinent questions to be answered from this research effort are:

1. How does water storage differ between degraded, natural, and improved riparian zones of high desert steppe streams?
2. Do different stream reaches have different water storage capabilities along improved cold desert steppe streams?
3. Do improved riparian zones change flow regimes and, if so, is there a prolonged release of water for downstream users during periods of shortage?
4. What are the hydrologic responses associated with riparian zone improvement practices of cold desert steppe streams such as: damming by beaver and instream flow structures, willow and grass establishment; brush control (burning, spraying) and fertilization?
5. Can riparian zone improvement practices initiated on cold desert steppe streams reduce nonpoint source pollution down stream?
6. What value does improved riparian zones of cold desert steppe streams provide for control and abatement of nonpoint source pollution?

7. What are the hydrologic responses associated with grazing of improved riparian zones of cold desert steppe streams by livestock and wildlife?

8. What are the economic costs and benefits of improving degraded riparian zones of cold desert steppe streams?

Vegetation response, stream flow, soil moisture, ground water recharge, stream channel morphology, root biomass of stream banks, particle size distribution of channel banks, animal grazing behavior, effect of season of use by livestock, effect of stocking rate of livestock on riparian vegetation, trash collector design, and techniques to reinforce beaver dams are examples of data being collected by the University of Wyoming. Change in stream channel morphology is being monitored using cross-section techniques. Permanent cross sections placed on meander and straight stream reaches are located in all study units. Changes in channel depth and cross-sectional areas are being determined.

Vegetation response to change in stream channel morphology is being determined by monitoring production, species composition, and density at each cross-section. Also at each cross-section, encroachment of vegetation and banks across the interim channel is measured by decrease in width of the open channel, and root biomass and partial size distribution of banks are determined by coring techniques. Utilization of vegetation by grazing is determined using marked plants along transects.

Soil moisture, water table change by season or flow event, stream flow, and precipitation are being monitored using neutron scattering techniques, well logging, gauging stations or peak flow techniques, and permanent gauges respectively. Soil moisture tubes and wells to monitor change in water table are located at permanent cross-sections from interim bank edge, across flood plains, and where needed to upland hydraulic controls. Suspended sediment will be collected at each stream gauging station.

BLM and DEQ are collecting sediment load data in stream flow. The University of Wyoming will soon be initiating a study designed to evaluate denitrification and sulfate reduction potential in riparian zones of cold desert steppe streams as well as planting of vegetation along degraded channels.

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EFFECT OF INCREASED IRRIGATION EFFICIENCIES ON SALT RIVER STREAMFLOW

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ABSTRACT

The Salt River drainage basin (Star Valley) is an agricultural watershed of 829 mi^2 ($2150 km^2$) in western Wyoming. Starting in 1971, several irrigation projects were completed that converted surface irrigation systems to sprinkler irrigation systems on approximately one-half of the irrigated acres in the valley. This conversion resulted in less total water being diverted from streams for the sprinkler systems than was the case for the surface systems on the same irrigated acreage.

Salt River stream flows were hydrologically analyzed and a comparison made of the flows prior to and after conversion to sprinkler systems. A test of mean monthly flows showed that spring flows increased significantly ($\alpha = 0.05$) by 58.7 percent following the conversion to sprinklers. The Salt River flows were also compared with flows of the Greys River, a nonagricultural watershed immediately adjacent to the Salt River, using the double mass analysis. This test again showed higher spring flows and also lower fall flows were evidently a consequence of irrigation practices rather than climatological factors.

Analysis of annual flood peaks was accomplished by several hydrologic and statistical tests. Included were a comparison of flood frequency distributions, a test of stationariness and a test of homogeneity. These tests revealed that flood peaks increased significantly ($\alpha = 0.05$) following the conversion to sprinklers. The mean annual flood peak increased by 47.0 percent.

INTRODUCTION

In parts of the semiarid West, the availability of sufficient water is one of the primary factors limiting agricultural production. For this reason, the development of irrigation systems with increased water application and conveyance efficiencies has been desirable to make better use of the limited available water. However, increases in irrigation efficiencies may affect streamflows by causing higher spring flows and lower fall flows (Interagency Task Force on Irrigation Efficiency, 1978). These can be undesirable effects especially in the lower portions of watersheds where impacts are expected to be most extreme. Developments in the Salt River drainage basin (Star Valley) in Wyoming have presented an opportunity to document some of the overall hydrologic impacts of increased irrigation efficiencies (Sando, 1985). Between 1971-1974, several irrigation projects were completed which resulted in a conversion from flood irrigation to sprinkler irrigation. After the completion of these projects, approximately one-half of the 60,000 irrigated acres (24,280 ha) in Star Valley were irrigated with sprinkler systems. Those farms that converted to sprinklers increased their irrigation system efficiencies by an estimated 50 percent and yields increased by an average of about 100 percent.

Site Description

The Salt River has a drainage area of 829 mi^2 (2150 km^2) and is located on the west-central edge of Wyoming. The Salt River flows northerly through the Star Valley for about 50 miles (80.5 km) before it enters Palisades Reservoir near Alpine Junction, Wyoming. The waters forming this river flow out of the Salt River

Mountain Range on the east, the Caribou and Webster Ranges on the west and the Gannett Hills on the south. The average discharge of the Salt River was 776 cfs (21.98 m^3/s) for the 29 year period prior to 1983 and the maximum discharge was 3870 cfs (109.60 m^3/s) on June 1, 1971. Peak discharges in this area result from snowmelt runoff in the spring. Flooding due to thunderstorms is a rare occurrence.

The Star Valley is a narrow, agricultural valley about 50 miles (80.5 km) long and about 15 miles (24 km) across at its widest point. It is one of the main dairy farming centers of Wyoming. Alfalfa hay and barley are the two main crops produced. The irrigation season typically lasts from late May to early September. Most of the soils in the valley are shallow, gravelly and well drained. Average annual precipitation is between 18-20 inches (45.7-50.8 cm).

Many of the analyses in this study involved comparison of Salt River flows with the flows of the Greys River. The Greys River flows through a narrow drainage basin (448 mi^2, 1160 km^2) on the other side of the Salt River Mountain Range immediately adjacent to Star Valley. It is bordered on the east by the Wyoming Mountain Range. The Greys River is essentially devoid of agricultural influence with less than 500 acres (200 ha) being irrigated from this river. The 30 year average discharge was 653 cfs (18.49 m^3/s) prior to 1983 and the maximum discharge was 7230 cfs (204.76 m^3/s) on June 19, 1971.

ANALYSIS OF STREAMFLOW DATA

As many hydrologic and statistical tests as were relevant and practical were employed in this study in an attempt to properly interpret streamflow changes observed on the Salt River. The primary tests employed were comparison of mean flows, flow duration curves, double mass analysis, a synthetic flows analysis and an annual flood peaks analysis. In all analyses, the period October, 1953 through April 1971, was assigned to represent the pre-sprinkler period and the period May, 1971 through September, 1982 to represent the sprinkler period.

Comparison of Mean Flows

For each month, the mean monthly flow for the pre-sprinkler period was compared to that for the sprinkler period using the T-test for unequal sample sizes (Snedecor and Cochran, 1974). Results of these comparisons appear in Table 1. The mean monthly streamflows for May and June were significantly higher in the sprinkler period. The average increase for these two months was 58.7 percent. No other months showed significant differences between the pre-sprinkler and sprinkler periods. It is of note that flows increased slightly during the months of August through November in the sprinkler period (an average of 4.5 percent) when they would have been expected to decrease. This is attributed to greater precipitation in the late summer and fall during the sprinkler period. This is further discussed in following sections.

TABLE 1. Comparison of Salt River mean monthly streamflows for the pre-sprinkler and sprinkler periods.

Month	Mean Flow in ac-ft (ha-m) Pre-sprinkler[1]	Sprinkler[2]	Percent Change	T Value	F Ratio
Oct	37,466 (4625)	39,188 (4837)	+4.6	-0.6	0.4
Nov	35,174 (4342)	35,579 (4392)	+1.2	-0.2	0.0
Dec	32,310 (4000)	31,987 (3948)	-1.4	0.2	0.1
Jan	28,154 (3475)	27,528 (3398)	-2.4	0.4	0.2
Feb	25,165 (3106)	24,097 (2974)	-4.3	0.8	0.5
Mar	26,700 (3296)	30,293 (3739)	+13.5	-1.7	4.0
Apr	51,641 (6374)	56,932 (7027)	+10.2	0.7	0.5
May	88,422(10914)	130,329(16086)	+47.4	-2.4*	6.9*
Jun	64,492 (7960)	109,559(13523)	+69.9	-2.7*	9.0*
Jul	45,532 (5620)	64,244 (7930)	+41.1	-1.9	4.5
Aug	38,396 (4739)	41,136 (5078)	+7.1	-0.6	0.5
Sep	38,614 (4766)	40,531 (5003)	+5.0	-0.5	0.3

[1]October, 1953 - April, 1971 [2]May, 1971 - September, 1982
*Significant at $\alpha = 0.05$

Double Mass Analysis

The double mass analysis was used to test the consistency of the streamflow observations on the Salt River for the period of record (Kohler, 1949). In this procedure, for each month, yearly accumulated streamflow values of the Salt River were plotted against those of the Greys River. A consistent record will generate a relatively straight line of constant slope. A record in which streamflow changes have occurred will yield a broken line with two or more segments of different slope. The double mass plots for the months of December-April and July yielded relatively straight lines of constant slope, indicating little change in Salt River flows relative to Greys River flows during these months.

The double mass plots for the months of May and June showed an upward break in slope in 1971, indicating that during these months Salt River flows increased in the sprinkler period relative to those of the Greys River. The double mass plot for May (Figure 1) is representative of the early season plots. In the late season months (August-November), the double mass plots showed a downward break in slope in 1971, indicating a decline in Salt River flows in these months during the sprinkler period relative to those of the Greys River. The double mass plot for August (Figure 2) is representative of the late season plots. This test is very valuable in discerning the effect of the conversion to sprinklers upon the Salt River streamflow. The close proximity of the Greys River to the Salt River provides that other factors including climatic influences are most nearly identical between these two drainages. Therefore, this double mass procedure tends to factor out the influence of climatic trends upon changes in the streamflow of the Salt River.

Synthetic Flows Analysis

A synthetic flows procedure was used to simulate what flows for the Salt River might have been in the sprinkler period if the sprinklers had not been installed. Cumulative flows of the Salt River for the pre-sprinkler period were regressed against those of the Greys River for each month. The line equations derived from these regressions were then used to generate synthetic cumulative

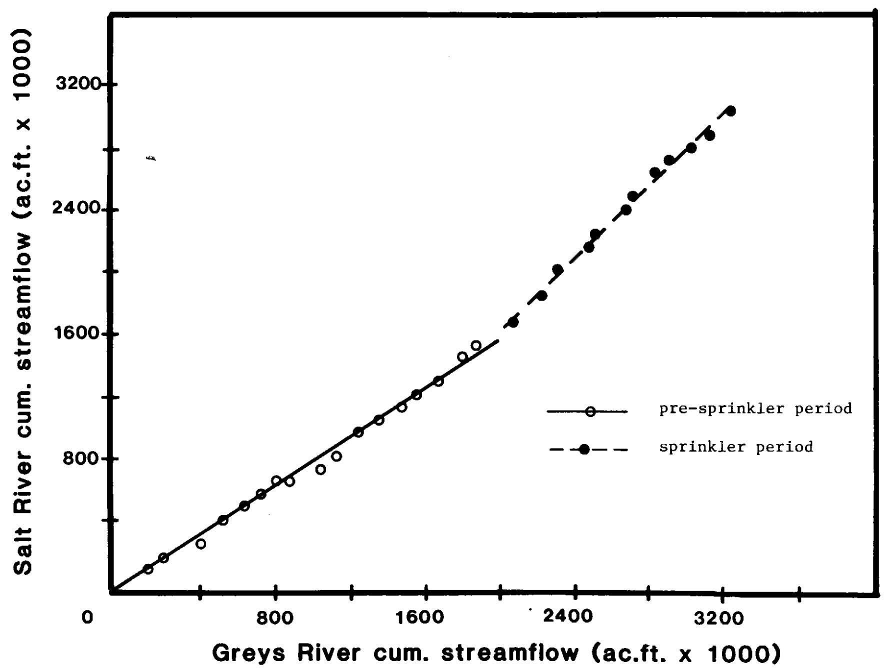

Figure 1. Double mass plot of Salt River flows versus Greys River for the month of August.

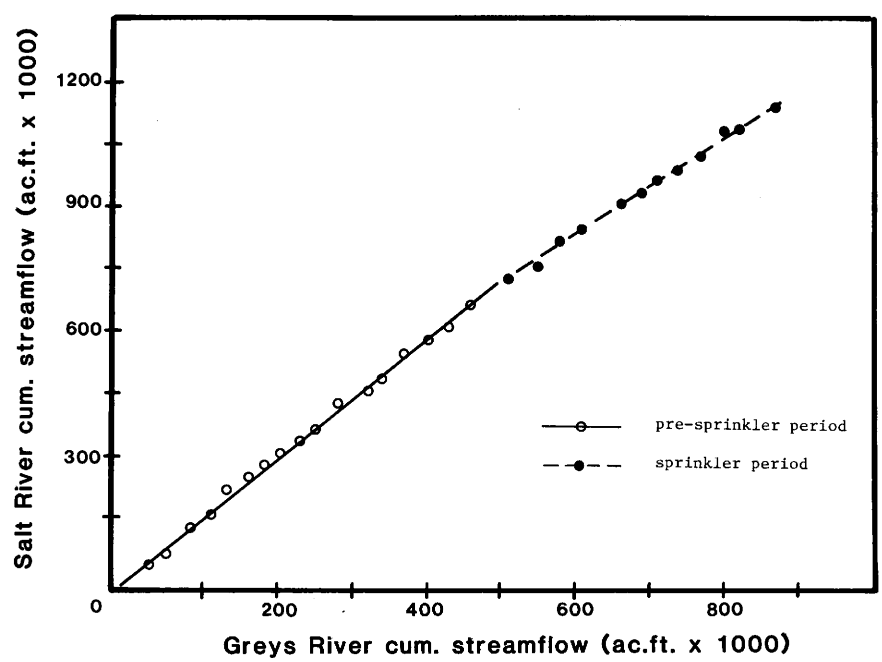

Figure 2. Double mass plot of Salt River flows versus Greys River for the month of August.

flow values of the Salt River for each month of the sprinkler period. These synthetic cumulative flows were then converted to yearly values for each month. A paired T-test was then employed to compare the means of the synthetic flow values with the observed flow values of the sprinkler period for each month.

The results of this analysis are presented in Table 2. This analysis substantiates the trends shown in the double mass analysis

TABLE 2. Results of the Salt River synthetic flows analysis for the sprinkler period[1].

Month	Observed Mean Flow in ac-ft (ha-m)	Synthetic Mean Flow in ac-ft (ha-m)	Percent Difference	T Value
Oct	39,188 (4837)	43,973 (5428)	-10.9	-4.6*
Nov	35,579 (4392)	39,579 (4885)	-10.1	-3.1*
Dec	31,987 (3948)	34,563 (4266)	7.5	-1.9
Jan	27,528 (3398)	28,509 (3519)	-3.4	-1.0
Feb	24,097 (2974)	25,393 (3134)	-5.2	-2.1
Mar	30,293 (3739)	28,799 (3555)	+5.2	1.8
Apr	56,932 (7027)	49,620 (6125)	+14.7	2.0
May	130,329(16086)	91,149(11250)	+47.8	6.1*
Jun	109,559(13523)	74,142 (9152	+42.3	-4.6*
Jul	64,244 (7930)	62,341 (7695)	+3.1	1.0
Aug	41,136 (5078)	49,117 (6063)	-16.2	-7.6*
Sep	40,531 (5003)	47,313 (5840)	-14.3	-8.3*

[1]May, 1971 - September, 1982 [2]Significant at $\alpha = 0.05$

with the observed Salt River flows being significantly higher in the spring and significantly lower in the fall than the synthetic flows all other months (December-April and July) showed no significant differences.

Annual Flood Peaks Analysis

A multi-test procedure described by Buchberger (1981) was used to determine whether the peak annual discharges changed significantly following the conversion to sprinklers. The primary tests employed in this procedure are comparison of log Pearson III flood frequency distributions, statistical tests of stationariness and homogeneity and comparison of Salt River plots of peak flows and peak flow moving averages with the same plots for the Greys River.

Log Pearson III distributions (Viessman et al., 1977) were developed for the Salt River annual flood peaks for the pre-sprinkler and sprinkler periods. Plots for both of these distributions appear in Figure 3. Using the presprinkler flood frequency distribution, the 50 year recurrence interval flood is calculated to be 2891 cfs (81.87 m^3/s). This peak discharge was exceeded in 7 out of 12 years during the sprinkler period. The hydrologic probability of exceeding the 50 year recurrence interval flood in 7 out of 12 years is 4.45×10^{-3} or approximately one chance in 225. This very remote possibility indicates that a significant change occurred between the two periods. A visual comparison of the flood frequency distributions of the two periods also shows that for all flood estimates greater than the four year flood, the sprinkler period distribution was greater. For all floods greater than the 40 year flood, the increase in the sprinkler period distribution was large enough so that there is little

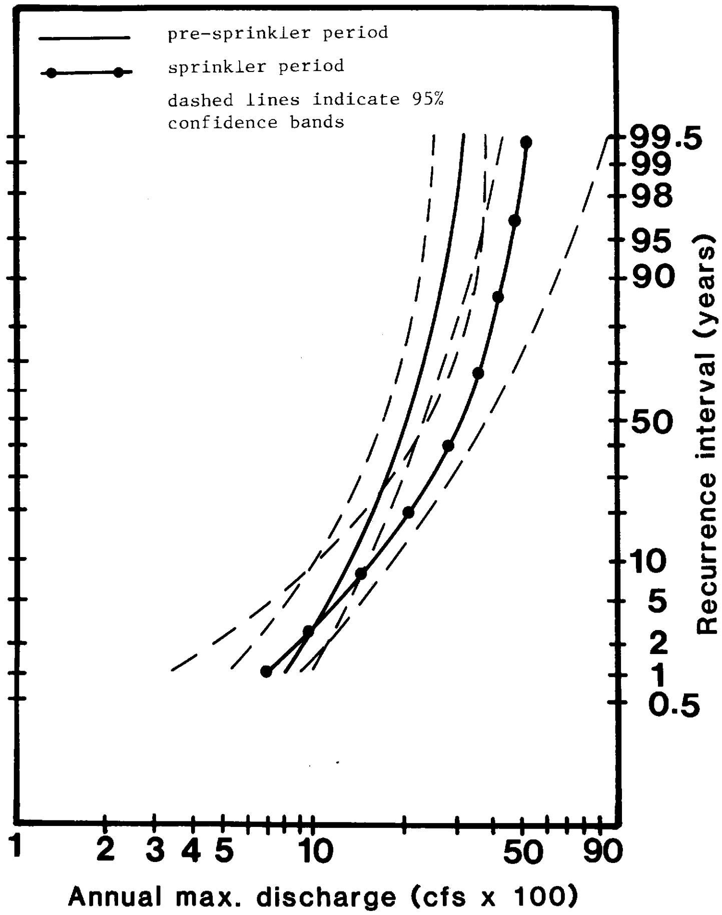

Figure 3. Log Pearson III flood frequency distributions of the Salt River for the pre-sprinkler and sprinkler periods.

if any overlap in the 95 percent confidence bands of the two distributions.

The statistical tests also revealed that peak annual discharges for the Salt River changed significantly following the conversion to sprinklers. The test of stationariness was performed on the entire record of Salt River annual flood peaks to test for any long term trends. Least squares regression is used to express the annual peak flows as a function of time. A stationary series will exhibit a regression line slope that is not significantly different than zero. The Salt River annual flood peak record yielded a critical value which was significant at α =

0.05. This indicates that a long term trend is present in the record of annual peak flows. An examination of the peak annual discharges reveals that this long term trend is due to an increase in the annual peak flows of the Salt River during the sprinkler period.

The test of homogeneity was performed to determine whether the Salt River peak flows record consists of more than one population. The Mann and Whitney U-Test, a nonparametric ranking procedure, was employed for this analysis. The calculated test statistic proved to be significant at the $\alpha = 0.05$ level, indicating that the pre-sprinkler period and sprinkler period flood peaks cannot be considered as being from the same population. An examination of the peak flows again reveals that the reason for this is that the sprinkler period peak flows are significantly higher than those of the pre-sprinkler period.

The final test employed in the annual flood peaks analysis was a comparison of the peak flow and peak flows moving average plots of the Salt and Greys Rivers. These plots appear in Figure 4. During the pre-sprinkler period, the difference between the Salt River moving average plot and Greys River moving average plot is large and relatively constant. Recall that the Greys River drainage is largely undeveloped agriculturally or otherwise and therefore, the Greys River flow represents a natural flow regime. The large difference between the Salt River moving average plot and the Greys River plot during the pre-sprinkler period can be

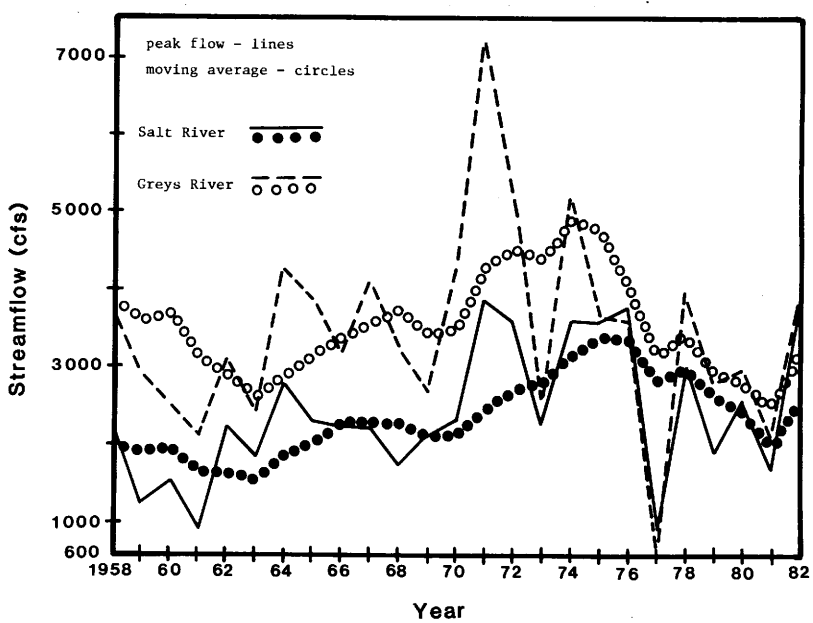

Figure 4. Peak flows and peak flow moving averages of the Salt River and Greys River.

partially attributed to the flood irrigation practices in the Salt River drainage. There are, of course, other factors such as drainage basin area, climatic and physical factors which also contribute to the differences in peak flows for the two rivers. Starting in 1974, the Salt River moving average plot begins to converge toward the Greys River plot and after 1976, the two plots stay consistently close to each other. The most likely explanation for this is that following the switch to sprinklers, a much smaller portion of the flows of the Salt River and its tributaries were diverted for irrigation, therefore, there was a relative increase in peak annual discharges.

ANALYSIS OF OTHER FACTORS

Where changes were observed in the Salt River flow between the two periods, it was necessary to consider the possibility that other factors besides the irrigation change may have contributed to those changes. Three primary influencing factors were identified and analyzed to determine their contribution to streamflow changes. These three factors were climatic trends, changes in crop water use due to increased crop production following the conversion to sprinklers and urban construction trends.

Climatic data (mean temperature and precipitation) from Star Valley was analyzed similarly to the streamflow analyses, employing mean comparisons between the two periods and double mass analyses with data from surrounding stations. None of the tests employed revealed significant trends that would have contributed to the streamflow changes. In fact, the climatic trends that were observed tended to be opposite to those expected from the streamflow changes and therefore, the climatic trends may have served to obscure some of the effects of the sprinklers. This is especially true during the fall months where an increase in precipitation of 22.7 percent in the sprinkler period may have obscured the expected decline in streamflows during these months.

The effect of changes in crop water use was analyzed by estimating yield increases following the conversion to sprinklers and then employing a crop water function based on yield (Hill, 1983) to estimate the increase in crop water use. This increase in crop water use was then compared with the deviation in observed streamflow from the expected streamflows determined by the synthetic flows analysis. This procedure gave an estimate of the portion of reduced streamflows in the late summer and fall months that might be attributable to increases in crop water use. This analysis was performed for the months of August and September when the influence of crop water use on streamflow would be most pronounced. The results of this analysis indicated that increases in crop water use accounted for approximately 40 percent of the streamflow decline in August and approximately 30 percent of the decline in September. While these are relatively large contributions, the biggest factor contributing to the streamflow decline during these months was probably a reduction in groundwater inflow due to less groundwater recharge with the sprinkler systems.

The impact of urban construction trends was also considered as possibly contributing to streamflow changes. Wyoming Highway Department and Lincoln County personnel were interviewed to determine whether major increases in road or building construction occurred during the study period. The interviews revealed that no significant construction had occurred which might have contributed to the observed changes in streamflow.

CONCLUSIONS

This study has described some of the hydrologic effects of increased irrigation efficiencies. As hypothesized, the primary effects of increasing irrigation efficiencies are higher flows in the spring months, higher peak annual discharges and lower fall flows due to decreases in groundwater recharge. Large increases in spring flows can cause bank erosion and can affect structures designed according to hydrologic variables. The possibility that increased spring streamflows and decreased fall streamflows may result from projects designed to increase irrigation efficiencies should be considered in irrigation project design. Where these effects appear likely to occur, procedures to alleviate the problems can be incorporated into the project design.

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WATER

LAW

WYOMING GROUNDWATER QUALITY LAWS AS APPLIED TO LONG STANDING POLLUTION SOURCES

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ABSTRACT

Long-standing pollution sources have posed a challenge to enforcement of Wyoming's groundwater quality protection statutes. Such sites as the Laramie Tie Treatment Plant and the Cheyenne Husky Refinery have required the State, industries and the EPA to seek innovative and cooperative solutions. The paper will examine several of the most recent controversies involving groundwater pollution. The paper will look at the applicable statutes and regulations and then present an overview of the remedial approaches that are being used at the various sites.

INTRODUCTION

Wyoming has been in the forefront of western states in developing regulatory programs for the protection of groundwater quality. This paper will examine the application of Wyoming groundwater statutes and regulations to long-standing pollution sources at the Husky Refinery in Cheyenne and the Union Pacific tie treatment plant in Laramie.

Statutes and Regulations

The Wyoming Environmental Quality Act provides in W.S. 35-11-301 that:

(a) No person, except when authorized by permit issued pursuant to the provisions of this act, shall:

(i) Cause, threaten or allow the discharge of any pollution or wastes into the waters of the State;

(ii) Alter the physical, chemical, radiological, biological or bacteriological properties of any waters of this State.

The Water Quality Division is required to promulgate rules and regulations to establish water quality standards. W.S. 35-11-302.

In addition to the powers possessed by the Department of Environmental Quality, the State Engineer has the authority to "require the abatement of any condition, or the sealing of any well, responsible for the admission of polluting materials into an underground water supply." W.S. 41-3-909. This authority is used primarily to require the sealing of wells.

The Department of Environmental Quality has enacted two sets of regulations dealing with groundwater quality. DEQ/WQD Rules and Regulations Chapter VIII establishes quality standards for Wyoming groundwaters. The standards are established to protect the natural quality of groundwater:

1. Receiving pollution or waste directly from a surface discharge or by migrating water or fluid of a discharge;
2. Invaded by underground water of inferior quality as a result of well or exploration hole drilling or completion practices;
3. From pollution which may result from above ground facilities capable of causing or contributing to pollution; and

4. From pollution which may result from surface mining operations.

The groundwaters of the State are classified by use and by ambient water quality. The groundwater is divided into classes.

Class I - Water suitable for domestic use.

Class II - Water suitable for agricultural use where soil conditions and other factors are adequate.

Class III - Water suitable for livestock.

Class Special (A) - Water suitable for fish and aquatic life.

Class IV - Water suitable for industry.

Class V - Hydrocarbon commercial, mineral commercial or geothermal.

Class VI - Groundwater which may be unusable or unsuitable for use.

The basic policy embodied in the statutes and rules and regulations is that water quality shall not be degraded. Discharges into an aquifer containing Class I, II, III, or Special (A) are not allowed to result in variations in the range of any parameter, or concentrations of constituents in excess of the standards of these regulations at any place or places of withdrawal or natural flow to the surface. A discharge which results in concentrations in excess of standards shall be permitted only of post-discharge water quality can be returned to water quality standards or better quality. Discharges into Class IV groundwater shall not result in water being unfit for its intended use. Discharges into Class V (mineral commercial) groundwater shall not result in the degradation or pollution of the associated or other groundwater unless the affected groundwater quality can return to background or better quality after mining ceases. If background quality cannot be achieved, the affected groundwater will be returned to a condition of quality consistent with predischarge use.

The second set of water quality regulations require a permit for a subsurface discharge (WQD Rules and Regulations Chapter IX). The regulations establish a permit procedure and list discharges that are specifically exempt from the permit requirements. The regulations require establishment of groundwater monitoring programs to ensure knowledge of migration and behavior of the pollution or waste.

Husky Refinery

The Husky Refinery in Cheyenne has existed for almost fifty years. During that time operations at the refinery and the handling of crude oil and refined products have caused substantial impacts upon the groundwater underneath the plant site and to a limited extent, downstream from the plant. The State of Wyoming and Husky undertook investigations of the extent of the contamination as early as 1981. Over 43 monitoring wells have been installed around the plant site and 19 shallow oil detection wells have also been in place. In July, 1984, the State filed suit against Husky, which resulted in a settlement agreement being reached and a consent order being entered by the District Court in November, 1984.

As a result of the settlement, Husky's successor RMT Properties has agreed:

1. To conduct promptly a "free oil recovery program."
2. To conduct an aquifer restoration program in conjunction with the free oil recovery program.
3. To continue to improve general housekeeping and maintenance programs.
4. To eliminate all point sources of possible pollution on the site.
5. To continue to prevent and use its best efforts to eliminate spillages.
6. To continue to report to DEQ as required by law or regulation, all spills.
7. If the experimental oil recovery program is unsuccessful another method will be employed.
8. To dewater and cease to use a waste containment pond.
9. RMT will monitor existing wells around the waste containment pond and evaluate whether off site contamination is occurring.
10. RMT will conduct a pond integrity study by doing a material balance around the upper and lower ponds in order to determine if leakage is occurring.

A copy of the detailed requirements of the settlement is attached.

Union Pacific Tie Treatment Plant

The Laramie Tie Treatment Plant is a 700 acre site located southwest of Laramie, Wyoming. The Union Pacific Railroad (UPRR) began tie treating operations in 1886 and treated ties and other wood products until 1983 when the wood preserving operations were closed. The wood preserving agents used in the treatment included zinc chloride (1886-1931), creosote oil and asphalt-based petroleum residuum oil mixture (1928-1983), pentachlorophenol (1956-1983).

Wastes were disposed in a number of areas around the plant site (Figure 1). Plant wastes were discharged into sloughs and ice ponds and to evaporation ponds that were built in 1958 to receive waste.

There are four distinct geologic units at the site. These are: alluvium - approximately 10 to 15 feet of alluvial deposits; Morrison - uppermost bedrock formation; Sundance-next lower bedrock formation; and Chugwater - lowest bedrock formation.

The extent of the contamination is fairly well characterized. The alluvium is heavily contaminated over about 140 acres west of the plant. The area of heavy contamination is surrounded by a fringe of lightly contaminated soil (Figure 2). The heavier oils lie at the bottom of the alluvium. An estimated 500,000 gallons of heavy oil is contained in the alluvium. The bedrock formations

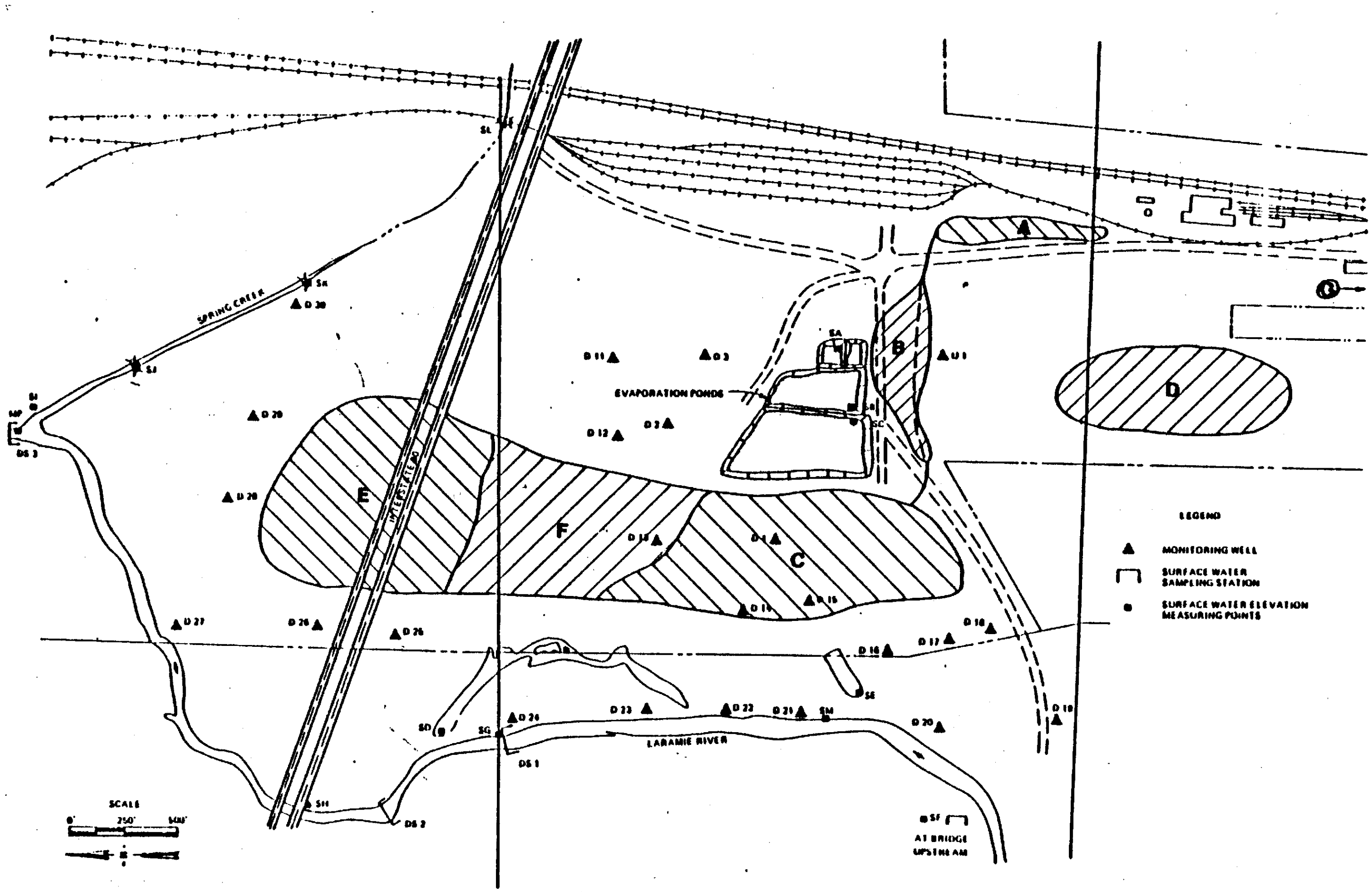

Figure 1. Waste disposal areas at the UPRR Tie Treating Plant, Laramie, Wyoming.

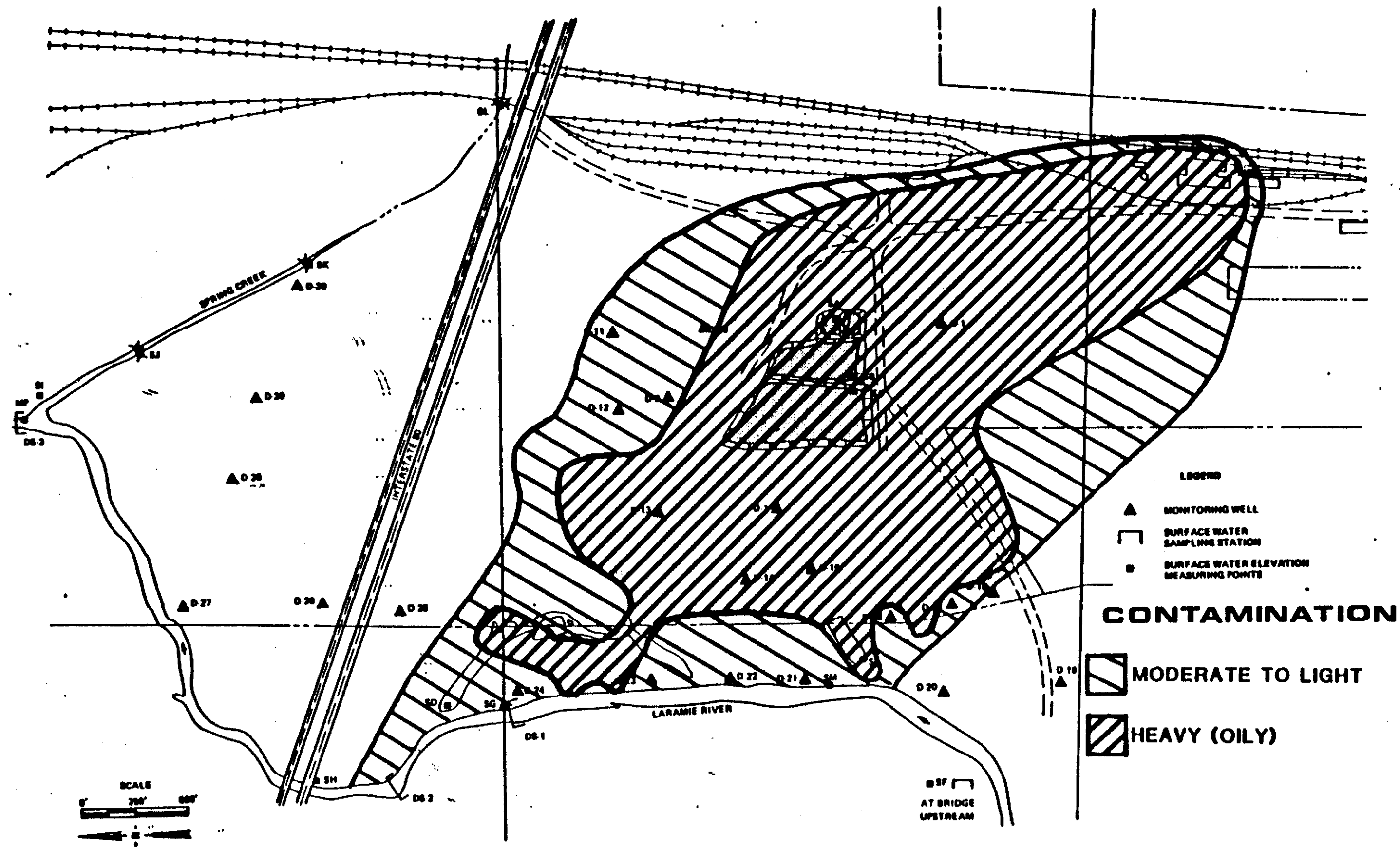

Figure 2. Contamination in alluvium at the UPRR Tie Treating Plant, Laramie, Wyoming.

are also contaminated. The upper parts of the Chugwater Formation are lightly contaminated, along with most of the Sundance and the bottom of the Morrison. The contamination in the Morrison Formation extends across the Laramie River.

The State of Wyoming brought suit against UP in 1981 for violations of the State's groundwater laws. The parties agreed to a suspension of the litigation, under which a phased plan of study was to be implemented and remedial measures evaluated and agreed upon.

In addition, UP and the Environmental Protection Agency agreed on regulatory measures under the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund).

UP has undertaken an extensive investigation at the site which has been summarized in a draft Phase II report. This investigation has resulted in a determination of the limits of contamination and an evaluation of the extent of contamination in the alluvium and the bedrock.

In October of 1983, UP placed a sheet metal wall along the east boundary of the Laramie River, to prevent seepage of contamination into the river. In addition, UP has installed oil recovery wells which have had some minor success in removing free oil from the alluvium.

In the summer of 1984, UP excavated and removed from the site the contents of the four receiving ponds. The removal involved extensive water treatment which was accomplished by an onsite plant and discharge into the City of Laramie water treatment system.

At the present time, UP is completing additional bedrock investigations and is evaluating the feasibility of construction of a slurry wall around the perimeter of the site. UP is also completing the Phase III report which is an evaluation of remedial alternatives for the site.

SUMMARY

Wyoming's groundwater quality laws have enabled the State to deal with pollution from long-standing sources. Though these laws lack the specificity and the great breadth and detail of the federal hazardous waste laws, Wyoming has been able to achieve environmentally sound results utilizing the provisions of the Environmental Quality Act and the rules and regulations.

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Ferland, R. 1983. The Protection of Groundwater Quality in the Western States - Regulatory Alternatives and the Mining Industry. 29 Rocky Mountain Min. Law. Inst. 899. (This article contains a discussion of Wyoming's groundwater laws and regulations.)

ATTACHMENT 1

I. Elimination of Point Sources of Contamination

A. API separators

1. Repair of west API separator.

a. West API separator has been dewatered and cleaned.

b. Cracks along floor and walls have been chipped out and regrouted.

c. Inside surface has been washed and sandblasted in preparation for installation of an epoxy fiberglass liner.

d. Work will be completed by November 15, 1984.

2. East API separator (two units).

a. Old east API separator will be abandoned, inlet blinded and the remaining contents will be transferred to new east API separator before January 1, 1985.

b. New east API separator will be taken out of service in 1985 and, if possible, necessary repairs to eliminate leakage will be made by November 1, 1985. If not, new one will be installed.

3. Removal of grossly visibly contaminated soils and escaped sludges, if any, around all the API separators will be accomplished as soon as reasonably possible.

B. Loading and unloading facilities

1. The light products loading facility has a concrete pad and drainage system for containing hydrocarbon spills.

2. The crude and gas oil unloading site will have a concrete pad and drainage system installed by November 1, 1985.

3. The wood treating load rack will be relocated to the slurry cut-back loading facility and a concrete pad and drainage system installed by November 1, 1985.

4. All residual products on the pad will be collected and transferred to a functional API separator.

5. Additive handling facilities will be equipped with drain pans.

C. Pools and pockets of oil - Refinery's vacuum truck will pick up all visible pools of oil and continue to suck up any free-standing oil pools throughout the refinery as they become visible. This oil will be discharged into the API separator for oil recovery.

D. The routing of the oily sewer system throughout the refinery will be carefully inspected, and any leaks repaired immediately upon discovery.

E. In accordance with RMT Properties' SPCC Plan, and the requirements of Chapter IV, Wyoming Water Quality Rules and Regulations, spills of oil and/or chemical substances will be immediately reported.

F. Alky unit CBM (Constant Boiling Mixture) pits

1. A new CBM (neutralization) pit has been constructed; necessary new piping will be installed and ready to put into service by November 1, 1984.

2. Once the new neutralization pit is put in service, the old CBM pit will be taken out of service.

G. Leaking 24-inch culvert which carries wastewater effluent from the east API separator to the westernmost "upper pond" will be replaced with an 18" coated and wrapped pipe.

1. New 18" pipe on hand will be completed by November 1, 1984.

2. Presently evaluating contractor bids for installation.

3. New line to be completed January 1, 1985.

H. Concrete flume (ditch) which carries wastewater effluent from east (last) "upper pond" to west (first) aeration pond will be cleaned and repaired.

1. A temporary 10" line has been installed to divert water from concrete ditch while repairs are being made.

2. Cracks in concrete will be chipped out and regrouted.

3. A 12" corrugated PVC pipe inside concrete ditch to further minimize chance of leakage into ground will be installed by October 15, 1984.

I. New water draw drainage system for tanks 15, 16, 17, 20, 21, 22, and 23 will be improved as described by RMT and installed by December 1, 1984.

J. The drainage system will be improved as described by RTM and a concrete pad will be installed throughout gas concentration unit to catch spills from leaking valves, flanges, pumps, and to catch all heat exchanger bundle cleaning sludges (K050) for transport to oily sewer system and east API separator. This work will be completed before November 1, 1984.

K. Bundle cleaning pad and drainage system to API separator in Alky unit will be constructed by November 1, 1984.

L. Leaking ram oil line

1. Leaky section of ram oil line has been dug up and plugged.

2. Free oil will be recovered and recycled.

M. A new water draw drainage and collection system will be installed at Tank 70 and 71 by December 1, 1984.

N. Pond integrity

RMT will isolate each pond and conduct individual mass balance tests for a period of time sufficient to definitively demonstrate the integrity of each pond. If these tests are inconclusive or if technical difficulties arise which render the tests inapplicable, then other appropriate measures, such as flownets and/or water quality testing of additional wells will be utilized to make adequate determinations.

The pond integrity testing is an initial step in the evaluation of the sources of groundwater contamination in that particular area of the refinery. It is recognized that many other sources may be contributing to the problem and that these sources will be addressed as they are identified. Some of the point sources are already being mitigated by the elimination of some unlined ponds and the installation of aprons at loading facilities. Further work will be required in terms of oil recovery systems and aquifer restoration systems in the area affected by the ponds.

The adequacy of the pond integrity measures and the adequacy of the oil recovery and aquifer restoration facilities will be evaluated at least annually by DEQ. Further remedial actions may be necessary.

O. Forty-eight inch storm sewer line which bisects the refinery

RMT Properties will work with the City of Cheyenne to relocate the 48" storm sewer off the refinery site.

This sewer transports oil from the refinery to a pond located immediately south of the refinery and subsequently discharges oily waste to Crow Creek. Since this line is located on a UPRR easement, extensive exploratory drilling for oil has not been conducted along this easement. However, several wells installed on both the east and west sides of the easement have found oil.

RMT plans to remove as much of the sewer line as possible. A portion of the line running beneath storage tanks in line with 4th Street will have to be abandoned and plugged with concrete. During excavation of the sewer line, a more complete survey of the existence of ground oil will be conducted. As free oil is encountered, it will be collected and removed.

With the permission of the City of Cheyenne, RMT plans to reroute the 48" storm sewer west on 5th Street to Morrie Avenue, then south on Morrie to Crow Creek. Additional storm sewer inlets will be constructed along the west boundary of the refinery for the purpose of controlling stormwater runoff. The western boundary of the refinery will also be graded in order to divert runoff into the sewer and away from the refinery property.

II. Installation and testing of oil recovery system and aquifer restoration system.

A. In June 1984, RMT Properties contracted an engineering firm for a four-year period to conduct work to reclaim hydrocarbons from the soils and groundwater for both economic and environmental benefits and to do consulting work primarily for evaluation and abatement, if any, of groundwater pollution.

B. From background data and information obtained from the exploratory well drilling program conducted in July, RMT has proposed to install an oil recovery and aquifer restoration system in Plant No. 1.

1. RMT will cause to be designed, constructed and operated a single pump system consisting of a yet-to-be determined number of 6" to 8" recovery wells in Plant No. 1.

2. RMT will construct up to eight additional monitoring wells in Plant No. 1 to monitor and facilitate their recovery/restoration system.

C. RMT plans to install additional monitoring wells in Plant No. 2 to obtain further data to determine the feasibility of installing an oil recovery aquifer restoration system.

D. The area in the UPRR easement will be included in the oil recovery system.

E. An aquifer restoration system will be installed in Plant No. 1 in conjunction with the oil recovery operation. Recovered contaminated groundwater will be sent to the refinery's existing wastewater treatment system (API separator settling and aeration ponds).

F. Further evaluation for the entire site will be completed by June 1, 1986. If necessary, as determined by this evaluation and review, an aquifer restoration system will be installed where necessary to mitigate migration of contaminants.

G. The specifics (nature, frequency, location, etc.) of sampling and analytical program will be specified in the DEQ construction permit necessary for oil recovery and aquifer restoration systems. Said permit must be obtained prior to construction of a permanent system of this type, however, no preconstruction permit will be required for the pilot study (oil recovery system). RMT will not be responsible for any delay in the State's issuance of any required permit.

III. Installation of monitoring wells, oil detection wells and piezometers.

A. Forty-three monitoring wells have been installed.

1. Thirty-two shallow wells extending into upper unconfined Ogallala aquifer.

2. Five intermediate wells installed in upper fine-grained aquitard.

3. Six deep wells installed in lower coarse-grained aquifer.

4. Piezometers were installed to determine the vertical hydraulic head of groundwater.

B. RMT installed 19 additional shallow oil detection wells throughout the refinery in July 1984.

1. Eight more monitoring wells in Plant No. 1 and five more wells in Plant No. 2 are planned.

C. RMT installed three wells in August 1984 at the SWSI (southwest surface impoundment) for evaluation of oil contamination and monitoring purposes.

D. Additional wells and piezometers will be installed as agreed by DEQ and RMT Properties to assure that the oil recovery and aquifer restoration systems will prevent degradation of the groundwater off-site and down-gradient of the refinery. RMT Properties will develop a monitoring schedule for all monitor wells, subject to DEQ approval.

IV. Reclamation of SWSI (southwest service impoundment)

A. Most of the debris has been removed.

B. SWSI was dewatered and continues to be dewatered (see below).

C. The area has been excavated so all liquids (including storm water runoff) drain toward northeast corner of impoundment.

1. Sludges and contaminated soils have been washed several times and accumulated liquids pumped to the east API separator for oil recovery and contaminated wastewater treatment.

2. SWSI continues to be dewatered and liquids pumped to the east API separator as need arises (i.e., after heavy rains or oil washing).

D. RMT will continue a monitoring program to determine if contaminants are moving off-site.

The information pertaining to this area is incomplete, partially unavailable and subject to discussion. A final determination of appropriate remedial action is not possible until a better understanding is gained about the waste characteristics, waste mobility, and effectiveness of the present oil recovery system.

E. It is agreed that, on a short-term basis of about six months, additional monitor wells be installed around the impoundment to:

1. Detect the existence and movement of oil and groundwater contaminants.

2. Provide the information necessary for a reliable evaluation of the effectiveness of the oil recovery system in eliminating the source of oil and groundwater contamination.

3. Define the cone of influence of the oil recovery/aquifer restoration system in this area.

4. Provide well-defined potentiometric surface maps useful for understanding seasonal changes in flow patterns and changes due to pumping.

5. Provide data on the concentrations the polynuclear aromatic hydrocarbons.

V. Land Farm

A determination on mitigation of groundwater contamination is pending the release of the Ecology and Environmental/EPA Report, and a final determination on mitigation will be made by the parties in May, 1985.

VI. Frontier Wells

A. RMT Properties agrees to re-monitor the Frontier wells, using proper procedures, to determine if the lower aquifer is being affected by contamination through those wells. If the water quality determined by the sampling of the Frontier wells is shown not to be degraded from background, the wells will be plugged and abandoned. If not, RMT Properties will install additional monitoring wells to determine the extent of contamination and will take appropriate steps to mitigate the problem.

B. This work will be completed by November 1, 1985.

Parameters for the Frontier wells sampling will include a GC/MS scan for volatiles/acid/base-neutrals. Ion balance will be done by the DEQ lab, and metals by the DEQ lab.

The wells found to be improperly plugged will be re-drilled, sampled, and evaluated prior to proper plugging.

VII. Northeast corner of the refinery

Product was identified in this area of the refinery but the extent and volumes of contamination were not determined. RMT will address this area in detail and submit appropriate well completion details, product thickness maps, and water table maps. It is anticipated that this portion of the investigation will extend beyond the east boundary of the site. The number of monitor wells will be determined in the field and evaluated for completeness by DEQ.

VIII. Light oils loading facility

At the west end of Plant No. 1, this facility is identified as a contaminant source. A more thorough evaluation of the extent of this contamination will be conducted to determine need for and the design of an aquifer restoration system. RMT will install additional wells during the spring and summer of 1985 to implement this investigation. Six samples will be collected over a one-year period.

IX. Sampling parameters and schedule

A monitoring program will be designed to meet the following objectives:

A. The program will establish baseline or upgradient water quality in both the shallow and lower Ogallala aquifers. This information will be used to evaluate the degree of groundwater quality degradation across the site and to develop criteria for the site cleanup.

B. The program will monitor on-site groundwater contaminant concentrations. The data compiled in this monitoring effort will allow periodic evaluation of the successful elimination of point sources and the evaluation of the progress made in groundwater clean-up.

C. The program will monitor oil levels and static water levels for the purpose of evaluating the progress and adequacy of the oil recovery systems installed throughout the site.

D. The program will monitor off-site groundwater quality for the purpose of:

1. Evaluating the ongoing impacts due to refinery operations.

2. Evaluating the need for additional remedial measures.

3. Evaluating the adequacy of the oil recovery systems, the aquifer restoration systems, and the measures taken to reduce contaminant sources.

4. Identify strategic wells or areas for wells to be monitored during the term of the program to characterize contamination.

5. The program will be conducted to determine the areas which would require an aquifer restoration program.

E. Modifications to Parameters and Schedules

RMT will perform an annual evaluation of the data in regards to:

1. The adequacy of the oil recovery and aquifer restoration system.

2. Progress of groundwater clean-up.

3. Significant changes in water quality characteristics on a well-by-well basis.

4. Mitigation of point sources of contamination.

These factors may necessitate modifications in the monitoring program in terms of adding or deleting parameters and in terms of altering sampling frequency. DEQ will review RMT's recommendations and evaluate the site remedial action progress prior to authorizing modifications.

Baseline wells - Reports

Data, system evaluations, potentiometric surface maps, product thickness maps, well location maps, and iso-concentration maps will be submitted to DEQ as they become available.

F. Parameters

Specific parameters and monitoring schedules will be set forth in the WQD, Chapter III permit authorizing the installation of the system(s) for oil recovery and aquifer restoration.

X. Housekeeping procedures

RMT Properties has implemented a maintenance program whereby leaks from valves, piping, pumps, tanks, etc. are repaired as soon as possible.

XI. Training

A. Per RCRA regulations Section 264.14 (Subpart B) and Section 265.16 (interim status) "Personnel Training" , all new employees are trained and given a copy of the "Emergency and Contingency Plan" to read.

B. Since October 18, 1983, all supervisors and employees that are available are required to attend an "Annual Hazardous Waste Training Class" (see attachment #4).

C. This requirement has also been provided for in Husky's Part B Permit Application.

XII. Demonstration of Qualifications of Contractors

A. Any contractor working with hazardous materials is given proper training before any work is started.

B. All contractor supervisors are required to attend the "Annual Hazardous Waste Training Class".

C. Outside contractors hired strictly for purpose of Hazardous Waste Transportation or Disposal must have an approved EPA RCRA permit ID. Also their references and hazardous waste handling background and references are checked before they are used.

XIII. Disposal of accumulated wastes

A. Spent catalysts - Presently investigating several alternatives for the disposal of the spent catalysts.

1. Analytical results showing chemical composition for each type of spent catalyst have been received.

2. These analyses, as well as a brief process description describing reaction taking place on the catalysts, are required before any disposal site will consider accepting it.

3. These catalysts will be disposed of by year end.

B. Drum disposal

1. Barrels containing oily wastes

a. An analysis for hazardous constituents was initially made to determine alternative disposal methods.

b. Presently, an investigation of sites used for the disposal of <u>nonhazardous</u> industrial solid wastes is being made.

c. An on-site separation and oil reclamation program will be installed to separate solids from oily material prior to disposal (tentatively June of 1986).

2. Empty drums

a. Drums which contained "hazardous" materials

(1) Empty drums are triple rinsed per RCRA regulations.

(2) Empty drums are then shipped off site for crushing and eventual sale to steel mills.

b. Drums containing nonhazardous chemicals or materials are also rinsed prior to recycling.

PREVENTIVE LAW FOR WATER DEVELOPERS AND OWNERS
Representing the Owner During the Pre-Construction Phase
(So You Want to Build a Dam?)

Raymond B. Hunkins
Jones, Jones, Vines and Hunkins

THE COMPLEX WORLD OF CONSTRUCTION

For those involved in it, the construction industry generates an undeniable excitement - an excitement born of the risk inherent in all aspects of construction, particularly construction projects having to do with water development and the construction of dams. It's a chancy, cyclic business which responds to fluctuations and a wide variety of economic and social factors. And while fortunes can be made in construction, the generally low profit margin on construction work is frequently not commensurate with the risk involved.

Perhaps the short business life span of the average contractor is attributable to the nature of the business itself. According to a fifty year statistical survey, 39 percent of all contractors survive only 2½ years. Sixty-three percent fail after 5½ years and the average life span of the contractor is 7 years.

But contractors, like ranchers, are eternal optimists. For each contractor who "goes under" 4½ new contractors take his place. His foremen, superintendents, and vice presidents will buy the used calculators, cranes, bull dozers and trucks and launch new enterprises. Too often these fledgling contractors lack even a rudimentary knowledge of such basics as accounting, actual costs and pricing - the basics of staying in business. And so, the contractor's life cycle repeats itself once again.

If high risk is the "salt" of the construction business, then controversy is the "pepper". Controversies arise out of the performance of a construction contract because of four conditions which are a part of virtually every project. They are:

1. The multitude of activity;
2. The technical nature of these activities;
3. The protracted performance period; and
4. The involvement of numerous parties with varying and often conflicting interests.

The interaction of these four conditions gives rise to disputes which must then be settled in one of three ways - negotiation, arbitration or litigation. Coordination of these four conditions so that disputes are avoided represents a challenge to the water developer, his engineer and the contractor.

THE MULTITUDE OF ACTIVITIES

One glance at a typical CPM schedule for a medium to large sized water development project is enough to convince anyone of how easily serious problems can arise if there is any breakdown in activity coordination. Coordination and cooperation among all parties is crucial. A delay in the progress of any one segment can easily delay the work of all others and result in the generation of enormous delay damages. Disruption, which decreased productivity and increases cost by throwing work out of sequence, can result in similar damage claims.

THE TECHNICAL NATURE OF CONSTRUCTION ACTIVITIES

As the technical complexity of a project increases, so does the inevitability of disputes. An innovative design or technology necessitates increased involvement of the project engineer. And when this innovative design or technology fails to function properly, the parties inevitably cast about for one party on whom to pin the blame. The main issue in such case is generally whether the defect is in the engineer's design or the contractor's implementation of that design.

THE PROTRACTED PERFORMANCE PERIOD

Complex construction, and most water development projects are complex, demands a lengthy performance period. This extended contract period, in turn, leaves the project vulnerable to changes in such variables as politics, regulatory requirements, the economy, and the weather. Changes of this nature are generally not provided for in the contract, with the result that their occurrence gives rise to disputes over who should bear the burden of unexpected price escalation. To aggravate the problem, an already long performance period may be extended even further by time extensions issued in conjunction with change orders, changed conditions and severe weather. Or, the parties may simply have miscalculated the time necessary to do the original work.

THE INVOLVEMENT OF MULTIPLE PARTIES

Performance of a water development or dam construction contract requires a large number of parties to coordinate their efforts on the work site. In addition, the activities of numerous peripheral parties also influence the success or failure of a project. The construction cast of characters is large. Those involved in the typical dam project include:

1. The owner.
2. The financier.
3. The regulators.
4. The design professional.
5. The prime contractor.
6. The subcontractor.
7. Suppliers.
8. The surety.
9. The construction manager.
10. The labor union.
11. Consultants.
12. Landowners.
13. The water users.
14. The local government body.
15. The State of Wyoming.
16. The Federal Government.
17. The bankruptcy trustee.
18. "The people".

Planning and constructing a water development project creates the right climate for controversy. Situations ripe for dispute can begin developing even earlier than contract bidding. Public hearings on 404 permits, environmental impact statements, etc., are beyond the scope of this presentation. I would, however, like to spend just a minute discussing disputes which are inherent in the "construction" process.

COMPETITIVELY BID PUBLIC CONTRACTS

Almost all public contract procurement, whether at the federal, state, county or city level, requires competitive bidding. Ordinarily prequalification is not required, and sealed bids are sought from any contractor who chooses to bid. Bids are based on a set of plans and specifications furnished by the awarding authority. Bids must be responsive to the invitation and variances from the terms of the invitation can, and usually do, result in rejection of the offending bid.

BID MISTAKES

Bid mistakes are a common occurrence because of the hurried conditions under which most bids are prepared. The most important thing for contractors to remember is that quick action must be taken. There are numerous cases which support a contractor's right to withdraw an erroneous bid stemming from an honest mistake, provided the awarding party can be returned to the status quo, and this usually means that notification of the mistake must be given prior to acceptance and award.

Even if the contractor's error was an honest one, not stemming from gross negligence, and he is entitled to equitable relief, some owners still endeavor to hold the bidder to his mistaken bid. Resort to the courts, which may be required in such a case to forestall award of the contract, is generally successful where the contractor is able to present evidence of the circumstances surrounding the mistake sufficient to support the grant of equitable relief.

THE "RESPONSIBLE" BIDDER

The statutory provisions which govern virtually all competitive bidding on public construction projects typically provide that the contract shall be let to the "lowest responsible and responsive bidder". The phrases "lowest responsive, responsible bidder," or "lowest and best bidder," as used in these statutes are not limited to the individual who submits the lowest dollar bid. Instead, the words "responsible" or "best", which focus on a contractor's overall ability to perform - are equally as important as the word "lowest". A "responsible" bidder is one whose offer best responds to the bid invitation in terms of quality, fitness and capacity to perform the work - in other words, the contractor most capable of undertaking and completing the work in a satisfactory fashion. In determining questions of "responsibility", the awarding authority looks to such factors as the contractor's skill, integrity, experience and financial resources.

THE "RESPONSIVE" BIDDER

The "responsive" requirement of most bidding statutes means that a bid must be in strict compliance with the terms of the invitation. "Responsiveness" focus on whether the bid as submitted is an offer to perform the exact tasks spelled out in the bid invitation and whether acceptance will bind the contractor to perform in accordance with the invitation. For these reasons, bids which are qualified or which contain exceptions are vulnerable to being declared "non-responsive". Public owners are ordinarily obliged to reject such bids because they are not submitted on a common ground, and thus undermine the competitive bidding system.

THE SITE

Most construction contracts contain a provision requiring prospective contractors to visit the site and make their own inspection of site conditions. Such a provision is extremely important in water projects, including dams, because so much of the work and material to be used in the project are below the ground. Such a provision is exculpatory in nature and seeks to put the burden of discovering hidden or suspect conditions on the contractor. Generally, however, a contractor has neither the time nor the resources necessary to do a thorough site investigation.

For this reason, the requirement for a site investigation has come to mean a "sight" investigation, with the contractor being held responsible only for those visible conditions which any experienced person would recognize on a visit to the site. The exculpatory provision will generally not be a bar to recovery by the contractor for a changed condition where the problem was not discovered by a reasonable site investigation. What is a reasonable site investigation for a building project is much different than a "reasonable" site investigation for a major dam construction project.

REPRESENTATIONS (AND MISREPRESENTATIONS)

The primary representations with which the contractor must deal at this early stage are those concerning subsurface conditions which are contained in the plans and specifications. The engineer who prepared the plans and specifications had ample opportunity to take complete borings and to analyze them. Despite the caveats which frequently accompany them, these borings serve a broader purpose than strictly design. A contractor must, of necessity, rely on them - he has no alternative but to base his bid at least partially on information contained in the borings. It is for the most part unfair, unrealistic and often impossible for a contractor to take and analyze adequate borings at his own expense at the same time that he is preparing his bid. Site investigations by a water developer are extremely important and much care should be taken in making the investigation complete.

Because the contractor has no real alternative but to rely on the design professional's analysis of subsurface conditions, such an analysis becomes a representation. In other words, a warranty attaches to the represented subsurface conditions. When actual conditions vary significantly from those described, most contracts allow the contractor to recover under a "changed condition" or "differing site condition" provision. In the absence of such a contract clause, the contractor may still be able to recover his additional costs under a breach of warranty or misrepresentation theory.

THE PHASES OF THE CONSTRUCTION PROCESS

The phases of the construction process fall neatly into three categories. Pre-construction begins with the selection of the engineer and goes through the bidding or negotiation of the construction contract with the contractor. The construction phase begins with the award of the contract and goes through the acceptance of the project by the water developer (the owner). The post-completion phase of the construction process begins with a guarantee period and runs through the end of the expiration of all parties' rights under the contract. The expiration of rights can be governed either by the contract language itself or by the applicable statute of limitations.

For a water development project, the pre-construction phase is extremely important. It carries with it the opportunity to anticipate and allocate risks. Every water developer should be conscious of this opportunity. Recognizing and acting upon the opportunity is one of the most important features of any water development project. Within the engineering contract for the water development project, there are opportunities to address variation from construction cost predictions, budget or design changes, delays, errors or omissions of the engineer, his consultants and others, disputes, insurance provisions, preconstruction assistance, construction phase contingencies, including interpretation, acceptance/rejection of, among other, contractor submittals, proposed subcontractors, or the work itself; determination of price and time adjustments, participation in and resolution of, contractor claims, certification of payments; and the engineer's role in post-completion deficiencies.

The opportunity to anticipate and allocate risks is also present in the development of the construction contract. Here, changes, delays, loss or damage to work, variation in site conditions, acceptance/rejection of work, payment, disputes, stop notices, liens, assignment, bankruptcy, work hours/prevailing wages, suspension/termination, general indemnity, insurance and bonding are all typical subjects which must be addressed in a properly drafted construction contract.

Why would any water developer not pay attention to these important "rules of the water way" which will guide an expensive and complicated project through and beyond completion?

The pre-construction phase also presents an opportunity to eliminate predictable sources of disagreement and to preserve rights. In the engineering contract, for example, the project scope, budget, schedule, minimum design standards, compliance with laws and permits, owner approvals, the extent of construction phase enforcement duty, definition of basic and extra services, fees, costs for reimbursables and non-reimbursables, exculpation, assignment, ownership of documents, records and record keeping requirements, lack of contractual or role coordination, ambiguity in choice of law are all predictable sources of disagreement if the contract is silent.

Within the construction contract, predictable sources of disagreement which may be addressed are: misrepresentation or non-disclosure, exculpation, indemnification of the engineer, subcontracting, work by owner or separate contractors, claims for additional costs, time and scheduling, specified items and substitutions therefore, safety, document inconsistency, ambiguity, order of precedence, warranty, arbitration, guarantees to repair, choice of law, record keeping requirements and right to inspect and copy, are all usually addressed in some form or another. The pre-construction phase also allows the owner and other construction participants the opportunity to reduce the causes of human error associated with construction problems. It presents an opportunity to develop good communications and a working relationship with those who will administer, represent or make construction phase decisions for the water developer.

The pre-construction phase also is an opportunity for the water developer to stress the importance of content review of specifications and drawings, documentation and good record keeping during the design and construction phases, to familiarize himself and prepare for compliance with contract terms and to stress the importance of fair dealing and prompt attention to problems, disagreements or claims. Attention should be paid to the need for bringing on competent, experience legal assistance early in the project and, in that regard, methods of preserving the attorney/ client privilege and record keeping requirements should be fully reviewed.

ROLE OF COUNSEL DURING THE WATER DEVELOPMENT PRE-CONSTRUCTION PROCESS

Counsel should either select, draft, adopt or review contracts which will be used to hire the engineer, the contractor, and the construction manager. Surety bonds and inspection contracts should be reviewed. Counsel should review, in their entirety, before release, the complete set of construction contracts.

Counsel may also participate in the resolution of bid irregularities or protests, should they arise. Counsel to the water developer, as well as the water developer, should be sensitive, at all times, to the need for "preventive advice". Effort and money spent on securing "preventive advice" can save literally hundreds of thousands of dollars in litigation costs and expenses during the post-construction process.

The water developer should not hesitate to informally discuss potential problems, disputes or claims with counsel on a full disclosure basis. Counsel would be asked to review proposed "demand" letters to others or the owner's reply to such letters from others. Water developers should consult with their attorney before hiring experts or having written reports about "responsible causation" or claims evaluation prepared. The confidentiality of legal advice should be preserved at all times.

In conclusion, the pre-construction phase of a major water development project represents an opportunity for the water developer to address and hopefully, eliminate, many problems which might otherwise occur. The ability to anticipate and allocate risks through the review and selection of contracts is an opportunity that will never again present itself during the course of the project.

There is an old saying that crime, casinos and construction claims never pay. Water developers should try and keep it that way.

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WATER RIGHT ADMINISTRATION IN WYOMING

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ABSTRACT

Discussion will include how water rights are acquired in Wyoming, the procedure followed and the intricacies of water administration and regulation. Topics to be addressed are permit time limits, extensions of time, adjudication of a water right, prior appropriation, reservoir storage and monitoring of reservoir levels, and changes of any kind in a water appropriation. The complexities of water compacts, treaties, and court decrees will also be included in this presentation.

INTRODUCTION

I have been asked to speak on the very broad subject of water rights administration in the State of Wyoming. I will give you a brief outline of how a water right is acquired, the procedures followed, and then discuss water administration and regulation in the State of Wyoming. I will also discuss water compacts, treaties, and court decrees.

A water right cannot be acquired in Wyoming for either surface water or from ground water without application to and the granting of a permit by the State Engineer. When a permit is granted by the State Engineer for either ground water or surface water, conditions are imposed setting out time limits within which work must be commenced, completed, and beneficial use made under the permit and such work must be completed during those time frames. If, however, additional time is needed, an extension of time can be allowed by the State Engineer for good cause shown. The Wyoming system is based on the system of prior appropriation where those that are "first in time are first in right". All water rights are regulated in times of shortage to provide water to the earlier priorities. Direct flow water is measured in cubic feet per second of time and storage or reservoir water is measured in acre-feet. Ground water is generally measured in gallons per minute.

After a water right permit has been completed, the final step is the adjudication or finalization of the water right. This adjudication is accomplished by the Board of Control. The Board of Control consists of the State Engineer and four Water Division Superintendents who are the water administrative officials responsible for the administration of water in each of the four Water Divisions in the State. Water Division No. 1 consists of the North Platte, the Niobrara drainage and the Little Snake drainage in the southeastern portion of the State. Water Division No. 2 consists of all the drainage off the east slope of the Big Horn Mountains which includes the Tongue River and Powder River drainages and the Belle Fourche River and the Cheyenne River drainages. Water Division No. 3 consists of the northwest portion of the State and includes the Big Horn drainage and the Clark's Fork drainage. Water Division 4 is the southwestern portion of the State and includes the Snake River drainage, the Bear River drainage and the Green River drainage. The Board of Control functions as a quasi-judicial body in that water rights are adjudicated or finalized by the Board of Control and all changes to adjudicated water rights are dealt with by the Board of Control.

Water administration in the field is accomplished by Hydrographer-Commissioners who are full-time State employees who are skilled in the measurement of water and in water administration. The more complex water administrative areas are generally administered by Hydrographer-Commissioners. The balance of the water administration is handled by the Water Commissioners who are County employees paid by the County with some supplemental funds provided by the State in certain instances. The Water Commissioners are generally employed on a part-time basis with some exceptions where full-time personnel are employed. Assistant Commissioners can also be appointed by the Water Commissioners to assist in the administration of water.

As mentioned earlier, water rights are administered in order of priority so that during times of shortage, water rights with later priorities are regulated or shut down to provide water for the earlier priorities. This is true no matter what use is made of the water; priority strictly governs as to who gets the water during times of shortage. The amount of water appropriated for a direct flow right for irrigation is fixed at a statutory rate of 1 cubic foot per second for each 70 acres of land irrigated.

Water rights for other purposes are fixed by reasonable use based on the capacity of the facility delivering the water.

Storage rights are adjudicated in acre-feet and in the case of an off-channel reservoir, a quantity of rate of diversion in cubic feet per second is also fixed for a supply ditch or pipeline to furnish the reservoir. A reservoir is limited to one fill per year and any water that is carried over from one year to the next counts against the next year's fill. For example, if a reservoir appropriation is for 100 acre-feet and 75 acre-feet is used in a year, with 25 acre-feet carried over into the following year, the reservoir is entitled to store 75 acre-feet to bring it back up to full capacity the following year.

A permit is required for any storage or diversion of water. There are thousands of reservoirs built in the State of Wyoming for stock purposes and a water right is required for these reservoirs as well as for the diversion of water for stock purposes. On-channel reservoirs oftentimes present problems in administration since inflows must be conveyed through the reservoirs to prior downstream appropriators. Administration of such a reservoir requires the close monitoring of reservoir levels so that there can be an accounting for withdrawals from storage. If found necessary, the Superintendent may order a measuring device be installed in the stream channels above and below a reservoir in order to facilitate regulation of the reservoir. A Water Division Superintendent has authority to order headgates and measuring devices in all ditches or other points of diversion in order to allow for the proper regulation of the facility and also to determine the quantity of water that is being conveyed through the system.

The law requires that before a change in point of diversion, or change in point of diversion or means of conveyance, is made or a water right is changed in any manner, a petition must be filed generally with the Board of Control for all adjudicated water rights and the State Engineer for unadjudicated water rights. In order to have either the Board of Control or the State Engineer, as applicable, allow such a change in point of diversion, means of conveyance or change in use, many factors must be considered. A change in use can only be granted by the Board of Control and can often be very complex. Such changes involve changes from irrigation to municipal or industrial use. A thorough review is necessary to make sure that there is no injury to other appropriators by the allowance of a change. Such a change cannot exceed the amount of water historically diverted, nor exceed the historic rate of diversion or decrease the historic amount of return flow or increase the historic amount of water consumptively used. The time period during which a right that has been changed can be diverted and used is fixed by the historic period of diversion. The Board, in looking at such changes, may also consider the economic loss to a community and to the State if the use of the right is transferred to some other use and as to whether the economic loss will be offset by the new use and whether other sources of water are available for the new use.

Headgates and measuring devices may be required in order to allow for proper regulation of water rights and the statutes allow the Division Superintendent to order such facilities, not only as previously mentioned with on-channel reservoirs, but also anywhere else they are necessary in order to allow for proper regulation of water rights. There are a number of acceptable measuring devices which will allow an instantaneous reading of the quantity of water going through a ditch or other facility.

Through the years, sophisticated water regulation has occurred in many areas of the State. This is especially true in the southeastern portion of the State where the streams are most fully appropriated. This administration is accomplished by utilizing State-paid personnel on a year-round basis. This is also true to a more limited extent in other Water Divisions in the State. The most highly regulated stream in Wyoming, (and one of the more highly regulated in the Nation), is the North Platte River which is regulated on a daily basis. Detailed records are kept of diversions and inflows, etc., on the total river system.

The requirement for regulation and administration of ground water has not been done as extensively in Wyoming as it is in many of the other states since the ground water use is of more recent origin. We do have a provision in the law which allows for the establishment of what are called Ground Water Control Areas.

These are areas where there are problems occurring or there is reason to suspect that problems will occur in the future. When a Ground Water Control Area is established under procedure set out in the law, then no further permits for ground water are allowed without a considerable review. Permits are only allowed if this can be done without injuring other appropriations in the control area.

All in all, the water administration in Wyoming has generally been satisfactory and the laws have been very workable. They have been modified from time-to-time to modernize and update them, but as I have mentioned, they have worked very well up to this point and we expect that water administration will improve as years pass, and as the competition for water becomes such that additional administration is needed.

I would also like to review for you the Compacts, Treaties, and Court Decrees involving Wyoming. Wyoming is a party to seven Interstate Compacts and is subject to Court Decrees on three rivers. Since Wyoming is a headwater state, all rivers flow out of Wyoming with a couple of exceptions. I will give you a brief review of each of these Compacts and Decrees. The State Engineer's Office also publishes a book of Compacts and Decrees in the event you are interested in more details. All the Compacts are also found in Title 41, Chapter 12, which is Wyoming Statutes 41-12-101 through 702. The laws related to Interstate Streams Commission are in Wyoming Statutes 41-11-101 through 206. Wyoming belongs to several interstate organizations which deal with matters involving the Colorado River. These are: the Upper Colorado River Commission, which is the administrative agency of the Upper Colorado River Compact and consists of members from the four Upper Basin States as well as one member from the Federal government; the Committee of Fourteen which consists of two members each from the seven Colorado River Basin states. This Committee was instituted for the purpose of addressing problems under the Mexican Treaty which deals with the allocation of water from the Colorado River to Mexico. Wyoming is also a member of the Colorado River Basin Salinity Control Forum which has representation from each of the seven Basin States and deals specifically with salinity in the system.

I will now discuss briefly the various Interstate Compacts to which Wyoming is a party.

BEAR RIVER COMPACT

The Bear River Compact was first signed in 1955 and was modified in 1980 and deals with the division of the Bear River among the States of Idaho, Utah and Wyoming. The Bear River heads in Utah and flows into Wyoming, back out of Wyoming into Utah, back into Wyoming and then back into Idaho. The Compact allows present uses and sets a procedure for regulation of the River when flows drop to a certain level in certain selected points within the Compact area. In addition to the Compact regulation, the 1955 Compact granted to Wyoming and Utah the right to store 17,750 acre-feet of Bear River water in any water year. The 1980 Compact, allows the depletion of an additional 13,000 acre-feet of water by the States of Utah and Wyoming. The 1980 Compact also set up a division of water between Utah and Idaho in the lower end of the Bear River below Bear Lake which was not a part of the original Compact.

BELLE FOURCHE RIVER COMPACT

The Belle Fourche Compact divides the waters of the Belle Fourche River between Wyoming and South Dakota and was negotiated and ratified by the two States and Congress in 1943. The Compact recognized all existing rights in Wyoming as of the date of the Compact and permitted the unlimited use of water for stock reservoirs in Wyoming not to exceed 20 acre-feet in capacity. It further allowed Wyoming to deplete the flows under conditions existing as of the date of the Compact by an additional 10 percent.

COLORADO RIVER COMPACT AND UPPER COLORADO RIVER COMPACT

The Compact between the four Upper Basin States in the Colorado River Basin and the Lower Basin States was negotiated in 1922. This Compact allocated the waters of the River between the Lower Basin States and the Upper Basin States. The Upper Basin States are obligated to deliver the minimum of 75,000,000 acre-feet in any consecutive ten-year period at Lees Ferry which point divides the River between the Upper and Lower Basin. There was a provision in the 1922 Compact for future treaties with Mexico. As a result of this clause, treaties were negotiated with Mexico for allocation of water to that country. In 1948, a Compact was negotiated among the Upper Basin States and ratified in 1949. The Upper Basin Compact apportions the water allocated to the Upper Basin States to the States of Colorado, New Mexico, Utah and Wyoming with Wyoming being entitled to 14 percent share of the water allocated.

UPPER NIOBRARA RIVER COMPACT

This Compact was negotiated and signed by the two States in 1962 and approved by Congress in 1969. It divides the waters of the Niobrara River between the States of Wyoming and Nebraska. It provides that Wyoming have the unlimited use to stock reservoirs in Wyoming with the capacity of 20 acre-feet or less and no limitations were placed on diversion and storage of water in Wyoming except on the main stem east of Range 62 West, and on Van Tassell Creek south of Section 27, T32N, R60W. In this area, diversions are regulated on interstate priority basis with rights in Nebraska. There are other limitations in this area also. One significant point about the Niobrara River Compact is the fact that groundwater development was recognized to be a significant factor and the Compact provides for investigation of the resource and possible apportionment at a later date.

SNAKE RIVER COMPACT

The Snake River Compact divides the waters of the Snake River and the Salt River between the States of Idaho and Wyoming and was negotiated by the two States in 1949 and was ratified by Congress in 1950. The Compact recognizes without restriction all existing rights in Wyoming as of the date of the Compact and permits the unlimited use of water for stock and domestic uses in Wyoming provided stock reservoirs do not exceed 20 acre-feet in capacity. It permits the diversion by Wyoming for developments either for supplemental or original supply of four percent of the Wyoming-Idaho stateline flow in the Snake River.

YELLOWSTONE RIVER COMPACT

The Yellowstone Compact divides the waters of the Clarks Fork, Big Horn, Tongue and Powder Rivers which are tributaries of the Yellowstone, among the States of Wyoming, Montana and North Dakota. This Compact was negotiated in 1950 and ratified by the three States and by the Congress in 1951. The Compact includes recognition of all existing rights prior to January 1, 1950, and the use of water for future stock and domestic purposes with stock reservoirs up to a capacity of 20 acre-feet being exempted from the provisions of the Compact. It also allocates the unappropriated and unused divertable flows of each tributary after supplemental supply water rights are satisfied between Wyoming and Montana on a percentage basis in these four major tributaries.

TREATIES

As mentioned previously, there is a Treaty between the United States and Mexico dated 1945, which could affect Wyoming's availability of water in the Colorado River Compact. This Treaty guarantees to Mexico the delivery of 1,500,000 acre-feet per year.

COURT DECREES

North Platte River

A United States Supreme Court Decree allocates the waters of the North Platte River among the States of Colorado, Wyoming and Nebraska. During the middle 1930's, Nebraska started an action against Colorado and Wyoming in the Supreme Court of the United States with regard to the waters of the North Platte River. A Decree was handed down in 1945 which allocates the waters of the North Platte among the three States. Basically, it allows the State of Wyoming and the State of Colorado above Pathfinder Reservoir to irrigate a specific number of acres and store a specific quantity of water for irrigation purposes. The flows below that point arriving at Guernsey Reservoir are then divided between Nebraska and Wyoming during the irrigation season for the period of May 1 through September 30 of each year on a basis of 25 percent to Wyoming and 75 percent to Nebraska.

A Stipulation was entered into by the three States and approved by the Supreme Court in 1953 which allowed the storage of water in Glendo Reservoir, a new reservoir constructed on the main stem of the River with a subsequent increase in irrigated acreage in Colorado.

Laramie River

In 1911, Wyoming started proceedings in the United States Supreme Court against Colorado to limit Colorado diversions from the Laramie River. In 1922, the Supreme Court handed down a Decree which limited Colorado to the diversion annually of 4,250 acre-feet of water for lands within the Laramie River Basin and also allowed the diversion out of the basin of 33,500 acre-feet plus additional water from the headwaters of the small tributary stream. In 1936, the amount of water allowed for the diversion out of this tributary stream, Dead Man Creek, was fixed at 2,000 acre-feet per year. The total amount of water therefore that could be diverted by Colorado for all purposes was 39,750 acre-feet. In 1957, a Stipulation was entered into by Colorado and Wyoming which modified the Decree so that only 19,875 acre-feet of water could be diverted out of the Laramie River Basin to other basins and that 29,500 acre-feet of water could be diverted by the meadow land users for irrigation of lands in the Laramie River Basin which are specifically described in the Stipulation.

Teton and South Leigh Creek

This is a Federal District Court Decree entered on February 4, 1941, known as the Roxana Decree which settled a conflict between water users on Teton and South Leigh Creek in Wyoming and

Idaho. This Decree is based on a Stipulation entered into by the States of Wyoming and Idaho water users and sets forth certain limitations on Wyoming diverters when the flow diminishes to 170 second feet. After flows reach that level, the amount diverted in Wyoming is limited to 1 cubic foot per second for each 50 acres of land irrigated and when the flows drop to 90 second feet, then the flows are divided equally between Wyoming and Idaho water users. Other limitations on diversions apply to South Leigh Creek.

Streams Not Covered by Compacts or Decrees

There are only two streams in the State that are not covered by either an Interstate Compact or Court Decree. These are the Cheyenne River and the Little Missouri River drainages. A Compact has been negotiated in the past on the Cheyenne River and agreed to by either one or the other two States of Wyoming and South Dakota, but there has never been a Compact negotiated and approved by both the States or the Congress. There is, therefore, no Compact on the Cheyenne River. On the other stream, the Little Missouri, there have been negotiations through the years for a Compact, but these have been inactive for many years with no real push to negotiate a Compact on this stream.

All in all, the Compacts and Decrees have worked reasonably well, but I think we can expect that there will be problems in the future as water becomes more fully utilized in each of the States.

WATER
DEVELOPMENT

WYOMING OIL AND WATER

Warren A. Morton

ABSTRACT

The 1973 Arab oil embargo created a shortage of petroleum products and started a rapid escalation in crude oil and other energy mineral prices (coal, natural gas, uranium). The combination of fear of fuel shortages leading to rationing and never ending price increases forced the nation to seek out alternative energy sources, primarily the oil shale of Colorado, Utah and Wyoming and the coal reserves of Wyoming, Montana and North Dakota, both with the common purpose of being converted into liquid or gaseous fuels. All of the coal conversion processes would have consumed large amounts of water and created predictable fear of shortages of available water in Wyoming, shortages which threatened the traditional users of Wyoming surface and subsurface water, namely agriculture, recreation, wildlife and municipalities. This scenario was reported in some detail in a Wyoming Heritage Foundation report entitled "Water Development, A Policy Analysis," published in January, 1985.

This earlier report demonstrated how a changing world oil and gas supply situation had depressed the price of crude oil and had rendered uneconomic all of the coal gasification and liquefication plants that were projected in the mid-1970's. The report also challenged the need to develop expensive new industrial water supplies in Wyoming, particularly in view of projected declining revenues as a result of lower oil prices; and abundant supplies of water already in storage.

The purpose of this paper is to elaborate on the world energy picture and its impact on the Wyoming economy, environmental population trends and the additional impact on revenues available to various levels of government. A reassessment of traditional and historical water policies in Wyoming is also addressed.

INTRODUCTION

In January, 1985, I prepared a study that was published by the Wyoming Heritage Foundation entitled, "Water Development: A Policy Analysis." A more suitable title might have been, "The

Impact of Worldwide Petroleum Supplies and Prices on Wyoming Water in 1985 Compared to 1975." While not a very catchy title, this does happen to be the core issue. That study dealt with the oil supply and price picture in the '70's and early '80's and describes the thinking that led to the many coal-related projects that would have required massive amounts of water, water that was not available at that time unless it was taken from some existing use. The threat of industry buying the then existing available water and converting it to consumptive use is clear in all our memories. In fact, very few people have been willing to recognize that this threat no longer exists.

What our paper did not go into was the new supplies of oil and gas that are now available worldwide as a result of the explosive search for oil and gas that was triggered by oil prices multiplying over tenfold from 1973 to 1981. While there was a shortage of petroleum supplies at $3.50, the worldwide search for petroleum products triggered by $35.00 oil not only wiped out the shortage but also knocked the price, that actually reached a peak of almost $40.00, back to $26.00 level today, with all pressures still on the down side. It is an interesting irony that the very greed of the OPEC consortism that managed to drive crude oil prices up tenfold in seven years created it's own destruction by stimulating a worldwide search for energy sources that effectively destroyed the OPEC monopoly.

While some people are aware of the fact that the OPEC countries are currently producing at approximately 50 percent of their daily capacity, what is not as well known is the giant conversion that is taking place in both eastern and western Europe, where imported OPEC oil is being displaced by natural gas from Holland, Norway and primarily Russia. The latter has literally hundreds of trillions of cubic feet of methane which they are moving by pipeline into western Europe (one building, three more in planning) that will displace even more OPEC oil. To put this figure in proper perspective, a 120 trillion cubic-feet gas reserve (by no means the largest gas field in Siberia) equates to a 20 billion bbl oil field, while the largest oil field in North America is the Prudhoe Bay field in Alaska with estimated reserves of 10 billion bbls. I cannot go into all the new petroleum supplies that are being developed all over the world, but they are numerous and all are looking for markets, and all will have very negative impacts on Wyoming.

The attractiveness of coal conversion in the 1970's were twofold--availability and price. However, the declining price of oil has made the coal conversion plants absolutely uneconomic as the Synthetic Fuels Corporation and all companies interested in producing synthetic fuels can attest. If there is any reluctance to accept this harsh reality as it relates to Wyoming coal, take a look at the non-activity and abandoned programs for oil shale development in Colorado. Furthermore, the geographic and political distribution of the newly discovered oil and gas supplies has effectively broken the OPEC monopoly and a threatened boycott would no longer be effective. Thus the dual threat of ever-escalating price, coupled with possible embargos of OPEC oil have disappeared, and with it the demand for synthetic fuels and the need for new industrial water in Wyoming.

A second impact on Wyoming as a result of declining crude oil prices will be the declining revenues to the State from ad valorem taxes, severance taxes, federal mineral royalties and state royalties. Furthermore, while there has been some recognition of declining oil prices, I have seen no public recognition that natural gas and coal prices will inevitably fall into lock-step with declining oil prices. The fuels are, in part, interchangeable in most stationary power plants.

I was not unaware that the subject matter of our first paper would be unpopular. There should be no thinking person in Wyoming who has not heard the "use it or lose it" theory and worried about the water to which Wyoming has title but is still leaving the State. To suggest a slowdown in water storage projects is to suggest a major reversal of state policy. However, it is our contention that all policy matters should be based on constant review and on the best available current economic criteria. Our position has been criticized as lacking in foresight and suggestions have been made that no dams would ever have been built if such policies had been practiced in the past. We believe this to be an over-simplification and suggest that virtually all the major dams in Wyoming today were either flood control, or hydroelectric sites, or public works programs during the great depression or some combination of the above. Of course most of these projects also made available water for agriculture which has been greatly beneficial to the State's economy. Historically the largest user of Wyoming water has been agriculture. Average use is about 2.24 million acre-feet or 85 percent of the State's use. However, most sophisticated forecasts for future agricultural needs project very little if any growth which should not be too surprising. Virtually all the economically attractive irrigable lands are already under cultivation and the economics of bringing new land under irrigation is not attractive in today's agricultural economy.

The January paper developed both the evaporating demand for additional industrial water and the declining revenue picture for the State based upon declining mineral prices and activities. The recently published 1984 Wyoming Mineral Yearbook, prepared by the Mineral Division of DEPAD, adds some interesting additional data on this latter subject. This excellent publication summarizes revenue from all mineral activities and reveals some startling information. For example, the assessed valuation of all mineral production peaked in 1982 at $5.85 billion and declined in 1983 and again in 1984. Ad valorem taxes peaked in 1983 and declined in 1984. Severance tax collections have declined annually since 1981. Sales and use taxes paid by the mineral industry have declined by over one-third since a 1982 high. Furthermore, the assessed values per unit of production show some discouraging trends. Oil prices have been in decline since 1982. Gas prices were lower in 1984 than in 1983, as were coal, uranium and trona. There is nothing in the foreseeable future to suggest a near term change in these patterns.

From 1973 to 1983, total revenue paid to the State from all mineral activities increased from $64 million to slightly over $1.0 billion annually, an increase of 1600 percent in 11 years, or an average of 145 percent per year. Not too surprisingly, the cost of government at all levels in Wyoming managed to keep pace with this spectacular growth in income. These spending habits may be hard to change and a 5 percent to 10 percent decline in revenue from mineral sources ($50 million to $100 million per year) is very easy to envision. Wyoming at all levels of government will have to start exercising discipline and priority of use as we move into a period of declining commodity prices.

Let me offer a more optimistic thought, particularly with regards to water, which after all, is the subject of this meeting. Prior to the projected synthetic-fuel-from-coal boom, supply and demand for Wyoming water were in pretty good balance. Certainly no cities were having any persistent shortages. Agriculture seemed to be operating at near capacity; whatever industrial use there was did not seem to interfere with the other uses, and there seemed to be adequate water to support recreation and all fish and wildlife needs. This quickly changed in the mid-70's when the available supplies of water were threatened in three ways by the projected explosion in the demand for industrial water. The first, and easiest, step was for industrial users to buy up ranches and strip the water off for consumptive industrial use, a threat to both downstream agricultural users and wildlife habitat. When it was perceived that this would be an inadequate supply for the expanding need, applications for storage permits were filed by dozens of industrial users and speculators on virtually every stream flowing off the mountains in Wyoming, particularly in the Powder River Basin, again a threat to every downstream agricultural user and to fisheries and other wildlife habitat. As if this were not enough, the projected use of underground water from the Madison formation to supply a transportation medium for coal slurry pipelines, raised fears in the minds of many that virtually all the shallow water wells for municipal, agricultural, stock or domestic use would all be sucked dry. This triple threat to traditional Wyoming water users created a demand to maintain some minimum level of streamflow to protect the flora and fauna of Wyoming and to further develop new sources of water for the State.

It is our contention that through a direct correlation between worldwide energy supplies and prices that this threat to traditional and existing Wyoming water users no longer exists. Indeed, when you take into account the unused water available today at Boysen and Yellowtail (525,000 acre-feet), DeSmet (54,000 acre-feet) and Fontenelle (177,000 acre-feet), supply far exceeds today's needs or the needs of the foreseeable future. If the

74,000 acre-feet that should be available with the enlargement of the Buffalo Bill Dam is added in, over 800,000 acre-feet of water is already available and unused in Wyoming today. With this in mind, is there any justification today to build additional expensive water storage projects for unidentifiable needs? Having dared that heresy, I will venture one more. While much is said about the 3.8 million acre-feet of Wyoming water that currently flows out of state, there is a very logical and simple explanation for this fact. Namely: there is no economic need or justification for this surplus water in Wyoming today. To carry this thought one step further, when there is such a need, the potential industrial user will willingly pay to develop the new source, leaving existing users unthreatened and unaffected. To illustrate this point, the proposed ETSI aquaduct from Oahe Reservoir in South Dakota to Gillette had an estimated construction cost of $200 million in addition to fees estimated at $1.0 billion over the life of the contract, all of which was to be paid by ETSI.

Our reservations for an aggressive dam building program are further heightened by the declining revenue picture that we foresee for the State. There is presently almost $20 million annually of earmarked revenue being set aside for water development. Might there be a better use for this amount of money at this time? Some areas that come to mind are agricultural assistance, industrial development, tourism promotion, municipal aid, tax relief, education, social services and a long list of others.

In closing, let me summarize my thinking on this large, vital, and complex issue. I am by training an Engineer and by circumstance a businessman, and I tend to think of issues in terms of facts and economic return. I am not a lawyer, most particularly I am not a water lawyer and I will try hard not to pretend that I am. Let's look at the facts:

Fact One: The projected demand for industrial water for coal conversion purposes has evaporated. The present price of oil and natural gas will not support a synthetic fuel industry. Furthermore, the size and diversification of the oil glut and the gas bubble in the world today continues to put downward pressure on prices, further discouraging any optimism for the future of a synthetic fuel industry in Wyoming.

Fact Two: There is approximately 800,000 acre-feet of water behind storage in Wyoming today for which there is no demand. It is available to anyone who will pay either the Federal Government (Boysen or Yellowtail), the State of Wyoming (Fontenelle), or private interests (DeSmet).

Fact Three: The declining prices of Wyoming minerals has had severance taxes in decline since 1981; ad valorem tax collecting falling since 1983, and sales and use taxes shrinking since 1982. The 1985 posted prices are significantly lower than 1984.

Fact Four: Approximately $20 million per year or $40 million per biennium is presently flowing into an earmarked revenue account for water development.

These are simple and undisputed facts. The basic issue of Wyoming water development then becomes confused by two cloudy legal questions. The first is whether or not the use by downstream states (namely Arizona and California) of water from the Colorado River that legally is part of the Wyoming allotment will result in a loss to Wyoming. This is the "use it or lose it" issue. The Compact itself contains no such language but there is some case law to support this position. The courts would have to determine the issue. The second legal question is whether or not simple storage by itself constitutes "beneficial use." Again the answer is not clear. The recreational value and use of the storage lake would be considered beneficial and so would any partial agricultural use. However, this does not address the major issues of the remaining flow-through whatever that amount might be.

With all of the above in mind, the question before Wyoming decision makers is simply this, "In view of the lack of industrial demand for additional water, and in view of the lack of industrial demand for additional water, and in view of the 800,000 acre-feet of unused water presently available, and bearing in mind the declining revenue picture of the State, is it wise for Wyoming to be building additional dams at this time for projects that have no identifiable beneficial use?"

I would not want my remarks to be construed as being opposed to a realistic and aggressive program for the development of

Wyoming's unused water. Quite the contrary. I feel that the role of the Wyoming Water Development Commission should be enlarged to conduct a twofold study: The first part might deal with supply with a careful study of both surface and subsurface water resources. The second part should deal with demand and develop a realistic appraisal at this time; for future uses for Wyoming water for municipal, agricultural, recreational and industrial purposes. The last comprehensive study of this type, to my knowledge, was in 1972 by the State Engineer's Office, entitled "The Wyoming Framework Water Plan." It is time for an update. Other very worthwhile projects to be resolved by the WWDC would be to develop uses for the existing 800,000 acre-feet of water that is presently diverted and stored but still unused. This could be a great stimulus to Industrial Development. I would further like to see a closer legal examination of all our existing interstate water compacts to evaluate the threat of loss by non-use or the protection that might be provided by storage alone. Most particularly, I would like to see Article X of the Yellowstone River Compact tested to determine just what are Wyoming's options in this area. Identification of all potential storage (dam) sites should also be undertaken and steps taken to clarify any archeological or ecological conflicts. Titles should be carefully examined and steps taken to clarify the State's potential ownership on ancient but inactive claims that might be outstanding.

The list is endless with regard to programs to constructively conserve and develop Wyoming's water resources.

It is our hope that these observations on the supply and demand of water and the supply and demand for revenue will be incorporated by those involved with and responsible for long-term planning for Wyoming.

WATER DEVELOPMENT: WATER USE AND CONSERVATION

Grant D. Parker
Powder River Education Project

ABSTRACT

Wyoming is currently involved in a multi-million dollar water development program. The political pressure to develop water, to "use it or lose it" is enormous. At the same time, Wyoming has significant needs and responsibilities to take care of the water projects currently in place in the State, and to use our water wisely. Private, federal, and potential State projects pose a real threat to future taxpayers as the costs of repairing and maintaining these facilities is shunted to the State.

Much of the water use in the State is for agriculture. Most of the demands for future water needs comes from industry and municipalities. Wyoming is faced with potential water needs, but most of them are speculative.

On the face of it, Wyoming has an adequate supply of water to meet future water needs. Wyoming has more than twice as much water available under interstate water compacts and decrees than is currently used. Water from Boysen, Yellowtail, Fontenelle, and Lake DeSmet is sitting unused, adding to the late season flows of downstream states. Much of this water, and other undeveloped supplies, is not available in areas of the State where future demands may develop.

There is more than one way to meet demonstrated water demands in Wyoming. The current approach seems to be to build new projects. Most of the proposed projects have no or little demonstration of actual need for the water. Alternatives to building new projects are rarely considered. This approach is expensive and the risks are high.

An alternative to much of the proposed water development program is conservation and rehabilitation of existing water supply systems. Dams, pipelines, and ditches around the State are in desperate need of repair. Water users need to have safe and efficient water supply systems to protect themselves from the liability of damage caused by poor dams or canals. If some projects are not repaired the existing water users may not be around to use the water in the future. The cost savings of efficient supply systems could be a boon to strained agricultural operations, and would help more people than most new development projects.

New techniques and technologies offer water savings for much of Wyoming. Agriculture, industry and municipalities now have a tremendous potential to "produce" water by implementing water efficiency measures. The cost of water produced in this way is much less than water developed under new water development projects.

INTRODUCTION

We live in dry country. Water is important. Having adequate supplies of water is important.

Wyoming has a water program and recently even adopted policy. Unfortunately when someone talks about water policy it usually means water development policy, not a balanced policy covering all aspects of water in the State. Water development, water quality, rehabilitation and conservation all should be factored into a comprehensive State water policy. Because Wyoming's emphasis is on water development, many important and viable alternatives are ignored.

WATER DEVELOPMENT - WATER USE

When Wyoming set up the Wyoming Water Development Commission, the Governor and the Legislature envisioned a $600 million massive water development program. To date, the Legislature has appropriated $114.6 million from the general fund to the program and about $27 million per year going into the program from coal and oil and gas severance taxes. The Legislature has authorized spending about $29 million on rehabilitation projects and over $190 million on new development projects. If no new development or rehabilitation projects are authorized, the new development account will have $21 million available in 1988 while the rehabilitation account will have $40 million available during that year. This does not account for the $114 million general fund appropriation. On the other hand, it does not take into account the many new projects on the books that would cost over $1.2 billion to construct, nor the over $1.2 billion in conservation and rehabilitation needs identified for agriculture in Wyoming (1). Groundwater development and municipal conservation needs are also not included in the financial projections of the Water Development Commission.

There is not enough water development money available to cover all of Wyoming's water needs.

Economics have changed and the expected energy boom did not materialize as some people expected. Energy conservation has replaced new production demands and the price of oil has not increased as much as many thought.

At one time people were projecting power plants and synfuel plants all over Wyoming. Power plants were proposed for Sheridan, Buffalo, Gillette and other areas in and near the Powder River Basin. Mobil, Carter, Texaco, Arco, Hampshire Energy and Panhandle Eastern all had Synthetic Fuel Plants in the works. In the early 1970s the National Petroleum Council, <u>U.S. Energy Outlook</u> projected water consumption in Wyoming's tributaries to the upper Missouri for electrical production and synthetic fuels to be 355,000 acre feet per year by 1985 (2). Studies as recently as

1983 identified 40 synthetic fuel gas and oil plants and 12 power power plants in the Powder River Basin area of Wyoming (3).

These projections have not come to pass. According to the Wyoming Department of Economic Planning and Development (DEPAD) all of the power plants, refineries, uranium mines and mills and trona operations in Wyoming today use less than 70,000 acre feet of water per year. Campbell County's existing power plants and coal mines claim they use less than 1,500 acre feet of water per year (4).

This does not reflect the disrupted aquifers and degraded water quality caused by energy development. It also does not portray the serious impacts this water use can have on local water users. But it does show us that current use by coal, trona, and uranium industries is much less than projected, and much less than the 570,000 acre feet of unsued water available in Boysen, Yellowtail, Fontenelle reservoirs and Lake DeSmet.

Another indication of the extent of interest in Wyoming's water for energy development is the amount of filings for water in the late sixties and the seventies. By 1972 companies and speculators had signed contracts for 450,000 acre feet of water per year out of Boysen and Wyoming's portion of Yellowtail reservoir. Another 258,000 acre feet were contracted for Montana Indian and non-Indian water (5).

In Wyoming there are still undeveloped permits and filings for storage of almost 8 million acre feet of water. These are speculative filings on water that have not been developed by the private sector. There have been aqueducts proposed to bring water to the coal fields of Gillette from the Green River, the Clarks Fork, the Big Horn and the North Platte. Of course there are many proposals to develop the Tongue, the Powder and the Little Big Horn Rivers that flow through rich coal areas (6).

The large number of filings on the Powder, the Tongue and the Little Big Horn should serve to dramatize the speculative over-filing that has taken place. This water has not been put to use. On the Powder there are speculative filings for 1,581,975 acre feet of water in Wyoming. This is almost 10 times as much water as is legally available to Wyoming through the Yellowstone River Compact. It is also 16 times as much water as is currently being used in the Basin and is 4.6 times as much water as leaves Wyoming on an average year. In the Tongue drainage there are 280,587 acre feet of undeveloped filings. This is three times as much water as Wyoming is legally entitled to. The Little Big Horn is in a similar situation with 286,778 acre feet of undeveloped filings. The Little Horn was not adjudicated in the Yellowstone Compact, but the filings still represent 2.5 times the amount of water that leaves the State in a year (see Table 1).

Obviously there has been and still is a lot of speculative interest in Wyoming's water. Despite all of the filings, there has been very little water development from the private sector. Instead, the State is moving ahead with a number of projects.

TABLE 1
WYOMING SURFACE WATER YIELD AND USE (7)
(figures in thousand acre feet)

River	Wyoming Yield plus inflow	Wyoming Consumption	Compacted H_2O Outflow	Undeveloped Filings
Wyoming	17,349	2,949	2,870	7,957
Powder	434	96	165	1,582
Tongue	460	84	94	281
Little Horn	119	5	--	287

Many of these projects admittedly have little or no demonstrated need for the water.

This strategy puts the State in the position of taking the risks, buying the permits, and possibly selling the high priced water back to industry at a later date. It is doubtful that the State can recoup its investment through high priced water sales to unknown industries in the future. There are no definite users for industrial water projects.

Even though there is little demonstrated need for water projects, there still is a large cry that we must "use it or lose it." This philosophy - if I might call it that - rests on some questionable premises. First, it assumes that building dams results in a use of the water. A good look at Boysen, Yellowtail, Fontenelle and Lake DeSmet should eliminate that belief. In fact, Boysen, Yellowtail and DeSmet have over 400,000 acre feet of unused water that had been earmarked for use in the coal fields of the Powder River Basin. 50,000 acre feet of unused water is controlled by Texaco and Reynolds at DeSmet - in the middle of vast Powder River Basin coal deposits (8).

Storage projects can even increase the dependence of downstream states on the water. Storing the water and not using it lets downstream users get used to less flooding and become dependent on late season flows enhanced by the reservoir releases.

The other factor often ignored in the "use it or lose it" argument is that almost all of Wyoming's water is already allocated through compacts and decrees. Other states (or the courts) have already agreed to the division of water between states. This agreement is hard to break. It would take an act of Congress to take water that is allocated to Wyoming and give it to another state. Considering the time and controversy surrounding the passage of earlier compacts, this is a very unlikely event.

Agriculture uses about 80 to 85 percent of surface water, and 75 percent of groundwater currently used in the State. Almost all of this is used in irrigation. Municipalities, domestic consumption and industry comprise a very small fraction of water use - less than three percent of the State consumption. Reservoir evaporation is responsible for about 15 percent of Wyoming's surface water consumption (see Table 2).

Nevertheless, potential industrial use and projected municipal demand is the driving force behind much of the proposed water development projects. Since agriculture controls much of the water, and almost all of the early priority water rights, there is always a threat that industry and municipalities will develop water and hurt agricultural supplies. The large amount of compacted water available to the State demonstrates that taking water from agriculture is not necessary. New water development could produce water for any foreseeable demands in Wyoming. But new projects have many problems.

It is often said that all of the good water projects have been built in Wyoming. The good dam sites, and the areas where there was a demonstrated need, generally agricultural uses, have developed water available today. Projects that are further from

TABLE 2
WATER USE IN WYOMING
(figures in acre feet)

Use	Surface Water Consumption		Ground Water Consumption	
	Percent	Acre-feet	Percent	Acre-feet
Irrigated Agriculture	80-85	2,427,000	75	300,000
Municipal & Domestic	1.4	41,286	Unknown	
Industry	1.3	38,337	75	100,000
Reservoir Evaporation	15	442,350		
TOTAL		2,949,000		400,000

Source: Wyoming State Engineer's Office and Wyoming Water Development Commission (9).

the end use and more expensive to develop are the ones stacked up on the desks of the engineers and economists of the Water Development Commission.

New dams usually create many problems. Dams that could provide new water supplies are usually far from identified users. They are expensive and difficult to justify on an economic basis. They also tend to disrupt lands and watershed that people have used and are using for other purposes. That means new dams often hurt people. Finally, there are no new projects before the Wyoming Water Development Commission that agriculture can afford to pay actual development costs for the water.

It is worth thinking of the position the State could be in if it continues pursuing a water development program where the State builds and owns many of the dams. The State of Montana built a lot of dams in the 1930s. Montana is now facing a $300 to $600 million bill to rehabilitate and make safe its state-owned dams (10).

Montana has also set up a water marketing program that has failed to find any large industrial buyers - the only parties to buy and use the water have been irrigators. A statement from Bruce Finnie at a water marketing conference held in Billings last summer describes Montana's situation.

> "Farmers and ranchers are afraid of losing their water to industrial developments which could pay nearly any price. Since energy development must have a firm water supply, the water debate is narrowed to sales from state and federal projects. <u>At the present time,</u>

however, there are no industrial buyers nor are there likely to be any in the future. The only possibility appears to be a synfuel development which is at best a long-shot (11)." (emphasis added.)

If Wyoming continues pushing State dams, it will soon face another layer of government bureaucracy that is trying to market water in a time when the federal government and Texaco have been unable to attract industrial buyers.

WATER CONSERVATION - WATER USE AND SAVINGS

Conservation provides a means of freeing up or "creating" new sources of water. There are many benefits of water conservation. It can increase water supplies to current water users as well as filling new demands for the water. Water conservation is viable for industry, municipalities and agriculture. I will briefly discuss conservation potential of industry and municipalities, then concentrate on agriculture - the largest water consumer in Wyoming.

Industry

In 1973 a report noted, "New Federal Studies show that energy development projects in the western states will require more water than is available (12)." The 1973 Wyoming Framework Management Plan projected industrial demands in the year 2020 to be 477,053 acre feet in northeast Wyoming, and 845,000 acre feet for the entire State (13). The potential for this scenario is still there, but the likelihood is small. Technologies are providing energy conversion methods that require less water, and the apparent demand for these facilities has not developed.

Nevertheless, the promise of industry is the driving force behind much of the water development plans in Wyoming. The forecasts of the early 1970s gave scenarios when all of the water in rivers near the coal fields could have been dried up. The filings still exist that could bring this to pass, but there has been very little recent activity by private developers to build new projects.

Industry will not go to an area just because water has been developed. This can be seen by Lake DeSmet with its plentiful water, massive coal reserves and no development. Boysen and Yellowtail are not ringed with industrial facilities.

Industry has tremendous potential to recycle and conserve water. If water is too expensive, industry will find cheaper alternatives. The Wyodak plant near Gillette chose to put in a dry cooling tower rather than pipe water from a well field only forty miles away. The 330 megawatt Wyodak Plant uses only 265 acre feet per year. The 1,650 megawatt Laramie River Power Plant uses 9,600 acre feet of water per year (14).

In the 1970s people projected massive water requirements from synthetic fuel plants. Synthetic fuels plants producing 50,000 barrels of syncrude oil or 250 million cubic feet of gas per day would use between 2,000 and 14,000 acre feet of water per year.

This is less than is generally required by large wet cooling tower power plants (15).

It is important to remember that the Hampshire Energy Synfuel Plant, proposed for the Gillette area, projected using under 6,000 acre feet of water per year. After public scrutiny Hampshire reduced its water projections to 2,870 acre feet per year. Intensive water recycling kept the water requirements to a minimum. This water was to have come from groundwater sources (16). Technology is pointing to ways to use much less water.

This should cast serious doubts concerning the wisdom of piping water from Middle Fork or the Little Big Horn to meet potential industrial needs near Gillette. Even if a company were to build a synthetic fuel plant or power plant near Gillette, it would likely choose a cheaper alternative than expensive transported water.

Municipalities

Towns and cities have a tremendous potential to conserve water. Metering, lawn watering restriction, reducing transmission losses, rate structures and pricing, plumbing codes, and landscape requirements all offer potential water savings. Even if no program is established, new residents will use less water than residents living in old houses and buildings. Low flow fixtures such as toilets, showerheads and faucets save about 50 percent over conventional models. These water saving fixtures are the only ones available (17).

Lower use projections for future users should be incorporated into any municipal forecasting for future water needs.

Water shortages for municipalities invariably appear as summer shortages. This is when lawn watering is at its highest and when competition with earlier priority water rights is most pronounced. These shortages often appear intermittently during some dry years.

Most "need" for future municipal water is to provide for lawn watering. Usually 50 percent to 60 percent of summer use goes to outside demand (18). People may prefer to choose conservation alternatives before buying into a water project that produces water that is only used in one summer out of ten. Water is only of value when it is used, but when a dam is built people must pay for it anyway.

A dam that will provide water that is just needed during dry years must also capture water during all the wet years. Residents of a municipality that choses to build a dam to provide new water supplies must pay a fixed price for the dam. Since the cheap water sources are mostly developed in Wyoming, this can be very expensive. Cheyenne's Stage II project will increase water bills at least 63 percent for a typical residential user. Water bills in Kaycee almost doubled to $25.75 a month as a result of a new water project that was 70 percent subsidized (19).

Conservation provides great water savings. Installation of low flow fixtures in new residences currently reduces residential consumption by 30 to 40 percent. Retrofitting old homes can reduce consumption 10 percent. An increasing rate structure and higher summer "lawn watering" rates can reduce consumption through changes in behavior, and installation of water conserving equipment in commercial establishments. Leak detection and repair or replacement of distribution systems can save significant amounts of water. Landscaping with drought resistant native vegetation uses much less water than typical lawns.

These water conservation applications can provide water at a much lower cost than developing new supplies. Implementing and taking account of conservation opportunities can delay water development for many years.

Wyoming is a boom and bust state. Growing cities and towns are likely to be losing people tomorrow, or in a few years. If there is a potential shortage, water users may prefer implementing some conservation measures before developing new sources of supply, waiting to build until a demonstrated demand actually develops.

Agriculture

Agriculture in the West accounts for most of the water use. Most of the water diverted and stored irrigation water does not reach the crop it was intended for. Instead, the water is lost to the air, to other plants, and to groundwater. Much of the water lost through seepage returns to the stream at a later time. This return flow is a major factor in keeping water in some streams during the summer and fall. On the other hand, the water is often of lower quality, and some of the water is permanently lost from the hydrologic system.

Many separate studies--by the U.S. Bureau of Reclamation, the Soil Conservation Service and the Department of Agriculture--show western irrigation efficiencies to be between 41 and 46 percent (20). Wyoming's figures are even lower, with a state-wide irrigation efficiency average of only 30 percent (21). Some irrigation systems, such as sprinklers can have an efficiency approaching 75 percent, while flood irrigation may only be 20 percent effective (22).

A significant portion of this "loss" returns to the water system. It often provides groundwater supplies and late season flows that are of benefit to fish, wildlife and other irrigators. The amount of return flow that doesn't return to the system is highly variable and depends on unique geologic and hydrologic conditions of an area. Some estimates place this loss at 13 percent (23). Stopping this loss would make between 630,000 and 1 million acre feet of water available for other uses in the State.

Some of this irrigation water can be conserved. An Inter-agency Task Force found that irrigation efficiencies in the Northern Great Plains and Rockies could be increased 11 to 16 percent (24). Increasing Wyoming's irrigation efficiency to the western average of 45 percent could add between 700,000 and 1.2 million acre feet of water to the available water supply. This conservation effort would also create construction jobs, help maintain agriculture in Wyoming by helping many of the State's irrigators, reduce energy use, help increase water quality, and decrease operation and maintenance requirements.

Irrigation is vital to Wyoming's agricultural economy. Irrigated crops brought in nearly 20 percent of the total 1983 agricultural production. Irrigated hay helped fatten and winter livestock responsible for another 75 percent of the total (25).

The 1973 Wyoming Water Framework Management Plan found that only 58 percent of the (then) 1.6 million acres of irrigated lands in Wyoming received adequate water supply (26). Over one-third of the State's irrigated land could use additional supplies.

Agriculture in Wyoming is in tough shape. Wyoming's farms and ranches have seen a large drop in net revenue than any other operations in the country (27). In 1982 the net farm income was a negative 71.4 million dollars. The 1983 net farm income was a negative $62.2 million (28). 1984 figures indicate farmer and ranchers are still losing money.

Irrigators are unable to buy water at the cost of development, and often are unable to put water to use even when it is heavily subsidized. In the case of the proposed Middle Fork of the Powder Reservoir, a Wyoming Water Development Commission (WWDC) consultant calculated that the ability of agriculture to pay was about $27 per acre foot of water. The irrigators stated they could not afford to use $27 per acre foot of water. The current price being negotiated by the WWDC is around $3 per acre foot (29).

Of even greater concern is the discovery that irrigators are not able to keep up existing irrigation systems. The Wyoming Conservation Commission estimates that only five to eight percent of the total conservation improvements needed each year on irrigated lands are being implemented (30).

The amount of water lost because of rundown systems can be tremendous. A 1978 Bureau of Reclamation Report found that four units of the Shoshone Project and the Riverton unit of the Pick-Sloan Missouri Basin Program were in serious need of repair (31). In these units a total of 137,696 acres were being irrigated. The Bureau of Reclamation found that 130,300 acre feet of water were lost from these projects each year. The estimated costs of rehabilitating these projects was $34.6 million.

Through the Rehabilitation and Betterment (R&B) Program, the Bureau of Reclamation has helped some of these districts rehabilitate the projects. The R&B money, however, can only be used for off-farm improvements. Some of the "lost" water has been saved--but much work remains to be done.

The amount of water efficiency work needed in Wyoming is truely staggering. The Wyoming Conservation Commission identified more than 50 water conservation needs. These system improvements carry a price tag of more than $1.2 billion.

A more limited agenda that addresses essential water conservation needs involves:

- Rehabilitating 5,110 miles of leaky canals, ditches, and laterals with linings and pipelines.
- Installing 125,115 control structures.
- Precision leveling of 554,353 irrigated acres.
- Instituting irrigation scheduling practices on 1.16 million acres.
- Conducting 415 tailwater recovery operations.
- Improving irrigation systems on 363,514 acres.

These priority conservation needs would cost $334 million and provide 2,272 man-years of employment if implemented. They would assist existing agricultural operators and allow Wyoming irrigators to continue putting Wyoming's water to use (32).

Wyoming has also identified up to $20 million in needed repairs for high hazard dams within the State (33).

It is interesting that the identified costs of a thorough water conservation program is about the same figure--$1.2 billion--as the projected costs of developing projects before the Water Development Commission. The figure for essential conservation needs is in line with the costs of a couple of the projects being actively pursued by the Wyoming Water Development Commission. In fact, implementing the "essential needs" conservation program would cost less than developing water on the Little

Big Horn and the Middle Fork of the Powder and shipping the water to Gillette.

The main difference between the two options is that the conservation alternative has identified users and need for the water. The program would benefit agriculture at a time when the long-term viability of this important industry is in question.

CONCLUSION

The case of the Casper-Alcova Irrigation District and the City of Casper demonstrates some of the potential benefits that can occur from water conservation. It demonstrates that conservation can "produce" needed water. Because the water is part of the Bureau of Reclamation's Kendrick project, it is possible, and fairly easy to transfer to conserved agricultural water to municipal use. Casper was able to get 7,000 acre feet of relatively cheap water with a good priority date. The irrigators had important improvements made on the system. This arrangement made everybody happy.

Current Wyoming water law prevents this conservation incentive from being used more often. If an irrigator uses less water, there will be less water that he can lay claim to in the future. Wyoming water law is predicated on use--the more you claim and use, the more you keep. The primary incentives for most irrigators to conserve are potential cost savings. There are no provisions for an appropriator to use conserved water to irrigate new lands or make that water with that priority date available to other uses.

The current and foreseeable industrial demand for water in Wyoming does not justify the money that is and could be spent on State water projects having little or no demonstrated demand. Conservation programs for Wyoming's agriculture and municipalities, on the other hand, would benefit existing water users.

The economic reality of conservation versus the costs of new development may force Wyoming to consider more sales or leases of water "developed" through conservation.

It is time for Wyoming to seriously look at its water conservation needs. Water conservation should take its place beside water development in Wyoming's Water Policy debates.

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AUGMENTATION OF CASPER'S MUNICIPAL WATER SUPPLY THROUGH CONTROL OF IRRIGATION CANAL LOSSES

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ABSTRACT

In the late 1970s, Casper faced an increasing water demand while holding junior water rights on an over-appropriated river system. At the same time, the nearby Casper-Alcova Irrigation District (CAID), while it held substantial storage rights, was experiencing a massive debt load, increasing operation costs, and the need for capital improvements. This was happening at a time when farmers could not afford a rise in irrigation costs. An agreement was reached between Casper and CAID whereby the City would be able to purchase up to 7,000 acre-feet per year. However, use of this water could not affect irrigation deliveries or downstream water rights. Under these constraints, funds provided by Casper would be used on improvements to save water which had been lost in transmission and only the amount thus saved could be used by the City.

A detailed study was undertaken to quantify transmission losses on the 62 miles of main canal and the 158 miles of lateral ditches. Seepage loss was determined on individual reaches using inflow-outflow techniques. The first improvements were completed in the spring of 1984 when 380 acre-feet were made available to Casper at an initial cost of about 500 dollars per acre-foot.

This project involves many levels of government, including the U.S. Bureau of Reclamation, Soil Conservation Service, Wyoming State Engineer, Wyoming Water Development Commission, City of Casper and CAID.

INTRODUCTION

In the late 1970s, a combination of population growth and drought prompted the City of Casper to look for alternative sources of water. One of those alternatives, The City of Casper - Casper Alcova Irrigation District System Improvement Program is currently yielding water. This approach did not dam any free-flowing streams, spoil any fisheries, inundate any farmland, or cost a lot of money. In fact, the program has received very little attention because it is not controversial.

The program is based on conservation. The City agreed to pay for improvements which would prevent losses in the irrigation delivery system in return for the amount of water saved. A potential of 7,000 acre feet per year could be available to the City. The benefits to Casper-Alcova Irrigation District (CAID) include increased system efficiency, on-farm irrigation improvements, reduced maintenance costs and freedom from debt.

BACKGROUND

The Kendrick Project

The Kendrick Project, located in Natrona County, Wyoming, is an old "make work" project project from the 1930s which is now operated by Casper-Alcova Irrigation District. Figure 1 shows the location relative to Casper. The system consists of 62 miles of main canal, about 140 miles of lateral ditches, and carries water to irrigate approximately 24,265 acres of farmland, mainly used to raise alfalfa hay, pasture, and small grains.

The primary source of water for CAID is natural flow from the North Platte River. However, this is a relatively junior right and is quickly shut off when spring runoff recedes. The secondary supply is storage water in Alcova and Seminoe Reservoirs which have a combined storage capacity of 1,192, 115 acre-feet when

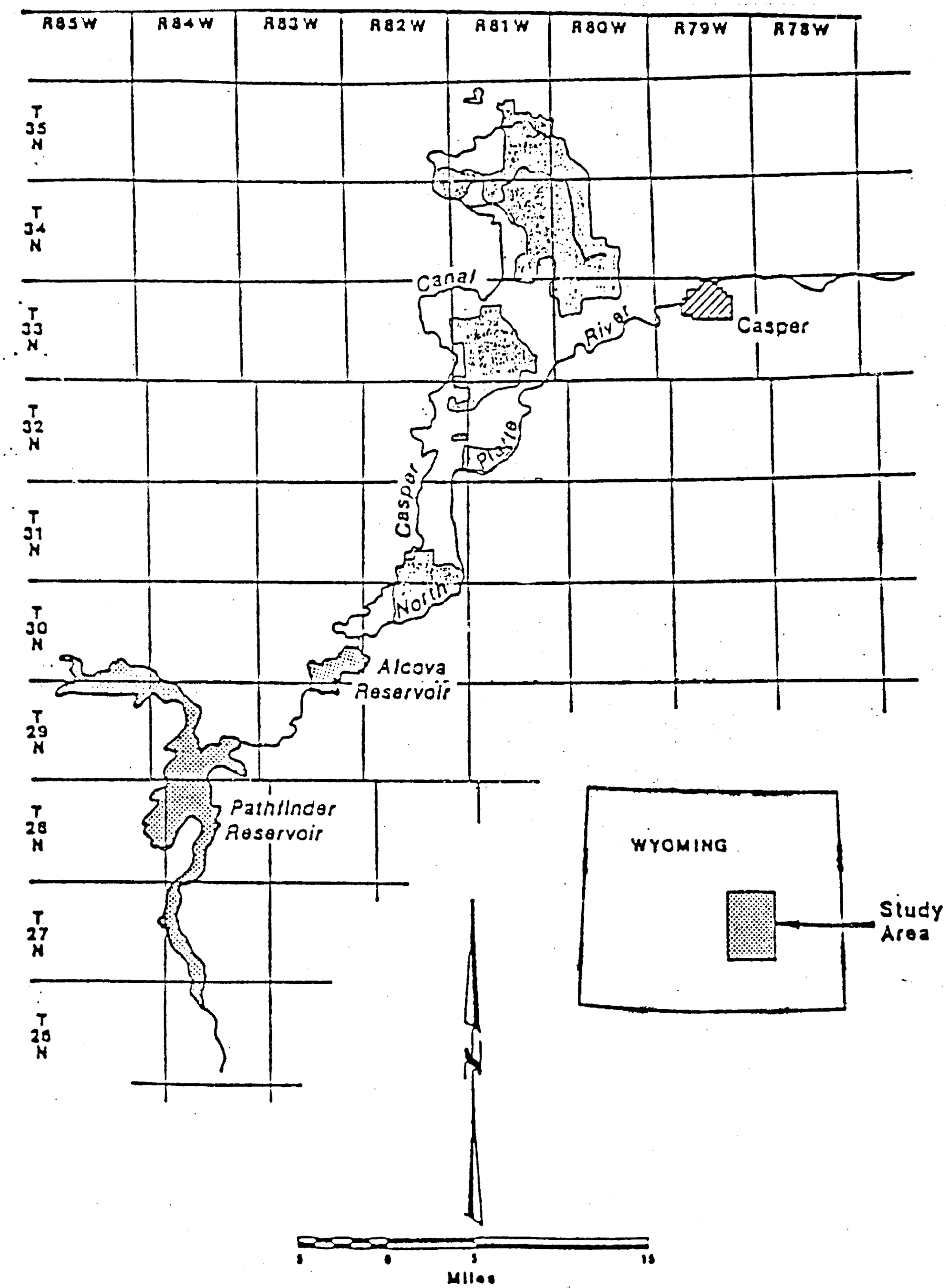

Figure 1. Casper-Alcova Irrigation District Map from U.S. Soil Conservation Service.

full, all of which belongs to CAID. The district uses an average of 61,000 acre-feet per year which means CAID can operate for eight dry years before depleting its supply in the reservoirs.

The original Kendrick Project accomplished an incredible amount of work; building two dams as well as an extensive canal and lateral system. However the project was never finished. A tremendous amount of drainage work was planned but never completed, and consequently productive farmland is now being spoiled as a result of canal seepage.

CAID is quite wealthy in water rights, but during the 1970s, it was not so well off financially. The district owed $750,000 to the Bureau of Reclamation, in addition to the yearly $10,000 payments for maintenance of the headworks. CAID was also faced with rising O & M costs on the lateral system. Meanwhile farmers could not afford an increase in irrigation costs.

City of Casper

Casper's economic boom in the late 1970s was accompanied by a corresponding boom in the demand for water. Although the economy is currently depressed, the expected trend for Casper is to grow, and for water needs to increase. For example, planners estimate that the population will exceed 110,000 by the year 2000.

The City obtains its water from two sources. The first is from shallow wells in the alluvial aquifer adjacent to the North Platte River. These wells can yield an estimated 30.9 cfs/day (with recharge from the North Platte) and 18.6 cfs/day without

(Black and Veetch, 1985). The second source is directly from the North Platte River where the City has rights to 14 cfs with a priority date of 1970, and to another 14 cfs with a priority date of 1977. Casper also has surface water rights to divert water from the North Platte River to recharge its ground water wells.

In the 1970s, the State Engineer informed Casper that in times of regulation, the City's junior water rights could be shut off. The City realized that it needed storage rights and it looked to the nearby Casper-Alcova Irrigation District to provide them.

THE ARRANGEMENT

The City of Casper hired Wright Water Engineers, Inc. to investigate the feasibility of obtaining Kendrick Project water. Since their report in 1979, the initial proposals have undergone quite a few changes. Currently, six agencies are involved in this program, including the U.S. Soil Conservations Service, the U.S. Bureau of Reclamation, the Wyoming State Engineer, the Wyoming Department of Economic Development, Casper, and CAID.

To initiate the program, Casper provided the funding to repay CAID's $750,000 debt to the U.S. Bureau of Reclamation. Secondly, Casper agreed to pay at least $150,000 per year to be used for water saving construction projects. In 1984, the State Legislature decided to match these funds, up to $150,000 per year. Thirdly, the City is required to pay the Bureau of Reclamation annual storage fees of $25 for each acre-foot used.

In return for this investment, Casper obtains the right to use CAID's stored water, though it does not get the water right itself. The amount of water available depends upon how much water is saved under this program, however, 7,000 acre-feet is the maximum which was stipulated by the contract. If Casper does not use all of its water in a given year, it cannot carry over the unused portion for use in future years. On the other hand, it can borrow water from the Kendrick Supply, to be paid back when construction projects make water available. If there are shortages in the Kendrick Supply, Casper agrees to share those shortages with CAID, but maintains the right to use 5,000 acre-feet if there is at least that much available. The term of the contract is forty years, and Casper has the option to renew the agreement.

The main obligation of CAID under this program is to make 7,000 acre-feet of water per year available to Casper as soon as possible. CAID must also coordinate the system improvement program, submit plans and annual reports, conduct hydrologic studies, and oversee the design and construction of all projects.

The benefit of this program to the City is obvious; it will inexpensively supply 7,000 acre-feet per year. The final cost of this water will be about $75 to $100 per acre-foot per year. In comparison, water from the proposed Deer Creek Dam storage project will cost about $450 per acre-foot per year (Banner Associates, 1984). There are many benefits to CAID from this program. Not only does the district enjoy freedom from a tremendous debt load and an improved water delivery system, but alkali problems can be prevented, pressure can be generated in pipelines to operate sprinklers, and maintenance problems can be reduced.

SYSTEM IMPROVEMENT PROGRAM

A hydrologic investigation was undertaken to locate and quantify leakage on the various ditches. The format for the study was developed by Ted Gilbert of the State Soil Conservation Service Office in Casper. Initially, potential loss for each lateral was estimated by using soils data and interviews with CAID personnel. This information served as a guide for the field investigations, currently in their third season.

For the study, laterals are divided into reaches of manageable length and each segment is examined using inflow-outflow techniques. Water level recorders are placed at the beginning and end of each reach, and also in areas where water enters the ditch as return flow. In this way, seasonal flow records for each lateral are maintained. The recorder stations are designed to be portable so they can be moved every year. They consist of 12-inch PVC pipe for a stilling well, a two-inch intake pipe, a cover box, a staff gage, and a control section. Under ideal conditions, a station can be installed in one hour.

Water delivered to farmers is monitored by the ditch rider using existing measuring structures (weirs, flumes and deflection meters). Daily records of changes to the headgates and readings on the staff gages are maintained. These data are subject to the largest errors in the study, so extra care is taken by the hydrologists to check the turnouts as often as possible. Each turnout is current metered to see if it is measuring flow correctly, and if not, a new rating table is developed.

Rainfall is measured on each lateral and evaporation is estimated using Bureau of Reclamation values for Pathfinder Reservoir. The role of evaporation is not as important as once thought. In fact, the net loss to evaporation has been less than 5 percent of that lost to seepage.

CAID transmission losses range from 3 percent to 35 percent per mile. For comparison, the loss on the Hawk Springs Project in Goshen County was determined by the U.S. Soil Conservation Service to be 67 percent for the entire 21.6 mile ditch or about 3 percent per mile (SCS, undated).

The hydrologic study requires 32 water level recorders per season, and a minimum of 150 flow measurements to make the corresponding rating tables, as well as a minimum of 600 charts to interpret. Each lateral is studied for at least two seasons and only three or four laterals can be studied per year. Such scrutiny may seem excessive, however because seepage loss is not consistent, this precision has been necessary to document specific areas of loss. Loss on any one lateral can be seen to vary with discharge, time of year, antecedent conditions, weather, etc.

When water loss in a segment has been determined and approved by the State Engineer, then the construction phase can begin. One conservation project has been installed under this program and another is currently under construction. The first project was a pipeline which replaced the entire 2.92 miles of Lateral 41 and saved 382 acre-feet per year. This construction was paid for by the City at a capital cost of $478 per acre-foot saved. The farmers benefitted by this project because they are now able to use the pressure in the pipe to operate sprinklers. The second project, underway this spring, involves lining 2.7 miles of Lateral 210 with concrete ditch for a savings of 370 AF at a capital cost of $772 per acre-foot. Plans for next year include lining the next 2.1 miles of Lateral 210.

The delivery point for Casper's water has not yet been determined. However, because the State Engineer is concerned that small amounts of water cannot be measured through Gray Reef Dam, the water must first enter the CAID Canal and then be diverted to the North Platte River downstream from Gray Reef where the City can pick it up at its intake.

CONCLUSIONS

There is a pressing need for most growing western cities to increase their water supplies. However, the costs of new storage facilities are often prohibitive and there are usually some controversies surrounding dam construction. The City of Casper has found an innovative way to obtain storage water rights based on conservation.

Casper and Casper-Alcova Irrigation District in Natrona County negotiated an agreement by which the City will fund construction projects to reduce canal losses in exchange for the water saved, up to 7,000 acre-feet per year. The final cost of this water will be approximately $75 to $100 per acre-foot per year, less than one fourth the cost of water from a proposed new storage facility.

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WATER

QUALITY

ACID DEPOSITION IN THE WIND RIVER MOUNTAINS[1]

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ABSTRACT

National attention has been focused on the discovery of acidified lakes in the Adirondack Mountains of New York and elsewhere in New England. It is commonly believed that the West, in particular the Rocky Mountain Region, is still pristine so far as acid deposition is concerned. The initial results of a USDA-Forest Service long-term monitoring program in the Wind River Mountains, Wyoming, indicate the potential for damage from acid precipitation exists at the present time. This monitoring program was undertaken due to development of natural gas refining facilities in southwest Wyoming, upwind of the Bridger and Fitzpatrick Wildernesses. These natural gas facilities, in combination with trona processing plants and coal-fueled power generators, also in southwest Wyoming, produce a sizeable amount of SO_2 and NO_x acid precursors. This paper will discuss the initial results of the monitoring effort.

INTRODUCTION

Acid rain has become a preeminent environmental issue (7,19). Since the original discovery of acid rain in the Scandinavian countries and subsequent verification at Hubbard Brook, New Hampshire (11), attention in the United States has been focused on the damage occurring in the eastern United States. Until quite recently, the conventional wisdom held that in the western United States the airsheds were still pristine. This view of a time that once was is no longer the reality of air quality in the Rocky

[1]This article first appeared in the "Proceedings of Watershed Management in The Eighties-New Direction" held during the annual convention of the American Society of Civil Engineers, April 30-May 1, 1985, Denver, Colorado.

Mountain West. Investigations in Colorado (2,6,9,10) and now in Wyoming (5) have shown that acid precipitation is taking place with annual weighted volume average pH of 4.6 to 4.7 having been observed. In this paper, the implications of acid deposition in the highly sensitive alpine environment of the Wind River Mountains will be discussed.

POTENTIAL SOURCE AREAS

The mandate of "affirmative responsibility" to protect the air quality and related values of the designated Class 1 areas under the 1977 Clean Air Act has caused the Forest Service to examine the potential for adverse effects in the Bridger and Fitzpatrick Wildernesses, Class 1 areas in the Wind River Mountains of Wyoming. The existence of established and proposed industrial operations emitting SO_2, NO_x and COS upwind of the Wind River Mountains, confirms the potential for local Wyoming sources. These sources have produced over 150,000 tons annually of acid rain precursors. Additionally, there is little doubt that the urban-industrial Wasatch Front in Utah contributes air pollution to the Upper Green River Basin setting of the Wind River Mountains. Rather strong circumstantial findings of air flow patterns from Arizona and northern Mexico suggest a source area associated with the copper smelter complex in this region (1). The well-documented long-range transport of sulphates and nitrates (3) would also implicate the generally upwind Los Angeles Basin as another likely source area. The apportioning of acid deposition among suspect source areas is an important and, as yet, unanswered question.

WATERSHED FEATURES RELATED TO BUFFERING CAPACITY

Alkalinity is considered to be the chemical property of a lake which best integrates the geochemical production of basic cations, the atmospheric deposition of alkaline substances, and the planktonic metabolic processes, all of which control the acid neutralizing capability of the lake water (20). There are approximately 2,000 lakes in the Wind River Mountains. A survey of 92 lakes in the Wind River Mountains has produced alkalinity measurements ranging from 10 to 160 ueq/l at elevations mainly from 9,000 to 12,000 feet (2740-3670 meters) (17). The highest elevation cirque basin lakes generally have the lowest alkalinity values and are thought to be the most susceptible to acidification. Despite the fact that two earlier lakes surveys which measured alkalinity have been made in the Wind River Mountain lakes, it is not possible at this time to compare results due to the imprecision of the earlier methods. Nevertheless, the alkalinity results indicate a very low buffering reserve for these lakes. Based upon the national study by Omernick and Powers (15), lakes in the Wind River Mountains are well below the 200 ueq/l alkalinity established for "sensitive" lakes.

The Wind River Mountains are composed of Precambrian metamorphic and igneous rock. The metamorphic component is comprised of migmatite, migmatic gneiss, felsic gneiss. The igneous fraction is made of granodiorite, granite, and porphyritic granite. From a geochemical standpoint the rocks have quite low contents of basic cations Ca and Mg primarily, of which a considerable portion is retained in resistate minerals (22). Like granitic areas in Scandinavia, eastern Canada, and the Adirondack Mountains, the capacity to neutralize acids is very limited in the Wind River Mountains due to the nature of the bedrock geology.

In a like manner the soils in the lake watersheds have an extremely low buffering capacity. Base saturation is less that 25 percent for the most part. The soils are shallow (less than one foot [0.3 m] deep), have a 50 percent rock content on the average, and are acidic; average pH of 5.2 (14). Based upon analytical results of similar soils (6), it is doubtful that the soils in the Wind River Mountains have significant sulfate adsorption capacity. In the higher elevation lake watersheds, soils have a sparse surface distribution--less than 25 percent for one of the long-term monitor lake watersheds. Preliminary modeling (5) of the soil hydrology has confirmed the minor buffering effect to be expected of the watershed soils.

RESULTS OF MONITORING

The Forest Service has mounted a monitoring program in the Bridger and Fitzpatrick Wildernesses designed to detect future adverse changes in air quality, water and soil chemistry, aquatic biology, and terrestrial vegetation which could result from air pollution (21). Field measurements have taken place for the past two years. Since 1982, an atmospheric deposition station in the national NADP program has been located near the boundary of the Bridger Wilderness close to Pinedale, Wyoming. The annual volume weighted average pH for November 1982 to November 1983 was 4.62 for this NADP site. Combining winter analyses of snow chemistry with the NADP summer measurements showed the H+ ion deposition to be nearly balanced by the of SO_4^{-2} and NO_3^{-1} for the same period. The precipitation acidity for the summer and fall season was nearly three times that of the winter months, possibly reflecting differences in the storm tracking and source areas for those two seasons (5).

The water chemistry analyses from the long-term monitor lakes have shown all the lakes maintaining a positive alkalinity balance, near neutral pH of 6.4 to 6.9, and moderate SO_4^{-2} concentrations of 20 to 35 ueq/l. By comparison, heavily acidified lakes in the northeast United States have SO_4^{-2} concentrations well above 100 ueq/l (6). Soil base saturation levels have been established for permanent transects and will be remeasured periodically. While the base saturations are low and the soils relatively acid, these conditions appear to be the norm for alpine soils dominated by spruce-fir vegetation.

Collections of stream insect larvae and lake zooplankton are an important part of the baseline. Norwegian studies have demonstrated a pronounced decline of macroinvertebrates and zooplankton which are intolerant of increased acidity (16). These invertebrates may be excellent "early warning" indicators due to their sensitivity to rather small increases in acidity. Our collections have identified species such as the mayfly, *Ephemerella doddsi*, or groups such as *Daphnia* and the copopods which may be quite intolerant of acidity increase (13). An evaluation of populations rather than individual species may prove more diagnostic of change. Relative species abundance, community structure and diversity are believed to be highly sensitive to stresses such as acidity increase (13).

The vegetation investigation was begun by a lichen analysis conducted by Dr. Mason Hale of the Smithsonian Institute. Dr. Hale has identified the lichen, *Xanthoparmelia cumberlandia*, as the most optimum inducator of air pollution. A heavy metals analysis of this species taken from the Bridger Wilderness revealed a higher concentration of lead than found in the same species in Colorado at a comparable elevation. Not only was the lead concentration three times greater but the concentration increased with elevation in the Bridger Wilderness but was unchanged with elevation in Colorado (8). This finding of an elevation relationship to lead concentration strongly suggests an orographic effect on atmospheric deposition.

CONCLUSIONS

What emerges rather clearly from the discussion of characteristics such as the geology, soils, and vegetative pattern is the realization of how acutely limited is the capacity of these watersheds to neutralize acid deposition. From a national perspective certain areas in the East are receiving nearly 100 ueq/l in acid precipitation (4). The average lake alkalinity in the Wind River Mountains is 70 to 80 ueq/l. An increase of acid deposition of two to three times the current levels would place the Bridger and Fitzpatrick Wildernesses on a par with areas in the Northeast where granitic watershed lakes have acidified. Furthermore, a threshold of acidic deposition represented by an annual pH of 4.7 has been proposed for granitic watershed lakes (23). Based on lakes data from Scandinavia, eastern Canada, and northeastern United States, lake acidification has been observed when the average precipitation pH has fallen below this 4.7 threshold. As previously mentioned, the 1983 average precipitation pH for the NADP site near the Wind River Mountains was 4.62.

A closely related threshold relating to sulfur deposition has achieved a consensus within the scientific community. This threshold establishes 5 kg/hectare/yr of sulfur deposition as a maximum above which lake acidification has occurred (18). At the Pinedale NADP site, the annual deposition for 1983 was 1.3 kg. If the orographic effect noted earlier is taken into account, at the higher precipitation zones in the Wind River Mountains, the annual deposition could have been three to four times the amount recorded at the NADP site. And this measured amount is wet deposition only. In addition, the possible unmeasured increases in sulfur deposition due to rime ice and cloud water reported elsewhere (12) would increase the total. Therefore, it seems quite likely that the Bridger and Fitzpatrick Wildernesses have experienced sulfur deposition in the past close to the 5 kg/H/yr threshold.

This discussion of thresholds highlights a key question--at what level of atmospheric deposition of acid, sulfate and/or nitrate ions will the watersheds in the Wind River Mountains be unable to generate a commensurate amount of buffering? The watersheds can be expected to vary in their response to atmospheric deposition with a three- to four-fold range corresponding to the variation in lake alkalinities. But, whatever the threshold for acid deposition turns out to be for the most sensitive cirque-basin lakes, these lakes will acidify rapidly, should the threshold be exceeded, due to the lack of soil retention of acidifying, mobile anions. Our ability to protect the resources of air, water, soil, and vegetation in the Bridger and Fitzpatrick Wildernesses may, in large part, depend upon our ability to accurately predict the acidification thresholds.

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GEOCHEMISTRY OF POSTMINING GROUND WATER AT THE CORDERO COAL MINE, NORTHEASTERN WYOMING

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ABSTRACT

Ground-water-quality changes from premining to postmining conditions at the Cordero coal mine were studied by geochemical-reaction-path modeling to explain the increased dissolved-solids concentrations in postmining ground water. Recent saturation of backfilled spoils has provided a source for data on spoil-water quality within the State. U.S. Geological Survey data collected from the Cordero coal mine were used to augment existing spoil and premining water-quality data previously collected by Cordero coal mine personnel. Overburden samples from the Cordero coal mine also were collected for quantitative mineralogical, batch-test, and chemical analyses.

Increased dissolved-solids concentration in ground water from premining to postmining conditions at the Cordero coal mine include the following geochemical observations: (1) Concentrations of calcium, sodium, magnesium, and sulfate were larger in postmining ground-water samples from the coal-mine spoil than in premining ground-water samples from the coal aquifer; and (2) calcite, dolomite, gypsum, and chalcedony are very close to equilibrium with the postmining ground water at the Cordero coal mine. Actual saturation-index values (log-transformed, unitless) calculated for the postmining ground water at the Cordero coal mine are 0.097 for calcite, 0.098 for dolomite, 0.117 for gypsum, and 0.065 for chalcedony. A saturation index is defined as the activity product of the dissolved species for a particular mineral divided by the equilibrium activity product for the same mineral. Therefore, a saturation index greater than zero would imply precipitation of a solid phase; whereas, a saturation index less than zero would imply dissolution of the solid phase.

Using geochemical-reaction-path modeling, measured changes in water quality from premining to postmining conditions at the Cordero coal mine were simulated. Equilibrium with respect to dolomite and calcite was maintained while the dissolution of gypsum was simulated until the postmining sulfate concentration measured in the sample collected from the Cordero coal mine spoil water was simulated. Measured versus calculated concentrations for calcium, sulfate, and magnesium in the Cordero coal mine spoil water then agreed within ± 2 millimoles per liter or less. Evaluation of the

batch-test leachate analyses and overburden mineralogy from the Cordero coal mine without regard to dissolution kinetics or limited dissolved oxygen, indicate that further degradation of the postmining ground-water quality will not occur unless significant quantities of acid-forming material are contacted by the postmining ground waters.

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CHANGES IN BACTERIAL POPULATIONS IN WYOMING MOUNTAIN STREAMS AFTER TEN YEARS

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ABSTRACT

Six sites on three streams within the Nash Fork Hydrologic Watershed were sampled on a weekly basis during the summer of 1982, to determine if changes have occurred in waterborne bacteria populations since 1972-72. Water samples were collected, processed, and analyzed using the same techniques as those employed during the 1971-72 study. Bacterial tests included: total coliforms, fecal coliforms, fecal streptococci, standard plate count at 35°C, total heterotrophic aerobic bacteria, denitrifying bacteria, and sulfate-reducing bacteria. The data collected were analyzed using organisms per 100 ml and organisms passing one point per second, to determine whether or not changes in counts were due solely to concentration/dilution phenomenon, or to user activities, as differences do occur. After ten years there were no significantly detectable changes in bacterial populations enumerated. Grazing management, recreational activities, and wildlife use of the watershed studied has not changed much over the ten-year span. These users appear to be contributing a constant bacterial load to the streams sampled by year and month during summer. Long-term bacterial trend data could be used to help managers determine management needs on high mountain watersheds.

INTRODUCTION

Users of watersheds may change water quality. For example, cattle grazing has been shown to increase fecal indicator organism densities in nearby waters (Buckhouse and Gifford 1976, Jahn et al. 1978, Stephenson and Street 1978, Doran and Linn 1979, Jawson et al. 1982, Stephenson and Rychert 1982). Recreational activities have been reported to decrease indicator organism densities in some streams, perhaps by causing wildlife to leave their habitat (Stuart et al. 1971, Skinner et al. 1974a, 1974b, Varness et al. 1978). Gary (1982) found that recreational use of a campground equipped with modern sanitation facilities did not significantly effect the densities of indicator bacteria in surface waters, whereas Skinner and Adams (1977) were able to show an increase in numbers below a ski area during winter months. These higher numbers, however, decreased to base levels during spring snowmelt. Other investigators have shown increased stream flow from snowmelt or precipitation events raised the numbers of organisms in water in various drainage basins (Walter and Bottam 1967, Stuart et al. 1971, Stuart et al. 1976, Varness et al. 1978, Kay and McDonald 1980, McDonald and Kay 1981, Erickson et al. 1982, Gannon et al. 1983).

Seasonal fluctuations of indicator organism densities indicate that higher numbers may be found during the summer months (VanDonsel et al. 1967, Skinner et al. 1974b, Hendry and Leggatt 1982) in both streams and lakes. These fluctuations in bacterial numbers may be due to settling of indicator organisms from surface waters to bottom sediments (Kay and McDonald 1980, Gannon et al. 1983, Skinner et al. 1984). Examples of indicator organisms more numerous in sediments than in overlying waters have been documented by Hendricks (1971), Van Dansel and Geldrich (1971), Matson et al. (1978) and Skinner et al. (1984). Organisms in sediments may be resuspended by various precipitation events causing flushing flows, recreational activities, and hoof action from wildlife and livestock. Indicator bacteria in surface water and sediment have been reported to survive and grow (Hendricks and Morrison 1967) yet this survivability is related to many other factors (Mitchell and Chamberlin 1978, Chamberlin and Mitchell 1978). Research documenting change in bacterial populations found in stream water originating from mountain watersheds subjected to multiple user pressure with intervals of years between sampling is lacking. This study was undertaken to document changes in seven bacterial populations in mountain streams after 10 years while management practices and user activities remained generally unchanged.

MATERIALS AND METHODS

From June through September 1982, samples were collected from the same streams and sites located within the Nash Fork Hydrologic Observatory approximately 53 km west of Laramie, Wyoming as described by Skinner et al. (1974a and 1974b), in order to compare bacterial water quality after 10 years.

Total coliforms (TC), fecal coliforms (FC), fecal streptococci (FS), and standard plate counts (PCA) at 35°C were enumerated following methods described by Skinner et al. (1974b). Total viable bacterial counts (HEN), sulfate-reducing bacteria (SULFR), and denitrifying bacteria (DEN), were enumerated as previously described by Skinner et al. (1974a).

One way analysis of Variance (ANOVA) was used to compare means from each site for each month by year for each bacterial population enumerated, water temperature, and flow rate. Significant means were separated using Duncan's New Multiple Range Test at the 95 percent confidence level (Steel and Torrie 1960).

Data were analyzed two ways. First, all values were analyzed on an organism per 100 ml basis. Secondly, stream flow for each sampling time was recorded and calculations were carried out to determine organisms flowing past a point per second by following the equation:

$$\frac{\text{organisms}}{\text{second}} = \frac{\text{organisms}}{\text{100 ml}} \times \frac{\text{1000 ml}}{\text{L}} \times \frac{\text{28.3 L}}{\text{cubic foot}} \times \frac{\text{flow (cubic foot)}}{\text{second}}$$

Data from 1971, 1972, and 1982 were combined and one way ANOVA was performed to determine significant contrasts between 1) months for each test at each site, and 2) differences between sites for each test during each month.

RESULTS AND DISCUSSION

Enumeration

Stream flow data has been collected continuously since from the Nash Fork Watershed Observatory. Calculation of estimate numbers of bacteria passing a point per second of flow from volume grab sampling techniques was therefore possible. This calculation relates to stream flow regime and may be important for: 1) standardizing bacterial numbers to compare one sampling period to another, 2) determining concentration/dilution effects, and 3) predicting flushing of bacteria from sediment during various storm events. Because results were reported previously on a per volume basis (Skinner et al. 1974a) and some on an organism per second basis, (Skinner et al. 1974b) data presented here have been calculated both ways. Table 1 illustrates differences between interpreting the significance of bacterial counts per volume and bacteria passing one stream point per second.

Log values at site 2 for the PCA count presented in Table 1 during 1972, depicts a high value of 3.66 organisms per 100 ml. This high value converts to a medium value of 7.11 organisms per second and the significance between yearly values is changed. The log value 0.31 FC per 100 ml at site 4 in 1971 is significantly lower than those of 0.44 and 0.40 for 1972 and 1982 respectively. In contrast, when calculated on an organism per second basis, 3.66 for 1971 is significantly higher than the values 2.34 for 1972 and 2.88 for 1982. This could mean that, on a bacteria per 100 ml basis, the water in 1971 would have been considered to be the least polluted, whereas on an organism per second basis, the water in 1971 would have been considered most polluted.

Differences, through methods of calculation, also occur in organisms used for monitoring ecological trends of water. A high log value of 6.30 HEN per 100 ml in 1972 becomes the low value of 10.04 per second at site 6. Denitrifying bacteria at site 6, as well, were significantly different and higher during 1971 per 100 ml whereas no difference between years occurred when calculated on

Table 1. Comparison of bacterial counts per volume and bacteria passing one point per second for July. Nash Fork Hydrologic Observatory.

Site	Year	log TC* / 100 ml	log PCA / 100 ml	log HEN / 100 ml	log FC / 100 ml	log DEN / 100 ml	log FS / 100 ml	log SULFR / 100 ml	FC/FS Ratio / 100 ml	Sample Size	Stream flow L / second	Water Temp °C
2	1971	0.56	3.45ab	6.17	0.30	3.45	0.22	3.07	0.825	3	1075.4a	6.83
	1972	1.44	3.66b	6.32	0.58	2.63	1.20	2.22	0.358	5	309.6b	10.40
	1982	0.62	2.38a	6.21	0.33	2.10	0.72	2.63	0.431	4	789.0c	6.75
3	1971	0.73	3.83a	6.09	0.22a	2.70	0.56	2.87	0.187	3	820.7	8.17
	1972	1.24	3.60b	6.50	0.35ab	1.52	1.23	2.39	0.093	5	366.8a	10.30
	1982	0.88	2.10c	5.98	0.66b	2.94	0.48	1.78	2.500a	4	788.2	7.75
4	1971	1.03	3.33	5.85a	0.31a	2.93	0.37	2.37	0.884	3	271.7	4.50
	1972	0.76	3.24	5.43	0.44	2.35	0.83	1.90	0.054	5	56.6a	7.10
	1982	0.54	2.21	5.51	0.40	2.35	0.62	2.18	0.119	4	204.3	4.88
5	1971	1.05	3.60	6.05	0.62	3.15	0.73	2.64	0.885	3	2603.6	8.00
	1972	2.11a	3.69	6.35	1.50	2.76	1.29a	2.50	1.944	5	714.9	9.70
	1982	1.09	2.64a	6.20	0.78	1.80	0.71	1.94	1.088	4	2177.1	7.33
6	1971	1.39	3.52ab	6.07ab	0.62	3.18a	0.70ab	2.73	0.827	3	2603.6	9.80ab
	1972	2.51	3.75b	6.30b	1.54	1.03	1.24b	2.13	1.635	3	714.9	8.50a
	1982	1.03	2.42a	5.78a	0.83	2.76	0.48a	2.57	2.584a	4	2177.1	10.80b

Site	Year	log TC / second	log PCA / second	log HEN / second	log FC / second	log DEN / second	log FS / second	log SULFR / second	FC/FS Ratio / second	Sample Size	Stream flow L / second	Water Temp °C
2	1971	4.56	7.48a	10.20a	4.29	7.51	4.26	7.09a	0.661	3	1075.4a	6.83
	1972	4.74	7.11b	10.41b	3.88	6.35	4.56	5.72b	0.463	5	309.6b	10.40
	1982	4.56	6.31c	10.45ab	4.23	5.99	4.62	6.50c	0.431	4	789.0c	6.75
3	1971	4.53	7.74a	9.99	3.66	6.71	4.47	6.77a	0.187	3	820.7	8.17
	1972	4.71	7.16	9.63	3.74	5.18	4.63	5.91	0.109	5	366.8a	10.30
	1982	4.77	7.09	9.89	4.57a	6.88	4.35	5.68	2.500a	4	788.2	7.75
4	1971	4.39a	6.78a	9.29a	3.66a	6.38a	3.72	5.84a	2.029	3	271.7	4.50
	1972	3.47	6.06	8.16	2.34	5.18b	3.61	4.84b	0.064	5	56.6a	7.10
	1982	3.78	5.55	8.83	2.88	5.82ab	3.85	5.55ab	0.167	4	204.3	4.88
5	1971	5.47	8.02a	10.52	5.02	7.61	5.11	7.07a	0.885	3	2603.6	8.00
	1972	5.94a	7.55	10.01	5.22	6.88	5.23	6.22	1.946	5	714.9a	9.70
	1982	5.39	6.97	10.63	5.07	6.17	5.02	6.27	1.088	4	2177.1	7.33
6	1971	5.80	7.91a	10.51a	5.01	7.64	5.11a	7.14a	0.827	3	2603.6	9.80ab
	1972	6.13	7.41	10.04	5.16	4.72	4.80	5.84b	1.643	3	714.9	8.50
	1982	5.37	6.78	10.12	5.12	7.18	4.75	6.98ab	2.585	4	2177.1	10.80b

*TC = Total coliforms, PCA = Plate count agar (standard plate count), HEN = Total heterotrophic aerobic bacteria, FC = Fecal coliforms, DEN = Denitrifying bacteria, FS = Fecal streptococci, SULFR = Sulfate-reducing bacteria.

Numbers within sites with same letters or no letters indicate no significant differences between years at = 0.05.

Data for 1971 and 1972 used from Skinner et al. (1974a and 1974b) with permission from National Research Council of Canada (Canadian Journal of Microbiology) and American Society of Agronomy (Journal of Environmental Quality).

a per second basis. No difference was observed for SULFR bacteria at site 6 when calculated as organisms per 100 ml but 1972 had lower counts than 1971 when organisms per second were considered.

Yearly Trend

Site 1 was located upstream from site 2 on the same stream. Sites 3 and 6 were upstream sites from 5 on a second stream. Site 4 was located on a third stream (Skinner et al. 1974b). The results from sites 1, 3, and 6 were similar to those found for sites 2, 4, and 5, therefore for simplicity only data from 2, 4, and 5 are reported in Table 2.

There appeared to be little change between 1971 and 1982 in numbers of any of the bacteria studied (Table 2). For example, at site 2, TC numbers were significantly higher only during August 1982. Total coliforms at site 4 were significantly higher during August 1982, and July of 1971 and significantly lower during September of 1971. Counts were significantly higher only during July 1972 at site 5. Fecal coliforms and FS often showed higher counts for 1982 but these were not significantly different from the data collected during 1971-72.

Data from all sites showed that in 16 out of 22 cases, TC counts were higher in 1982 than 1971 or 1972, but only in six of those cases were the differences significant. Numbers of FS and FC were higher in 1982 than 1971 or 1972 in 12 of 22 cases but these differences were only significant seven times and once,

Table 2. Mean microbiological values obtained (organisms per second) comparing years by sites, within months. Nash Fork Hydrologic Observatory.

Month	Year	Site	log TC*	log PCA	log HEN	log FC	log DEN	log FS	log SULFR	FC/FS Ratio	Flow L/sec	Temp. °C	Sample Size
June	1971	2	4.64	7.83a	10.60a	3.39	8.05	4.31	7.16	0.241	1480.9a	1.50	3
	1972		4.79	7.57ab	10.10b	3.22	7.79	4.86	6.48	0.043	948.1	4.75a	4
	1982		5.19	6.50b	10.10ab	4.16	7.85	4.83	6.80	0.271	890.0	2.00	2
July	1971	2	4.56	7.48a	10.20a	4.29	7.51	4.26	7.09a	0.661	1075.4a	6.83	3
	1972		4.74	7.11b	9.64b	3.88	6.35	4.56	5.27b	0.463	300.6b	10.40	5
	1982		4.56	6.31c	10.10ab	4.23	5.99	4.62	6.50c	0.431	789.0c	6.75	4
Aug	1971	2	4.62	7.45a	10.10a	3.73	6.06a	3.88	6.81a	1.159a	287.0	10.50	5
	1972		4.98	6.76b	9.56	3.06	3.81	3.49	5.78	0.382	85.7a	9.75	4
	1982		6.03a	7.31ab	9.00	3.80	4.98	4.89a	6.05	0.062	255.8	10.80	5
Sept	1971	2	3.89	6.69	9.31	3.13	6.13	2.97	5.82	1.200	114.0	6.00	3
	1972		4.19	6.73	9.43	3.28	5.21	4.06	5.57	0.728	68.8	4.50	2
	1982		5.02	6.86	8.95	3.80	4.66	4.62	5.66	0.243	109.8	5.63	4
June	1971	4	3.88	7.28a	9.94	2.97	6.88	3.90	6.51	0.262	253.3	0.75a	4
	1972		4.28	6.97ab	9.55	2.82	7.48	3.62	6.05	0.204	364.5	2.75b	4
	1982		4.49	5.98b	9.41	2.86	6.50	3.67	6.06	0.223	431.6	2.00ab	2
July	1971	4	4.39a	6.78a	9.29a	3.66a	6.38a	3.72	5.84a	2.029	271.7	4.50	3
	1972		3.47	6.06	8.16	2.34	5.18b	3.61	4.84b	0.064	56.6a	7.10	5
	1982		3.78	5.55	8.83	2.88	5.82ab	3.85	5.55ab	0.167	204.3	4.88	4
Aug	1971	4	3.20	5.70ab	8.14	2.20	5.45	2.70	5.20a	0.291	26.0ab	5.60	5
	1972		3.59	5.20a	7.24	1.21	4.55	1.66	4.74	0.347	9.3b	5.25	4
	1982		4.59a	6.01b	8.62	2.72	5.00	4.05a	4.29	0.063	43.0a	5.70a	5
Sept	1971	4	2.05a	5.37	7.83	1.34	5.42	2.26	4.23	0.176	11.3	2.83	3
	1972		3.07ab	5.37	8.38	1.45	4.57	2.51	4.15	0.186	10.5	3.83	3
	1982		3.78b	5.28	7.00	1.93	4.40	2.90	3.98	0.065	9.9	3.75	4
June	1971	5	5.80	8.03ab	10.90	3.72	8.18	5.21	7.32	0.100	3124.3	2.40	5
	1972		5.79	8.24b	10.50	4.22	8.50	5.15	7.50	0.288	3551.7	5.88a	4
	1982		5.09	7.41a	10.30	4.63	8.19	5.11	7.04	0.261	2277.6	2.50	5
July	1971	5	5.47	8.02a	10.50	5.02	7.61	5.11	7.07a	0.885	2603.6	8.00	3
	1972		5.94a	7.55	10.00	5.22	6.88	5.23	6.22	1.946	714.9a	9.70	5
	1982		5.39	6.97	10.60	5.07	6.17	5.02	6.27	1.088	2177.1	7.33	4
Aug	1971	5	5.24	7.58	10.10	4.75	6.95	5.72a	6.83a	0.195	589.2	9.90	5
	1972		5.89	7.06	9.06	4.20	5.36	4.19b	6.19b	1.875	277.2a	8.83a	4
	1982		6.25	7.69	9.47	5.09	5.73	5.37ab	6.54ab	0.637	633.3	10.80	5
Sept	1971	5	3.82	7.06	9.42	3.63	6.28	4.28	5.90	0.174	239.7	4.00	3
	1972		5.37	7.10	10.10	3.38	6.65	4.34	5.80	0.102	189.6	5.83	3
	1982		5.63	7.31	9.12	4.92	6.68	5.13a	6.54	0.731	283.8	6.13	4

*TC = Total coliforms, PCA = Plate count agar (standard plate count), HEN = Total heterotrophic aerobic bacteria, FC = Fecal coliforms, DEN = Denitrifying bacteria, FS = Fecal streptococci, SULFR = Sulfate-reducing bacteria.

Numbers between years with same letters or no letters indicate no significant differences at = 0.05.

Data for 1971 and 1972 used from Skinner et al. (1974a and 1974b) with permission from National Research Council of Canada (Canadian Journal of Microbiology) and American Society of Agronomy (Journal of Environmental Quality).

respectively. No discernible trends could be found for the SULFR bacteria, DEN bacteria, and the PCA counts at 35°C.

Monthly Trend

Generally monthly trends in bacterial numbers follow those described by Skinner et al. (1974a,b). Total coliforms remained rather constant in trend from June through September at all sites (Table 3). Counts were significantly higher in June and August when calculated as organisms flowing past a point per second at site 2 whereas, there are no differences when calculated by volume. Counts were, however, significantly higher at site 5 for August when calculated by volume but not for organisms passing a point per second.

Plate counts at 35°C were significantly higher at all but one of six sites during June when calculated as organisms per second. At sites 2 and 5, however, PCA counts were higher during August.

Fecal coliform counts did not change by month when calculated as organisms per 100 ml for all six sites whereas a difference did occur for all sites except site 1 as shown in Table 3 when calculated in organisms per second. Higher values occurred during July at all sites except site 1 for organisms per second, while the counts at site 5 were higher during July and August.

Fecal streptococci counts did not change with month for sites 1 through 3 when calculated both ways. When calculated by volume at sites 4,5, and 6 FS increased from June through August, and then decreased into September. When calculated as organisms per second

Table 3. Mean values for microbiological data comparing monthly averages. Nashfork Hydrologic Observatory.

Month	log TC* orgs/ 100 ml	log TC orgs/ sec	log PCA orgs/ 100 ml	log PCA orgs/ sec	log HEN orgs/ 100 ml	log HEN orgs/ sec	log FC orgs/ 100 ml	log FC orgs/ sec	log DEN orgs/ 100 ml	log DEN orgs/ sec	log FS orgs/ 100 ml	log FS orgs/ sec	log SULFR orgs/ 100 ml	log SULFR orgs/ sec	Stream Flow L/ sec	Water Temp °C
Site 1																
June	0.18	4.25	3.38	7.24	5.92	9.77a	−0.66	3.32	3.16a	7.01a	1.35	5.08a	2.00	5.94	677.80a	5.5b
July	0.95	4.90	3.44	6.89	6.02	9.41ab	−0.44	3.02	2.34	5.97	1.00	4.37	2.08	5.51	292.21b	9.9a
Aug	1.66	4.68	3.70	6.98	5.94	9.35ab	0.02	3.39	2.36	5.70	1.19	4.78	2.80	6.15	200.11b	9.8a
Sept	1.79	5.20	3.71	7.24	5.83	8.69b	0.83	3.70	1.96	4.83	1.31	4.13	2.42	5.20	77.31bc	5.2b
Site 2																
June	0.87	4.88ab	3.52a	7.60a	6.23	10.32a	−0.51	3.68ab	3.81a	7.91a	0.71	4.73	2.78ab	6.88a	1115.0a	3.1a
July	1.14	4.65a	3.43a	7.13	6.24	10.00	0.45	4.13b	2.97	6.97	0.88	4.50	2.70a	6.64ab	659.4b	8.3b
Aug	2.33	5.62b	3.95b	7.27	6.42	9.76	0.25	3.65a	2.13	5.65	1.09	4.47	3.12b	6.46b	217.9c	10.4c
Sept	1.66	4.69a	3.77ab	6.75	6.35	9.25	0.52	3.56a	2.71	5.67	1.26	4.25	2.68a	5.69b	99.1c	5.4d
Site 3																
June	0.68	4.81	3.64	7.76a	6.12	10.22a	−0.14	3.33a	3.56a	7.46a	0.53	4.59	2.89a	6.95a	1174.5a	3.3a
July	1.04	4.69	3.56	7.31	6.25	9.84	0.41	4.20a	2.63	6.59	0.96	4.50	2.49b	6.30	619.8b	6.0b
Aug	1.60	5.18a	3.72	7.03	6.40	9.67	0.33	3.60	2.42	5.74	1.32	4.62	2.83ab	6.13	200.9c	8.9c
Sept	1.88	4.65	3.76	6.78	6.04	9.05	0.42	3.43	2.47	5.55	1.16	4.14	2.67ab	5.71	107.5c	10.7d
Site 4																
June	0.57	4.73	3.30	7.06a	5.99	9.73a	−1.30	2.89ab	3.48	7.20a	0.00a	3.76a	1.59a	6.29a	447.1a	1.8a
July	0.82	4.80	3.13	6.33	5.64	8.89	−0.03	3.17b	2.64	5.94	0.68ab	3.75a	2.15b	5.51	158.5b	5.7b
Aug	1.50	5.11	3.33	5.71	5.88	8.31	−0.08	2.40a	2.74	5.17	1.09b	3.62ab	2.66a	4.90	25.5c	5.9b
Sept	1.34	4.60	3.24	5.34	5.87	7.98	−0.52	1.64a	2.90	5.00	0.67b	2.67b	1.98b	4.13	11.3c	3.5c
Site 5																
June	1.10a	4.62	3.50a	7.99a	6.12	10.67a	−0.23	4.34a	3.86a	8.30a	0.72a	5.16ab	2.87ab	7.31a	2943.2a	3.4a
July	1.87a	4.66	3.50a	7.64	6.22	10.39ab	1.21	5.13b	2.79	7.14	1.05a	5.14ab	2.43a	6.63	1669.7b	8.5b
Aug	2.31b	5.50	3.82b	7.53	5.94	9.73b	1.08	4.83ab	2.90	6.53	1.74b	5.45a	2.93b	6.61	500.9c	9.9b
Sept	1.99ab	4.70	3.77ab	7.15	6.33	9.74b	1.05	4.55a	3.20	6.58	1.41ab	4.92b	2.78ab	6.21	240.6c	5.4c
Site 6																
June	1.32	5.01	3.39a	7.88a	6.05ab	10.60a	−0.17	4.42	3.54a	7.99a	0.80a	5.25	3.08a	7.41a	2943.2a	2.8a
July	2.07	5.30	3.44ab	7.43	6.08ab	10.26	1.16	5.10a	2.84	7.29	0.83a	4.92	2.54b	6.91	1669.7b	8.4b
Aug	2.01	4.93	3.72b	7.44	6.23a	9.97	0.64	4.41	2.98	6.79	1.59b	5.32	2.90ab	6.57	500.9c	9.8b
Sept	2.19	5.50	3.71ab	7.07	5.68b	9.08	−0.16	3.24	2.79	6.15	1.44ab	4.87	2.48b	5.90	240.6c	5.2c

*TC = Total coliforms, PCA = Plate count agar (standard plate count), HEN = Total heterotrophic aerobic bacteria, FC = Fecal coliforms, DEN = Denitrifying bacteria, FS = Fecal streptococi, SULFR = Sulfate-reducing bacteria.

Numbers are mean values for that site and month, using 1971, 1972, and 1982 data. Data for 1971 and 1972 used from Skinner et al. (1974a and 1974b) with permission from National Research Council of Canada (Canadian Journal of Microbiology) and American Society of Agronomy (Journal of Environmental Quality).

Numbers within sites with same letters or no letters indicate no significant differences between months at = 0.05.

FS were lower during September at sites 4 and 5. There were no significant changes in FS at site 6 between months when calculated as organisms per second.

Stream flow steadily declined from June to September at all sites sampled. If counts remain constant then there should be an increase in the density of organisms per stream volume. Fecal coliforms, PCA at 35°C, and FS were higher during months of lower flow which could mean that these organisms were concentrated in stream flow during July and August.

Reasoning for increase or decrease of concentration of organisms in stream flow remain as discussed by Skinner et al. (1974b). No change in multiple use management has occurred since 1972 with exception of increased winter sport activities such as cross-country skiing and snowmobiling.

SUMMARY AND CONCLUSIONS

Bacteriological water quality in the streams of the Nash Fork Hydrologic Observatory has not changed drastically after 10 years. Grazing management, recreation activities, and wildlife use of this drainage basin seem to be contributing a constant bacterial load to streams sampled as no evident increases in fecal indicator organisms was noted after ten years.

Higher densities of health indicator organisms were generally found in July and August as found by Skinner et al. (1974b). Results may vary depending on how calculations are carried out. Reporting data based on organisms per volume and organisms passing a point per second often differ and may indicate contradicting levels of bacterial pollution due to changes in stream flow and organism densities. Where stream flow records are available over many years, standardization of data sets to stream flow is possible. Care should, however, be taken to interpret results using both types of calculations. In both cases, one assumes that grab samples are representative of a water column passing a point in time. This may not be true but funding and time constraints most often dictate these research boundaries. Obtaining trend data as was carried out in this study is one way to provide replication data sets to help managers of wildland watersheds monitor user effects. If increasing amounts of indicator organisms are noted with time, given relatively little changes in stream flow, then management practices could be modified to reduce the bacterial load.

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GROUND
WATER

MODELING CONTAMINANT FLOWS IN UNSATURATED SOILS

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ABSTRACT

This investigation focuses on the development of a methodology for modeling contaminant movements in the unsaturated zones of soil columns. Such problems are of great technical as well as social interest. They are mathematically difficult and poorly understood from the physical point of view, yet they arise in most incidents of aquatic contamination by sources near the earth's surface. Of particular concern are multiphase flows, which occur when contaminants having limited solubility in water enter the soil column. This article reports progress on several fronts in modeling subsurface contamination. First, we advance a one-dimensional finite-element collocation scheme for solving the nonlinear equation governing unsaturated water flows. The new scheme overcomes mass balance errors characteristic of this class of problems. Second, we propose a continuum-mechanical formulation of the equations governing multiphase unsaturated flows. These equations are extensions of the equation for unsaturated water flow. Finally, we discuss the extension of the collocation method to two space dimensions and to multiphase contaminant flows.

INTRODUCTION

Groundwater is a precious resource. Through most of Western history economics have partially masked this fact. Groundwater has usually been available in sufficient quantity and quality to satisfy most needs fairly cheaply. Consequently, the price per unit volume of groundwater remains very low compared to that of oil, a resource that is similar in many respects. Nevertheless, demand for groundwater is rising dramatically in parts of the country where surface water supplies either are declining in quality or, as in the water-scarce Western United States, are simply inadequate in volume. Declining aquifer levels coupled with increased pumping offer convincing evidence that groundwater is a bounded and easily threatened natural asset.

Along with the rise in demand has come a different threat to groundwater: contamination. Disposal of industrial wastes at or near the earth's surface often leads to pollution of nearby underground water supplies. For many years this problem drew less attention than the problems of air and surface-water pollution caused by other waste disposal practices. The reasons for this are simple. Groundwater is relatively inaccessible to observation, so contamination seems invisible until it appears at a production well. However, groundwater typically moves through the subsurface so slowly that a contaminant source may not affect water produced at wells for many years. Inaccessibility and large time scales make groundwater contamination a particularly insidious form of pollution. A contaminated aquifer is difficult, if not impossible, to clean, and by the time the contamination is discovered, it is often hopelessly widespread and hard to trace.

Inaccessibility and large time scales also mean that quantitative understanding of an aquifer's contaminant transport properties can be difficult to establish. Groundwater obeys fairly complicated dynamical laws, and even with good measurements of an aquifer's rock and fluid properties hydrologists may have difficulty predicting or tracing contaminant movements. Here is where mathematical simulation plays a role. Given an adequate description of a groundwater system, a hydrologist can use a mathematical model as a conceptual surrogate for the natural system. A properly constructed simulator--one that is faithful to both the fundamental mechanics of groundwater flow and the geologic peculiarities of the aquifer under study--can approximately reconstruct the history of a contaminant plume, can estimate how the plume will move in the future, and can furnish a method for comparing proposed remedial measures. For these reasons, mathematical techniques for modeling underground contaminant flows have attracted intensive research in the past two decades.

There is a class of contaminant flows, however, for which available mathematical techniques remain inadequate. These flows involve movement of contaminants in the unsaturated zone of the soil column. This zone typically connects surface disposal sites with the water table and is therefore an important pathway for aquifer contamination. Flows of water-soluble contaminants in the unsaturated zone have received a fair amount of attention in the simulation community, although there are still many open issues there. However, in a surprising number of cases contaminants percolate downward from near-surface dumpsites in the form of nonaqueous, relatively insoluble liquid phases. Such flows have received relatively scant scientific attention. The aims of our investigation are twofold. First, we wish to establish a quantitative dynamical understanding of multi-liquid, or multiphase, contaminant flows in the unsaturated zone. This understanding takes the form of a set of differential equations governing the flow of fluids in the soil column. Second, we wish to develop mathematical techniques for generating approximate numerical solutions to these equations. These goals are theoretical in the sense that they concern methods, not actual field problems. Given the present state of technology in unsaturated flows, however, research at this level is a pressing need. We hope our work will contribute to the technical foundation necessary for the construction of valid, field-scale mathematical simulators of multiphase unsaturated flows.

DESCRIPTION OF UNSATURATED FLOWS

By definition, a groundwater flow is unsaturated if it occurs in a porous medium, such as soil, whose accessible pores are partly occupied by air. Such flows occur just beneath the earth's surface, where cycles of precipitation and dry weather lead to incomplete saturation and dessication of the soil. Unsaturated flows stand in contrast with saturated groundwater flows, in which the pore space of the rock or soil matrix is occupied completely by liquid.

From a physical standpoint, unsaturated groundwater flows are quite a bit more complicated than saturated flows. One source of complication arises essentially because the presence of air in the void spaces of the medium interferes with the flow of liquid. In general, water flows more easily in a porous medium when a larger fraction of its pore space is occupied by water. In other words, the hydraulic conductivity of the medium increases with its moisture content. Another source of complication arises from the surface physics that act at a scale of observation comparable to the size of a typical pore. The interaction between the surface tensions of air and water and the microscopic geometry of the porous medium imply a direct relationship between the moisture content of the soil and the average water pressure. Thus the moisture content depends on the water pressure. This phenomenon, known as capillarity, means that we can compute water pressure (or pressure head) and then compute the corresponding moisture content using the functional relationship between the two.

From the mathematical point of view, these two complications make the equations governing unsaturated flow significantly more difficult to solve than the equations governing saturated flows. To see why, consider the task of computing pressure head as an unknown function of space and time in the soil column. The equation governing pressure head contains as parameters the moisture content and hydraulic conductivity. To solve for pressure head, we must therefore know values for the moisture content and hydraulic conductivity, but to compute these parameters we need values of the unknown pressure head. Problems in which the parameters in an equation depend on the unknowns are nonlinear, and often they can be solved only using approximate numerical methods. Except for certain physically unrealistic simple cases, this is the case with unsaturated flows. Huyakorn and Pinder (1984, Chapter 4) review some of the last decade's research in this area.

So far we have considered only unsaturated flows in which water and air are present. As mentioned, however, many contamination problems involve flows of water and air in a soil matrix together with the simultaneous flow of some nonaqueous liquid that is immiscible with water. When such "oily" contaminants are present the physics, and hence the mathematics, become even more complicated. Now, in addition to the old nonlinearities, the presence of nonaqueous liquid will affect the flow of water and vice versa. Also, there will be another capillarity relationship coupling the pressure head in the water to that in the immiscible contaminant. Again, numerical solution techniques are necessary, but in this case we have very little in the way of previous research to guide our approach.

MATHEMATICAL DIFFICULTIES

One task facing the applied mathematician wishing to model unsaturated flows is to select a numerical method capable of producing veracious solutions to the governing equations. In the simplest of cases--one-dimensional flow of a single liquid--the governing equation is a partial differential equation derived by Richards (1931). In its primitive form, Richards' equation is

$$\underset{[\mathrm{I}]}{\frac{\partial \theta(h)}{\partial t}} = \frac{\partial}{\partial z}\underset{[\mathrm{II}]}{\left[k(h)\frac{\partial h}{\partial z}\right]} - \underset{[\mathrm{III}]}{\frac{\partial k(h)}{\partial z}} \tag{1}$$

The first term (I) is the temporal rate of change of the moisture content θ [m^3 water/m^3 soil matrix] expressed as a function of pressure head h[m] according to the capillarity relationship. The second term (II) arises from Darcy's law for flow in a porous medium and accounts for fluxes of water attributable to gradients in pressure head with respect to height z above a datum. The parameter k(h) [m/s] in this term is the hydraulic conductivity of the soil, again expressed as a function of pressure head. The third term (III) accounts for the influence of gravity on the fluid flow. Given information about the initial pressure head distribution in a soil column and conditions at the spatial boundary of the column, Equation (1) determines a function h(z,t) giving the pressure head distribution, and hence the moisture content θ, throughout the soil column at all subsequent times. However, the dependencies θ(h) and k(h) that render the equation nonlinear make the actual calculation of h(z,t) a tricky job.

One apparent simplification to Equation (1) is both quick and quite common among modelers. By using the chain rule, one can write

$$\frac{\partial\theta(h)}{\partial t} = \frac{d\theta(h)}{dt}\,\frac{\partial h}{\partial t} = C(h)\frac{\partial h}{\partial t}$$

This device allows us to rewrite Equation (1) as a partial differential equation in which the pressure head h appears explicitly as an unknown in each term:

$$C(h)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left[k(h)\frac{\partial h}{\partial z}\right] - \frac{\partial k(h)}{\partial z} \qquad (2)$$

The new parameter $C(h)$ is the specific moisture capacity [1/m], and, as the notation indicates, it too depends on the pressure head. Hydrologists sometimes call Equation 2 the "head-based formulation" of Richards' equation.

We set out to solve Equation (2), subject to a commonly used set of initial and boundary data, using the numerical technique of finite-element collocation. This method is attractive for several reasons. First, it shares with the more conventional Galerkin finite-element methods a degree of accuracy that forces errors in the approximate solution to diminish very rapidly for given increases in the computational effort. This rapid improvement in solution quality stands in contrast to the relatively slow improvements available through standard finite-difference approximations. Second, finite-element collocation bypasses some of the computational complexity of Galerkin methods and thus promises even more efficient use of computational resources. Third, finite-element collocation in recent years has produced good numerical solutions to other problems involving multiphase flows in porous media (Allen and Pinder, 1983; Allen, 1984; Allen and Pinder, to appear), so we believe it is a natural candidate for unsaturated flows.

Roughly speaking, the idea behind finite-element collocation is to replace the unknown function $h(x,t)$, whose spatial variation has an infinite number of degrees of freedom, with an approximating trial function $\hat{h}(x,t)$ whose spatial variation has a finite (and therefore computable) number of degrees of freedom. In particular, we choose the degrees of freedom of h to represent the values of pressure head and its vertical gradient $\partial\hat{h}/\partial z$ at each of a collection of representative spatial locations $z_o,\ldots,z_N$, called nodes, spread throughout the column. Then we can model the variation of $\hat{h}$ between nodes by smoothly interpolating between adjacent nodes. This interpolation relies on a set of interpolating functions known as Hermite cubic polynomials (see Prenter, 1975, Chapter 3). To get an approximate version of Equation (2), for example, we substitute the trial function $\hat{h}$ for the true solution h and demand that the resulting equation hold at a number of collocation points $\bar{z}_1,\ldots,\bar{z}_M$ located throughout the soil column:

$$\hat{C}(\bar{z}_k,t)\frac{\partial\hat{h}}{\partial t}(\bar{z}_k,t) = \frac{\partial}{\partial z}\left[\hat{k}(\bar{z}_k,t)\frac{\partial\hat{h}}{\partial z}(\bar{z}_k,t)\right] - \frac{\partial\hat{k}}{\partial z}(\bar{z}_k,t), \qquad k = 1,\ldots,M \tag{3}$$

Here $\hat{k}$ and $\hat{C}$ are interpolatory representations of the parameters k and C. Notice that the collocation points $\bar{z}_k$ are logically different from the nodes. We choose exactly as many collocation points as are necessary to furnish the correct number of equations of the form (3) to solve for the unknown nodal values and gradients of h. Allen and Pinder (1983) give a more detailed description of the method.

One may reasonably anticipate certain difficulties with finite-element collocation in the context of Equation (2). To see why, consider the performance of a closely related family of finite-element Galerkin schemes for unsaturated flow investigated by van Genuchten (1982). As Figure 1 shows, the agreement between the approximate numerical solution and the correct solution to Equation (2) is quite sensitive to the manner in which one computes the integrals arising in Galerkin's method. The curves labeled "2GP" in this figure lag the correct curves at two hours and nine hours after the problem's initialization. Since the lagging numerical solutions predict an incorrectly slow advance of water into the soil column, they exhibit mass-balance errors. Less water enters the numerical model than would enter a physical system governed by Equation (2). It happens that the numerical scheme used to generate the curves "2GP" in Figure 1 is algebraically similar to finite-element collocation. This observation bodes ill for collocation. Indeed, our first attempt at solving an unsaturated flow problem using collocation led to results suffering the same mass balance errors as those shown in Figure 1. Figure 2 displays these results; Allen and Murphy (to appear) describe the numerical scheme used in some detail.

It is only fair to mention that mass-balance errors are not uncommon in numerical solutions to Richards' equation. Milly (1984), for example, discusses an iterative procedure for improving mass balances in the time-stepping algorithms for Equation (2). His approach essentially prescribes a technique for choosing a representative time level at which to evaluate a nonlinear coefficient $C(h)$.

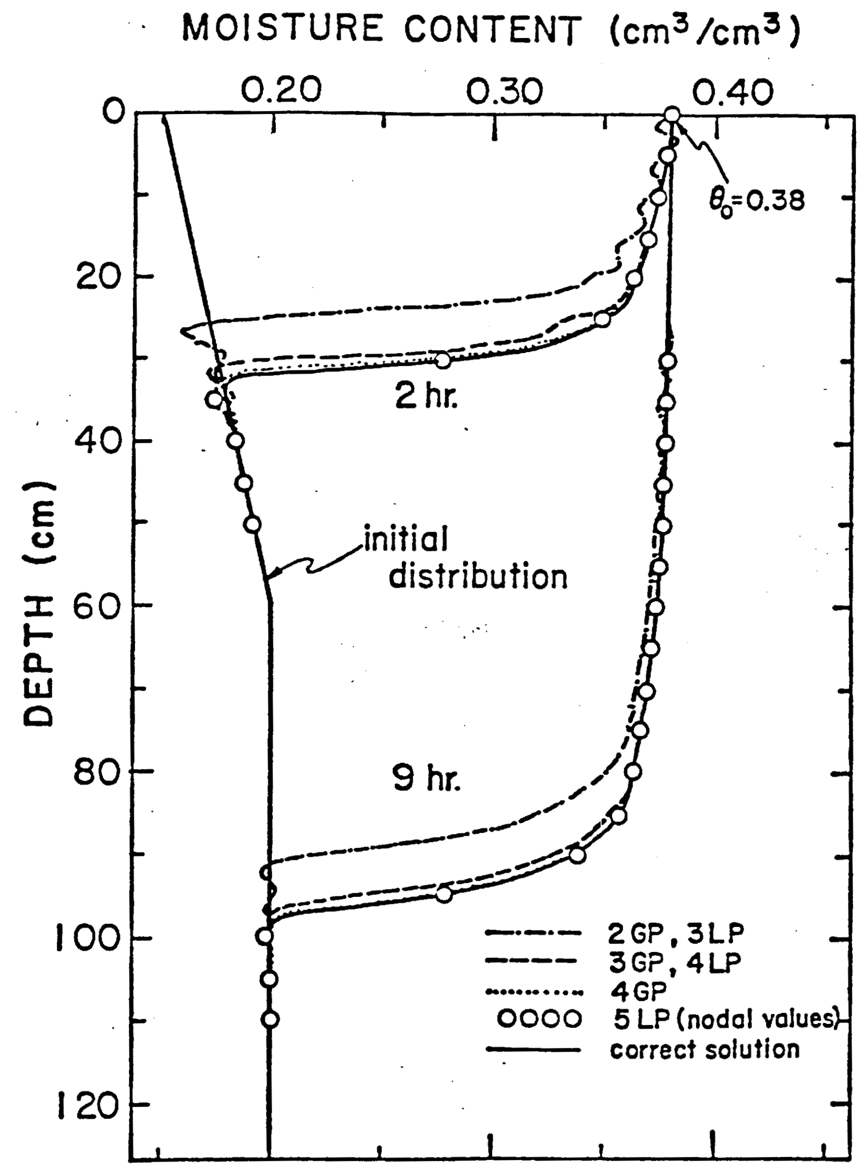

FIGURE 1. Finite-element Galerkin solutions to Richards' equation (from van Genuchten, 1982).

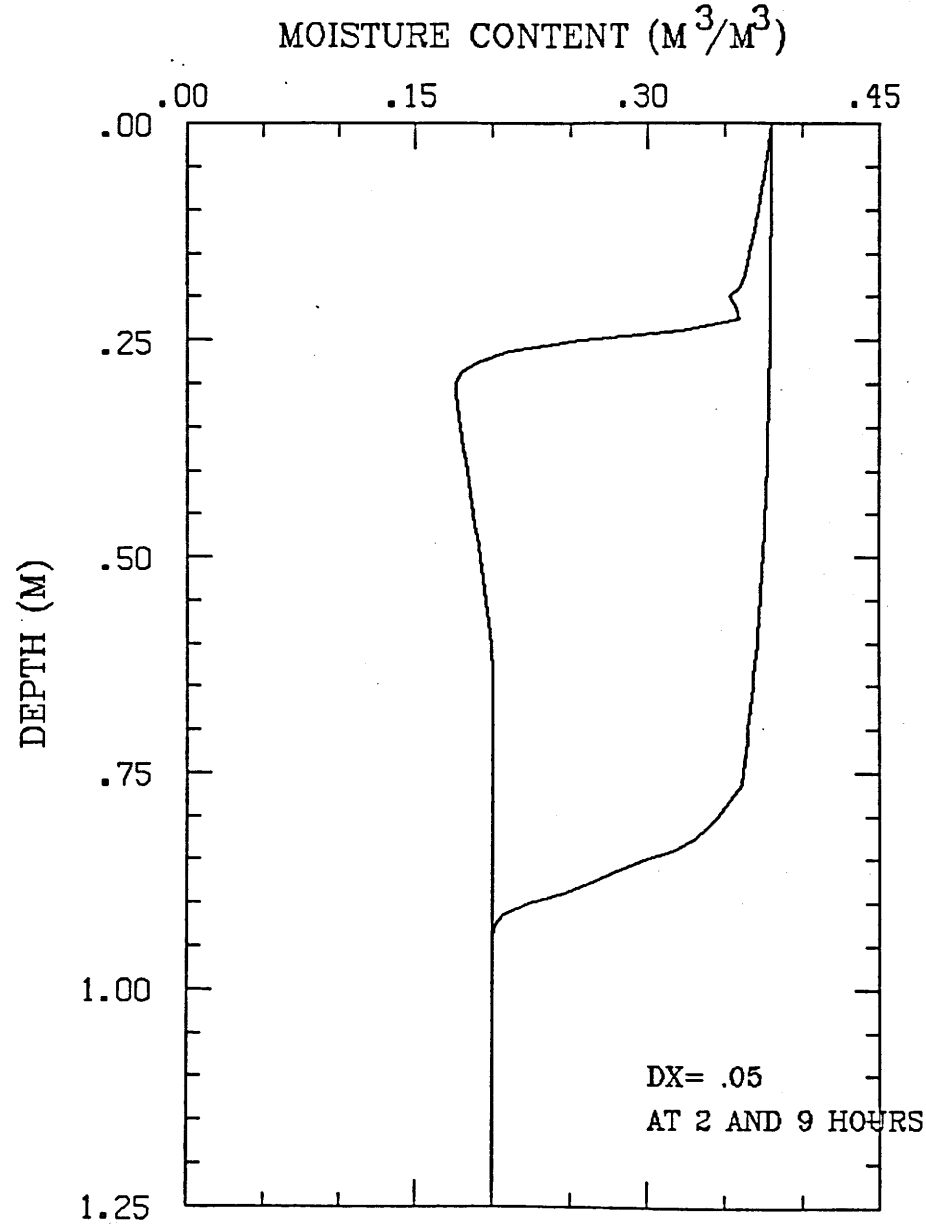

FIGURE 2. Finite-element collocation solutions to Richards' equation using the head-based formulation.

Our approach to reducing the mass balance error is in some ways more natural. We return to the primitive form of the governing equation, Equation (1). In bypassing the apparent simplification offered by the chain rule, we circumvent the issue of where to evaluate C(h) in time. Instead, we approximate term (I) in Equation (1) directly using an interpolatory finite-element representation. In this way the discrete analog of term (I) truly represents the rate of change of moisture content over a time step. Again, Allen and Murphy (to appear) give the details of the procedure. Figure 3 shows numerical solutions generated by our new finite-element collocation scheme. These solutions agree closely with the correct solution.

As a result of this effort, we now have an efficient numerical scheme capable of giving good approximate solutions to unsaturated flows. We shall examine extensions of this method to more general geometries and, ultimately, to problems involving more complicated physics.

EXTENSION TO MULTIPHASE FLOWS

While Richards' equation is well established as the equation governing unsaturated flows of water, there has been very little investigation into the fundamental mechanics of multi-liquid flows in unsaturated soils. Therefore part of our effort has been to propose a continuum-mechanical formulation of multiphase contaminant flows in porous media. This line of inquiry differs from our investigation into finite-element collocation. There we

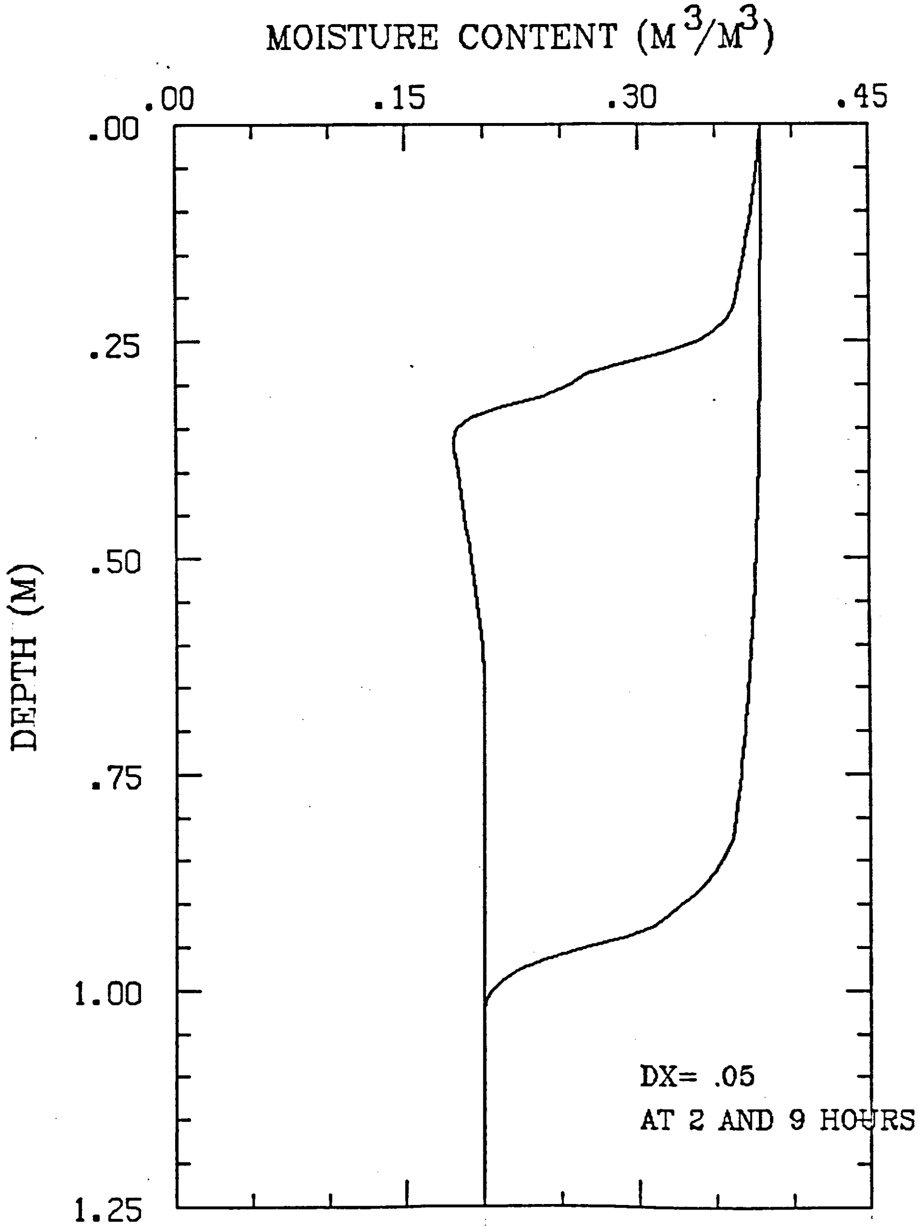

FIGURE 3. Finite-element collocation solutions to Richards' equation using the hybrid formulation.

were concerned with the development of effective solution procedures given an established governing equation. With multiphase unsaturated flows our contribution has been more basic: we have derived a set of governing equations consistent with sound physical principles and plausible assumptions about unsaturated porous media.

Several other investigators have looked at physics similar to those of interest here. Raats (1984), for example, discusses a general mechanical formalism for treating unsaturated flows of air and water in soils using the theory of mixtures developed by Eringen and Ingraham (1965). Schwille (1984) discusses practical aspects of multiphase flows in the unsaturated zone, but presents no continuum-mechanical formulation for the governing equations. Corapcioglu and Baehr (to appear) derive a governing equation without referring specifically to a velocity field equation such as Darcy's law.

Our work is similar in spirit to that of Raats in that we use principles from continuum mixture theory. However, the current project focuses on multiphase flows in unsaturated zone. By considering a mixture containing soil, air, water and nonaqueous liquid and neglecting interphase mass transfer and chemical reactions, one can derive an extension of Richards' equation to two liquid phases (Allen, to appear). In three space dimensions the new equations take the form

$$\left(C_W + \frac{\theta_W s_W}{\emptyset}\right) \frac{\partial h_W}{\partial t} = \nabla \cdot (k_W \nabla h_W) + \nabla \cdot (k_W e_z)$$
$$\left(C_N + \frac{\theta_N s_N}{\emptyset}\right) \frac{\partial h_N}{\partial t} = \nabla \cdot (k_N \nabla h_N) + \nabla \cdot (k_N e_z) \quad (4)$$

Here h_W and h_N stand for the pressure heads in the water and nonaqueous liquid, respectively; C_W and C_N stand for the specific moisture capacity of the soil with respect to water and nonaqueous liquid; θ_W and θ_N stand for the aqueous and nonaqueous moisture contents; s_W and s_N stand for the specific storage coefficients for the soil in the presence of water and nonaqueous liquid, and k_W and k_N stand for the effective hydraulic conductivities of the soil to water and nonaqueous liquid. The vector e_z is the unit vector pointing vertically upward. The coefficients k_W and k_N, at least, depend on the relative amounts of water and nonaqueous liquid present and are therefore functions of two moisture contents:

$$k_W = k_W(\theta_W, \theta_N), \quad k_N = k_N(\theta_W, \theta_N)$$

In addition to these new functional dependencies there are some new constraints. To begin with, the three fluids (air, water, and nonaqueous liquid) must occupy all of the pore space of the solid matrix. Therefore the fluid content variables θ_A, θ_W, and θ_N, giving volume of fluid per bulk volume of soil, must add together to give the total fraction of the matrix that is void:

$$\theta_A + \theta_W + \theta_N = \emptyset .$$

Moreover, the presence of three fluid phases implies the existence of three distinct pressures. From these pressures there arise two independent pressure differences $p_W - p_A$, and $p_N - p_A$, that is, the differences between the two liquid pressures and the air pressure. These pressure differences, and thus the corresponding pressure heads h_W and h_A, vary with moisture content. Inverting these relationships gives two functional relationships having the forms $\theta_W = \theta_W(h_W)$ and $\theta_N = \theta_N(h_N)$ analogous to the relationship $\theta = \theta(h)$ arising in the single-liquid theory reviewed above.

Using principles from continuum physics to develop governing equations in this way has at least two benefits. First, since these principles have their basis in rigorous physical theory, the resulting flow equations at least have a sound conceptual foundation. The arguments used to derive Equations (4) explicitly show how multiphase unsaturated flows fit into a general and widely accepted body of physical theory. Second, the resulting set of partial differential equations serves to guide experimental work by indicating new variables and functional dependencies that need to be quantified to allow precise descriptions of the flows in question. Progress in understanding multiphase unsaturated flows urgently needs empirical work, and a sound mechanical framework provides an essential context for the design of experiments.

DIRECTIONS FOR FURTHER WORK

The work reported above needs to be extended in two directions. First, to be fully applicable to realistic problems the finite-element collocation scheme must be valid in at least two dimensions. Second, to promote further understanding of multiphase unsaturated flows, we wish to generalize the simulation methodology established for air-water flows to accommodate air-water-nonaqueous liquid flows.

Our investigation into the extension of the collocation scheme relies in part on analogies with similar finite-element Galerkin schemes (van Genuchten, 1983). The formal extension of the iterative time-stepping technique for the nonlinear equation is relatively straightforward given an appropriate set of two-dimensional interpolating polynomials with which to approximate the spatial variation of the pressure head $h(x,z,t)$. The simplest such polynomials are linear combinations of the tensor-product Hermite cubics. To form these, we multiply Hermite cubic functions of x by Hermit cubic functions of z, so many of the theoretical error estimates for one-dimensional problems carry over to the two-dimensional case. The development of a computer code to carry out the two-dimensional calculations is in progress.

The extension of the methodology to multiphase unsaturated flows is a somewhat more delicate undertaking. The mathematical problem in this case is considerably more complex simply because Equations (4) constitute a pair of coupled nonlinear partial differential equations. In this respect they pose many of the same computational difficulties as the equations arising in petroleum reservoir simulation. Several decades of research in the oil industry have yielded a variety of approaches to solving coupled flow equations, most notably the simultaneous solution (SS) and implicit pressure-explicit saturation (IMPES) formulations. The SS method is attractive for unsaturated flows because it tends to be stable for relatively large time steps. This advantage may be offset in large-scale problems, however, where the SS approach can yield matrix equations large enough to tax CPU time and storage limitations on most digital machines.

Each of these directions for further work can yield results that contribute to our understanding of unsaturated flows. What is more, each can lead to the development of numerical techniques that may become useful engineering tools. Given the urgency of many known contamination problems, such tools are vitally important.

ACKNOWLEDGEMENT

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AN EXAMPLE OF SOLUTE TRANSPORT IN LOW PERMEABILITY AQUIFERS-- ABANDONED OIL-SHALE RETORT NEAR ROCK SPRINGS, WYOMING

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ABSTRACT

Many areas of possible ground-water contamination in Wyoming are associated with low permeability aquifers. Sites for hazardous-waste disposal or sanitary landfill commonly are located within or overlying low permeability aquifers in attempts to minimize migration of contaminants. An in-situ retorting experiment within oil shale near Rock Springs, Wyoming, was conducted by the Laramie Energy Technology Center in 1976. Subsequent solute migration has provided the U.S. Geological Survey with an opportunity to study solute transport in low permeability rocks. Large-scale oil-shale development is unlikely to occur in Wyoming, but many of the techniques used in studying solute transport in oil shale can be applied to other ground-water contamination problems.

Study of the retort site showed the need for careful attention to small changes in lithology when investigating ground-water flow and solute transport in low permeability aquifers. Accurate description of information, such as potentiometric surfaces and the distribution of solute, was only possible after mapping thin tuff and sandstone layers with relatively large values of hydraulic conductivity compared to the adjacent rocks. These thin, permeable strata constitutes less than 10 percent of the total formation thickness, yet are the principal paths for water movement.

The pattern of solute transport from the retort shows the importance of these thin permeable strata. Movement of solute from the retort site was expected to be slow because of the small, average values of hydraulic conductivity of the oil-shale formation. However, solute has migrated primarily within a thin sandstone layer overlying the oil shale. The greater permeability of the sandstone has resulted in rates of solute movement that greatly exceeded initial expectations.

Ground-water flow and solute-transport modeling of the retort site showed that accurate simulation required complex three-dimensional models. Three-dimensional models were needed because the hydraulic-head distribution within the system showed large vertical gradients. The hydraulic-conductivity distribution was estimated only after detailed measurements of ground-water discharge were obtained and flow-model calibration was completed. A

quasilinear-regression technique was used to calibrate the flow model. The simulated distribution of solute was dependent on estimates of ground-water velocities. As a result, a flow model using regression techniques that quantify the uncertainty in estimates of hydraulic conductivity had an advantage over more simple models. The use of regression techniques at the retort site greatly simplified subsequent development of a solute-transport model. As a result, it was concluded that the rate of the solute transport at the retort was well understood.

Editor's Note: A manuscript of this talk is unavailable.

SOIL CHANGES ASSOCIATED WITH SNOW FENCES

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ABSTRACT

A study was initiated to determine if various soil properties examined in the surface 15 cm of soil varied significantly throughout the snow catchment zone of three snow fences in southeastern Wyoming. Emphasis was placed on the causative agents of this variation.

Analysis of the data collected revealed significant differences in some properties do exist at all tested locations and indicated leaching, as evidenced by reduced soil pH values and electrical conductivities, occurred as a result of the additional water deposited by the snow fences at two of the test locations.

INTRODUCTION

Blowing snow is a phenomenon common in much of the western United States. Control of blowing snow is highly desirable for many reasons including increased water yield, reduced snow removal costs and reduced travel hazards for winter travelers. Snow fences are commonly used to control blowing snow. One study (Tabler and Furnish 1982) concluded that snow fences constructed along Interstate 80 in southeastern Wyoming were responsible for a 27 percent reduction in automobile accidents due to wind only and a 70 percent reduction in accidents due to ground blizzard control. Snow removal costs were reduced about one third due to the fences. Based on these results, economic analysis indicates snow fence construction costs can be amortized within ten years (Tabler and Furnish 1982). Considering that the snow fences are designed to have a life expectancy of about 25 years, the cost savings are considerable.

Although there are many styles of snow fences, the three basic configurations used in Wyoming are the horizontal slat or "Wyoming" fence, a version of the horizontal slat with the top portion inclined upwind known as the "Swedish" fence, and the vertical slat or "Canadian" fence.

Much snow fence has been constructed in Wyoming. Approximately 52.8 km of snow fence was built along Interstate 80 between Laramie and Walcott, Wyoming (a distance of approximately 124 km), between 1971 and 1979 (Tabler and Furnish 1982). Many hundreds of kilometers of fence has also been constructed along railroads and other transportation routes in the State.

Each style of snow fence forms its own characteristic drift morphology. These morphologies are described by Tabler (1980) as characterized by moderate upwind drifts, massive downwind drifts and long downwind drift tails.

Snow fences have the potential of altering the vegetation and the chemical and physical characteristics of the soil in the area influenced by the fences.

Vegetation in the snow catchment zone of snow fences is often affected. This is evidenced by either an increase or decrease in plant size, growth and vigor, and/or by a complete change in the plant community occupying the site. Shantz (1938) hypothesized that, "The plant cover, if properly interpreted, can be used as an indicator of the climatic conditions under which it was produced, of the soils on which it grew and the practices of grazing or other uses to which it has been subjected." Based upon this well respected hypothesis, the change in plant cover associated with some snow fences must correspond to a change in climatic conditions, soils, and/or grazing created by the fences.

Microclimate changes associated with snow fences can be caused by the increased amount of water present as a result of the created drift. Ackerman et al. (1955) reported that an average of 381 mm, water-equivalent of melted snow, remained behind some snow fences in Utah after all undrifted snow had melted off. This is substantial considering that the average annual precipitation in this study area ranges from 279 mm to 406 mm. The localized accumulation of snow creates an environment which stays wet much of the time. Loss of sagebrush (Artemesia sp.) in the localized area where the maximum snow accumulation occurs is often observed (Federal Highway Administration 1980). Artemesia is common throughout much of the West and is present in many areas with blowing snow. Artemesia is not tolerant of a site which is frequently wet for extended periods of time. Only one of four species of Artemesia found in Albany County, Wyoming inhabits sites where the water table occurs within the root zone (Thatcher 1957). The high water table created by the melting snow is probably responsible for the loss of Artemesia observed behind snow fences.

In contrast, the additional water from snowdrifts can compensate for insufficient precipitation, thereby, improving plant vigor and increasing biomass production. The vegetation behind snow fences remains green later in the season, probably due to favorable soil moisture (Federal Highway Administration 1980).

The accumulation of snow moderates soil temperatures (Shulgin 1967); that is, by insulating the soil, snowdrifts can reduce frost depth. The snow also shades the soil and saturates it with cold water in the early summer, thus keeping the temperature lower at this time of year. Differences in thermal regimes between the area in the snow catchment zone and outside it depend upon the characteristics of the area outside the snowdrift. In much of the western United States, the area outside the snow catchment zone of the snow fence is blown clear of any snow cover and, is therefore, exposed to the cold in the winter and to the sun's heat in the spring and summer. In regions which are not blown clean, the insulating layer of snow is maintained. In these regions, the lesser depth of snow outside the snow catchment zone melts more quickly and, therefore, exposes this area to the sun's heat earlier in the spring. Consequently, the soil in the area outside the snow catchment zone warms up earlier than that under the snowdrifts created by the snow fences.

The cold wet soils can impede plant growth. Low soil temperatures delay seed germination, reduce tillering in grasses (Shulgin 1967), and lower seed production (Korovin 1961). Robertson (1947) found that lowered soil temperatures and delayed snowmelt associated with removal of *Artemesia* delayed initiation of grass growth by two weeks. Greatly slowed plant growth was observed in the snow catchment zone of several snow fences in southeastern Wyoming (Federal Highway Administration 1980). Many plants such as conifers have a basic soil temperature below which they are unable to translocate water. These trees begin transpiring at significant rates when the temperature of their needles and, thus, the air temperature rises above the freezing point. The roots, however, are unable to take up appreciable amounts of water when the soil temperature is below 5°C. It is possible, therefore, for small seedlings which have a small water reserve to die of physiological drought even though they may be in saturated soil (Daniel et al. 1979, Armson 1977).

Domestic livestock and wildlife have been shown to favor snow fences for both protection from the wind and sun and grazing (Federal Highway Administration 1980). Changes in grazing intensities can cause changes in the plant community (Beetle et al. 1961, Shantz 1938). In addition to possibly causing changes in the plant community, increased usage of the area behind snow fences by animals results in an increase in the amount of animal wastes being deposited on the site (Federal Highway Administration 1980).

Movement of salts, both by leaching and accumulation, can cause the soil pH to change. Soil pH could be reduced by the snowmelt since the pH of snowmelt has been observed to be approximately 5.3 (Farnes 1985). Studies in forest environments have shown changes in soil pH under large recurrent snow drifts (Miles and Singleton 1975). Changes in soil reaction can greatly affect several characteristics of the soil including cation exchange capacity and nutrient availability. The cation exchange capacity of most soils is highly pH dependent because most clays have a pH dependent charge (Bohn et al. 1979).

The primary objective of this study was to determine if selected soil properties vary significantly throughout the snow catchment zone of snow fences. A secondary objective was to hypothesize, if possible the cause for any changes in these soil properties.

MATERIALS AND METHODS

Three fences were selected for this study. They were located on level sites, known to fill to equilibrium most years, and of age 10 to 20 years.

The terrain around each fence was measured for slope and direction of slope using a clinometer.

One transect was established at each of the three fences. The transects were oriented to extend from 30 times the fence height, H (30 H) upwind to 35 H downwind on a bearing perpendicular to the fence. Each transect was located more than 12 H from the ends of the fence, and situated to avoid the influence of other snow fences and minor topographical features such as depressions or mounds.

Nine stations were established along each transect. These were located at the following distances from each fence: 30 H, 11 H, and 6 H upwind; 2 H, 7 H, 12 H, 17 H, 22 H and 35 H downwind. All samples were collected in June, 1981, using a 10 cm soil auger which sampled to a 15 cm depth. Two samples located side by side in a line parallel with the snow fence were collected for each replicate (Figure 1).

All samples were transported back to the laboratory in a cooler and then air dried at 2°C for 24 hours. Duplicate samples were consolidated for each replicate and passed through a 2 mm sieve. Following this, the samples were mixed again to insure adequate mixing and stored at -2°C. All soil samples were chemically and physically analyzed (Table 1).

One soil pit was dug for each fence. This pit was dug at a spot located approximately 17 H downwind along the transect. Soils were classified to the Great Group level (Soil Survey Staff 1975). A soil sample representing the sampling depth (15 cm) of the replicate was collected at this time and subsequently analyzed to determine the proportion of coarse fragments and the texture. This sample was air dried at 23°C for 72 hours. The soil was

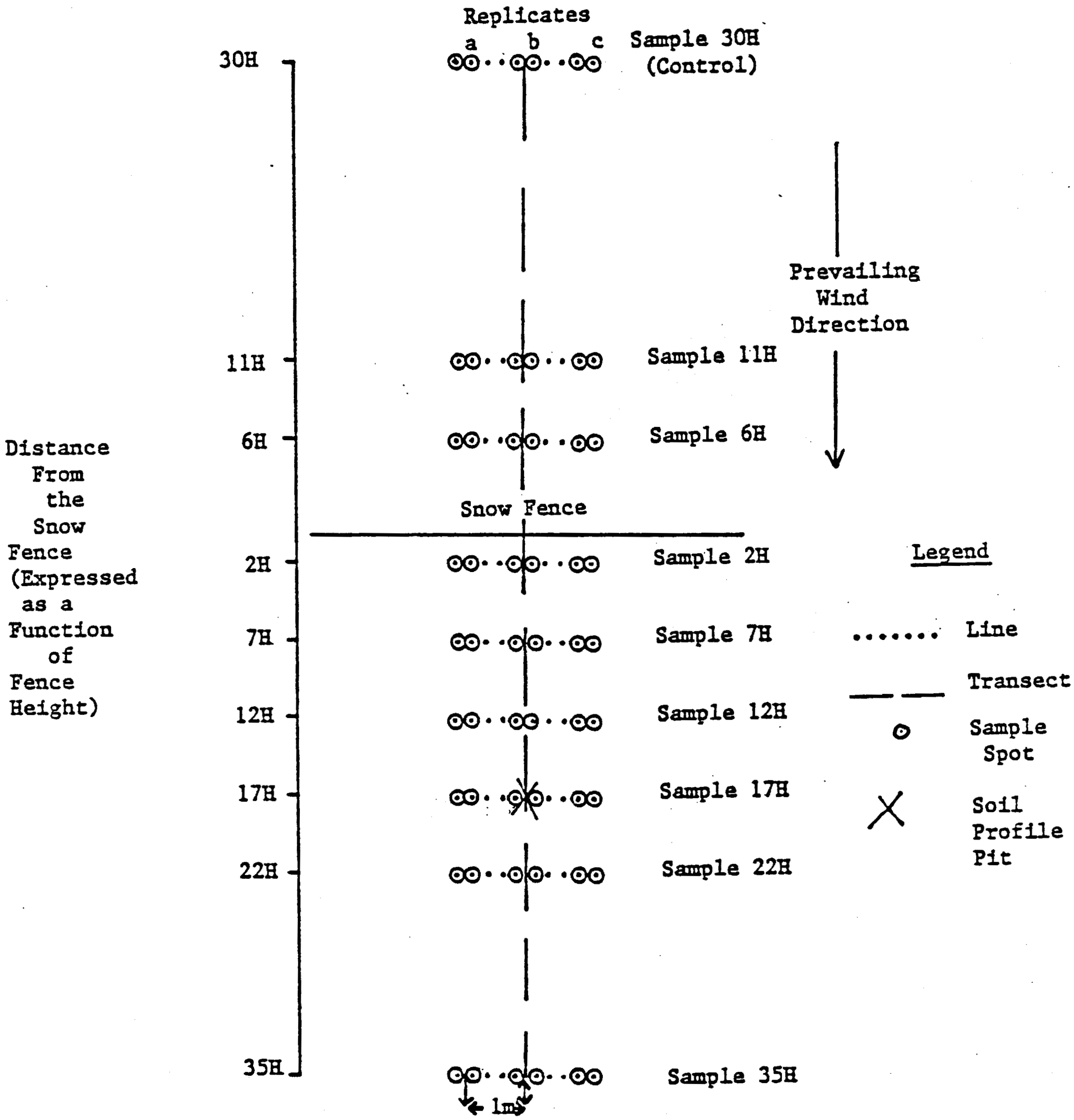

Figure 1. Sampling scheme used for each sampling.

Table 1. Soil properties examined for all replicates.

Property	Reference
pH	Richards (1954)
Electrical Conductivity	Richards (1954)
Plant Available Calcium	Greweling, Thomas and Peech (1965)[1/]
Plant Available Magnesium	Greweling, Thomas and Peech (1965)[1/]
Plant Available Potassium	Greweling, Thomas and Peech (1965)[1/]
Plant Available Sodium	Greweling, Thomas and Peech (1965)[1/]
Phosphorus	Watanabe and Olsen (1962)
Organic Matter	Greweling, Thomas and Peech (1965)
Total Nitrogen	Jones (1971)
Ammonium	Bremner (1965)
Nitrate	Bremner (1965)

[1/]As modified by Greweling (1976)

passed through 76 mm and 2 mm sieves. Texture of the fine earth remaining was determined by particle size analysis using the hydrometer method (Day, 1965).

Parametric methods were used to make statistical comparisons between the control and individual stations. Population means were compared using Student's t statistic.

RESULTS AND DISCUSSION

General Site Characteristics

Slope ranged between one and three percent for all fences. All sites sloped downhill toward the tail of the downwind drift on a bearing perpendicular to the alignment of the fences.

The Elk Mountain and Cooper Cove fences are 3.8 m tall and had been in place 10 years when the sampling was conducted. The Pole Mountain fence was approximately 20 years old at the time of sampling and is 1.8 m tall. The Pole Mountain fence is a Swedish style while the other two are Wyoming style fences. Sagebrush-grassland vegetation is predominant at the Elk Mountain site. Loss of sagebrush (*Artemesia* sp.) has occurred in a band extending from the fence to about 20 H downwind. Grassland vegetation types occur on the Cooper Cove and Pole Mountain sites.

Soil pits excavated at each fence site showed markedly different soils (Table 2) and soil textures (Table 3).

Table 2. Soil profile descriptions from each of the three snow fence sites.

Location	Horizon	Depth (cm)	Color	Texture
Pole Mountain	A	0-5	2.5 YR 3/4 moist	gravelly sandy loam
	BW	5-20	2.5 YR 3/4 moist	gravelly sandy loam
	CR	20-30	2.5 YR 3/4 moist	very gravelly sandy loam
	R	30+	-----	granite rock
	Classification: Lithic Cryochrept, loamy			
Coopers Cove	A	0-17	10 YR 3/2 moist	gravelly sandy loam
	BK_1	17-35	10 YR 5/4 moist	gravelly sandy loam
	BK_2	35-50	10 YR 6/4 moist	very gravelly sandy loam
	Classification: Aridic Calciboroll, loamy-skeletal			
Elk Mountain	A	0-9	10 YR 3/2 moist	sandy loam
	Bt	9-30	10 YR 5/4 moist	sandy clay loam
	Btk	30+	10 YR 5/4 moist	calcic sand
	Classification: Borollic Haplargid, fine-loamy			

Table 3. Soil textures from each of the snow fence sites.

		Location					
		Pole Mountain		Cooper's Cove		Elk Mountain	
Size (mm)	Class	% Total	% Fines	% Total	% Fines	% Total	% Fines
76	Stones	0.0	----	0.0	----	0.0	----
2-76	Gravel	33.9	----	46.8	----	8.3	----
0.05-2	Sand	45.9	69.4	40.1	75.4	58.1	63.4
0.002-0.05	Silt	12.2	18.4	8.7	16.4	12.3	13.4
0.002	Clay	8.0	12.2	4.4	8.2	21.3	23.3
Texture		Sandy Loam		Sandy Loam		Sandy Clay Loam	

Soil Characteristics

Tables 4, 5, and 6 indicate soil characteristics of the Pole Mountain, Cooper Cove and Elk Mountain fences. At all three locations, the quantity of snow melt water is correlated with soil parameters. At the Pole Mountain and Elk Mountain sites, snow melt water (determined from equations given by Tabler 1980) is negatively correlated to pH and E.C. This suggests that leaching is modifying these characteristics, probably via mechanisms of cation removal and introduction of acidity from the melt water. At the Cooper Cover fence, snow melt water is not correlated to pH and E.C., but rather is directly correlated with soil P, soil organic matter and soil nitrogen. This suggests that the snow melt water is enhancing plant growth and perhaps retarding organic matter decomposition. Enhanced plant growth would enhance phosphorus biocycling into upper portions of the soil. Thus increased plant growth would also result in higher soil organic matter and high soil nitrogen (Table 5).

Fence Transect Evaluations

Soil parameters at each fence location were compared along the sampling transect (Figure 1) with soil parameters at a control site for each fence. The control site is the 30 H site located upwind of each fence.

Significant differences in some soil properties were observed at all test sites (Table 7).

Table 4. Relationships among site characteristics at the Pole Mountain site.

Dependent Variable	Independent Variable	R [1/]
pH	H_2O (snow melt)	-.5679**
	EC	.4368*
	Ca	.6753**
	Mg	.3892*
	P	.4130*
	%N	-.3800*
EC	H_2O (snow melt)	-.6080**
	pH	.4386*
	Mg	.4366*
Ca	pH	.6753**
	P	.5488**
Mg	pH	.3892*
	EC	.4366*
K	P	.4569*
P	pH	.4130*
	Ca	.5488**
	K	.4569*
%N	pH	-.3800*

* Significant at 95 percent ($p \leq 0.05$)
** Significant at 99 percent ($p \leq 0.01$)
1/ Based upon 26 degrees of freedom

Table 5. Relationships among site characteristics at the Cooper Cove site.

Dependent Variable	Independent Variable	R^2 1/
pH	NO_3	.4074*
	Ca	-.4995**
	Mg	-.6084**
	P	-.3978*
EC	Ca	.3861*
Ca	Mg	.6170**
	%N	-.6460**
	pH	-.4995**
	EC	.3861*
Mg	pH	-.6084**
	H_2O (snow melt)	-.4611*
	%N	-.5569**
	Ca	.6170**
K	NH_4	-.4092*
P	H_2O (snow melt)	.7759**
	pH	-.3978*
%OM	H_2O (snow melt)	.4374*
%N	H_2O (snow melt)	.5472**
	Ca	-.6460**
	Mg	-.5569**
NH_4	K	-.4092*
NO_3	pH	.4074*

* Significant at 95 percent ($p \leq 0.05$)
** Significant at 99 percent ($p \leq 0.01$)
1/ Based upon 26 degrees of freedom

Table 6. Relationships among site characteristics at the Elk Mountain site.

Dependent Variable	Independent Variable	R^2 1/
pH	H_2O (snow melt)	-.5969**
	EC	.3809**
	NH_4	-.4735*
	NO_3	-.4642*
EC	H_2O (snow melt)	-.5068**
	pH	.3908*
	Mg	-.5140**
	P	.5942**
Ca	H_2O (snow melt)	-.4512*
	Mg	.4408*
	Na	.4278*
Mg	EC	-.5140**
	Ca	.4408*
K	H_2O (snow melt)	-.4543*
Na	Ca	.4278*
P	%N	.4499*
	EC	.5942**
	%OM	.4064*
%OM	%N	.4398*
	P	.4064*
%N	P	.4499*
	%OM	.4398*
NH_4	pH	-.4735*
	NO_3	.7665**
NO_3	pH	-.4642*
	NH_4	.7665**

* Significant at 95 percent ($p \leq 0.05$)
** Significant at 99 percent ($p \leq 0.01$)
1/ Based upon 26 degrees of freedom

Table 7. Summary of test significance for all test sites.

	Test Sites		
Tests	Pole Mountain	Cooper Cove	Elk Mountain
pH	(4)*, (2)**	NS	NS
EC	(1)*	(2)*	(1)*
Ca	NS	NS	NS
Mg	NS	NS	NS
K	(1)*	(1)*	(1)*
Na	NS	NS	NS
P	(1)*	NS	NS
%OM	(1)*	NS	NS
%N	NS	NS	NS
NH_3	NS	NS	NS
NO_3	NS	NS	NS

(n) = number of samples significant at that confidence level

NS = not significant

* = significant at 95 percent ($p \leqslant 0.05$)

** = significant at 99 percent ($p \leqslant 0.01$)

Soluble cations were leached at Pole Mountain, resulting in reduced electrical conductivities and pH values. Plant growth was apparently responding to the deposition of additional water (snow melt) at this site, subsequently, reducing available phosphorus levels due to plant consumption.

The high level of cations in the soil at the Cooper Cove site appeared to be influencing available phosphorus and the soil organic component, however, the influences of the snow fence on the cations, electrical conductivity, and soil pH is unclear.

Analysis of the data for the Elk Mountain location indicates leaching of some of the cations was occurring, thereby, resulting in a lower soil pH and reduced electrical conductivity. Levels of available phosphorus at this site appear to be limiting plant growth. The effect of the snow fence at this site on available phosphorus is unclear.

More definitive results were obtained at the Pole Mountain location than at the other two sites. This is probably due to the older age of this fence (twice as old as the other two) and to the nature of the soil on this site; it being a dry, shallow, highly permeable, and weakly buffered soil.

The sampling intensity used in this study was adequate to indicate several trends and possible effects of snow fences on the various sites, however, it was insufficient to detect differences that could be significant or to fully reveal the interrelationships between the various properties tested.

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FEDERAL
ROLE

FEDERAL ROLE IN WATER RESOURCE ISSUES

Teno Roncalio

First, thank you for inviting me. I will say as an old timer, it is nice to be recognized once in a while, even in this designated hitter's role, and I'm happy to be here to pinch hit for you.

Second, my subject matter generally will be the federal/state relationship in the development of water projects. It's an interesting historic development and there have been some profound changes in it in the last 10-15 years. It began pretty much with the United States of America needing to do two things.

1. Round up those plains Indians and either kill them, of which a good bit was done, or put them on reservations, of which a good bit was done, and say to them this is your home, don't wander around the West any more and you can have that home. In 1918 the United States Supreme Court said you can have some water, enough to irrigate all of your practically irrigable acres.

2. The United States of America said to all the western states, "As soon as you organize into a territory and a state and we adopt your constitution, we give you the right of the ownership of your water. We give you the right to issue rights to your settlers and we encourage people of the United States to come out West and settle your land. We give them certain provisions of

title and fee simple if they develop the land over so many years of homesteading."

These two actions have come into conflict in the West, and now the glaring exception to the diminishing role of federal financial construction funds ought to be in those cases where the federal government promised the state the right of development and conservance of its water and promised the Indians the right to development of their water. That has occurred in Wyoming.

Wyoming is the first state in the nation to take upon itself the duty of determining in its state courts the adjudication and quantification of water rights on the Indian reservations within its boundaries. Why that action was taken, I don't know, but Alan Simpson, a friend of mine, your junior senator, number two man in the United States Senate today after seven short years in that body, has said to me: "Teno, I know why the action was brought, because I was speaker of the Wyoming House of Representatives when the legislation was passed that brought on the quantification of those Indian water rights. We simply had to know, do the Indians have the right to every drop in the Wind River, as some Indians have asserted, or do the Indians have a right to a certain amount of water and no more." So that's the reason that lawsuit was brought. That lawsuit was brought and the quantification was made of a given amount of water for those Indians and enough for their future development of future acreage in case it ever takes place.

The glaring exception, therefore, to the fact that Uncle Sam no longer should pay for water projects occurs in Wyoming. Storage in Division #3, which is the Wind River and Big Horn Basins, ought to be federally supported since Wyoming encouraged both the Indians to settle and the settlers to come in after the Indians from 1905 on, all the way along the Wind up to Worland, on up through to the Montana line. The United States should, therefore, pay for some storage in that area. The reason for the storage necessity is that there will inevitably be damage to the downstream State of Wyoming water right owners if and when the Indians ever develop their full potential of adjudicated water.

Now that may never come. Pretty hard to find anybody that says that it is going to be reasonable to put any money into agriculture in Wyoming these days. If you know of any banks that do, let me know, I know of a hundred ranchers that want to know about that. But the day may come, not in our lifetime probably, but in the next decades, eight or nine or ten decades ahead, when there will be development on that reservation and there will be damage to the downstream water users unless there is storage provided. About a hundred and ninety thousand acre feet a year of beneficially used water can be stored, if it is stored at Blue Holes. There can be more, I am told by engineers, if the modifications can be made around Bull Lake with an extension to it and it can also bring about a beautiful exchange of water situation with Boisen Dam.

This is the one exception to those arguments that are raised in through here that say we don't need any more storage in Wyoming, we've got storage coming out of our ears. That may be true on Fontenelle; that may be true on Warren Morton's Powder River, he knows more about that than anybody I know. But it is not true on the Wind and the Big Horn Rivers. Each of you has a duty as good citizens of the State to encourage all of your elected officials, Democrats or Republicans, young or old, state or federal, to move ahead full speed on the construction of storage facilities on the Wind and Big Horn Rivers or your grandchildren are going to be sorry about it and take you name in vain, as well as mine. That's a lesson I am trying to get across to everybody. The three elected officials in Washington say, "Of course your right." The State Water Development people say: "Of course you are right." But I don't see any progress and I'm too old to make any noise about it now because I think no voice should be heard on controversial public things after so many given years. No man should have to fight in the uniform more than so many given years, whether it is military or civilian or legal, or anything else.

Next, let me return for a moment for the remainder of my remarks to the state/federal relationship. There was some progress toward a national water policy but it is of no real value to Wyoming because it means less and less participation, money-wise, in the construction of projects. States are starting, however, to make contributions to make up for the shortage of monies received from the federal government. Wyoming, I am pleased to observe, has been a leader in that role with appropriations over the years for programs in Wyoming that, had there been a continuing need for certain projects following the 1973 quadrupling of the oil prices, would have resulted in many projects that we don't have now. Which again sustains the observations made earlier today that you have to review these things periodically. What made sense six years ago may no longer be economically feasible, that is a very important requirement, once you can prove the economic justification for a project, just as you had to prove unitary cost-benefit ratios in the old days, then it becomes that much more important. But, with Wyoming's appropriations of the dollar amounts over the years for the Wyoming projects, some 16 of them, Wyoming is taking a lead role in financing these programs. Because Wyoming, in the last 10 or 12 years, has taken a larger share of the return on oil and gas revenues (a change from 37.5 percent to 50 percent made about 7 years ago) there are those in the national Congress who say it is appropriate and proper that Wyoming should pay a little more.

Consider, for example, the modification of Buffalo Bill Dam. We are putting a 25-foot high collar across that Dam which raised significant engineering concerns like:

1. Would the additional pressures on the sides of the canyon permit that much more water storage.

2. Is the Dam firm and solid enough that there will be no problems in the next 50 or 75 years from a collar construction. Those are uneasy questions because if it turns out that engineering-wise it is not the thing to do, you are going to lose half the town of Cody one of these decades if that thing ever breaks loose with the new storage.

I have observed that the funding for that project is now 45 percent Wyoming, 45 percent United States of America and 10 percent from some type of user appropriation. That would have been unheard of in my years of activity as a law maker. In nearly every case we were trying to get total federal funding. Even if we had to sometimes rationalize fish and game enhancement, flood control and some other factors to make the economical justification for a water project.

Other examples: Pennsylvania recently has appropriated a $300 million special loan for public water supply. Now, to other states the water projects mean water for municipalities and for public purposes and industry. While in our West, we still have input in some states for: 1) irrigation and reclamation, 2) industrial development and 3) some municipal. Texas has set up a $600 million revolving fund for water supply and waste water treatment. (I will have to touch on the importance of waste water treatment and reclamation in world water policy in a few minutes.) In Arizona there are some remarkable things being done to cut down waste of fresh water and to bring about the end of the mining of ground waters. In a few years, in states like Arizona, if the aquifer recharge isn't sufficient to maintain the aquifer water level, you must discontinue the use of that groundwater facility. That I think will become the law of the land over the next 30 or 40 years, depending on the particular area.

A few years ago, and I am indebted to a remarkable lawyer named Raphael Moses of Boulder, Colorado for these observations, a Nebraska farmer and his son owned a nice chunk of land that strattled the Nebraska/Colorado border. He went to his neighbor who went bankrupt and he bought some more land in Colorado that touched his Nebraska land and he proceeded to irrigate it with the water from his Nebraska well. The State of Nebraska said to him, "We're not going to give you a permit for that other acreage so you can't to that. That's against the law of exporting water from the State of Nebraska." He said, "That's absurd. I had two sons who went to war in Viet Nam. Nobody told me what country they were going to fight in for the United States. Whether they come from Colorado or Montana they're both my sons and you took them both." He took that general argument all the way to the United States Supreme Court in a case called Sporhes versus Nebraska and he won. That decision has had a profound effect upon the future development of water everywhere in America. It turns us now in a direction of determining whether water will ultimately be available for interstate commerce. If so, is it going to seek its own value by the disciplines of the free market place which have governed everything in our country. This is a position of the Heritage Society in its Mandate Volume 2, just published. It again insists that water has to find its own value in the market place. When can water, therefore, be exported from one state to another by its owner or leased from one state to another? I think the United States Supreme Court has said that it can when it does not constitute an impermissible offense to interstate commerce; those are very key words. If the action consists of an impermissible obstruction in interstate commerce, it will be forbidden by the Supreme Court.

Now as lawyers know, the genius of all this living and legislating isn't so much to tell people what the law of the land is. We all can read decisions. We know that the law of the land is what the United States Supreme Court says it is, or it's what the Constitution ordains and the Legislature enacts as interpreted by the Supreme Court. But the law of the land is really what the Supreme Court is going to decree next year, that is what has involved all of us. So there is a whole new direction on exporting of water and what it means.

Can people sell excess flows of Colorado River water to San Diego? What will happen in the lifetime of your children, you young people who are here, when you have a continuing impact of millions upon millions of people settling in Arizona and California and relatively smaller numbers, in the hundreds or thousands, settling in Wyoming, Utah, Nevada? What will happen to the Colorado River Compact that gives 18 percent of the waters of that river to Arizona and California and higher total percentage to Utah and Wyoming? Will it stay intact? I don't know. I will be long, long since gone, but it is something for you to think about. That case will have repercussions for a terribly long time because state lines are no longer barriers to the transfer of water. Is it morally right for individuals or companies to make money from the sale of a commodity as essential to life as water? You can get some pretty strong moral arguments on that.

I have a friend and a lot of you do too, Ceese Andrews, formerly Secretary of Interior and Governor of Idaho. He says if the day ever somes when water is sold upon its market value as a free commodity to interstate commerce that will be the end of the greening of the West. I replied to Ceese Andrews, "There hasn't been any greening of the West for the last forty years in Wyoming and damn little in Idaho." So that's our problem. If Wyoming were beneficially using 600,000 acre feet of water more than it is every year, it wouldn't have an unutilized flow of that size, year after year, in the wet years, going down the Colorado River. That unutilized flow gives Arizona and California that much more water than its 18 percent because it is flowing and they take it for nothing.

So some people are advocating that we sell some of the water we have a right to to those people. Utah's legislature is wrestl-ing with this idea now. It is an idea that shocks the conscience of old timers in Wyoming and Utah. So they go home and they say to themselves, "Well, we're giving it away to them now so maybe there's nothing wrong with leasing 10 or 20 percent of it for 30 years and making some money for our water projects."

In 1973, Doyle Berry, head of Galloway, thought that the new embargo was going to last a long time, the horrific shortage of gasoline, shale was finally on, the Colorado shale fields would develop the oil out of karogen. He bought some ranches around Meeker, Colorado and acquired about 300,000 acre feet of water rights and started to work with EXXON to supply them with the water they need. (At that time figures were that you would need about three barrels of water to turn out one barrel of oil from karogen.) About three years later the shale projects were cancelled and today oil shale still isn't off the ground. Well, he was left with a horrendous amount of water and he invisioned this fact: water will someday be sold interstate.

But if he were to change his mind and do something else with his water tomorrow, I believe that in six months you would have somebody else along with the concept that Wyoming can no longer afford to let hundreds of thousands of acre feet of water, that it has an entitlement to under the Compact, go downstream without compensation of some type. That is a foolish waste of a vital resource. By earmarking a given percentage of that resource in flow, on the wet years you could make some real money by selling it to those who are going to have the difficult problem of serving their people and watering the 75 golf courses in Phoenix and 45 in Tucson and so on. The real problem is San Diego County. They're begging for more water. That, I think, is something that you should keep in mind as you go and plan your other matters.

I would like to recommend very much to you the publication called, Water Management in Transition, published by the Freshwater Society. I never heard of it until this week. The Freshwater Society was founded by John Ordway of Minneapolis, Minnesota, whose nephew, Gilman Ordway, is a citizen of Wyoming. He lives on Fish Creek in a magnificent place and he lives a good life. He flies a twin engine airplane and knows how to live. The Ordways were a family who were originally part of the Minnesota mining people. The Freshwater Foundation address is 2500 Shady Wood Row, Box 90, Navarre, Minnesota 55392. I think they will send one for nothing if you like. It's the finest publication I have ever seen combining the federal perspective on water programs, the state perspective, the private sector responses, and the case for water markets and for water conservancy. It's a beautifully done piece of work. I would like to think your library would get it too.

Now do any of you have questions, either on this transition of state/federal problems or on the new concept?

QUESTION: How would you address in the Third Division, preservation of water in relation to the Yellowstone Compact?

ANSWER: I don't believe it has an effect on the Yellowstone Compact. The evidence in the case was discussed one day and there are some records of a discussion by Michael White, I think, one of the State Attorneys handling the litigation. He was afraid that if there was to be a deficiency in the Yellowstone Compact that it would shoot upstream and have an ultimate damage against upstream water users. I can't see where there is a deficiency under the Yellowstone Compact. As I recall, your scratching memory now, you have all year long to make the contribution to the flows required by the Yellowstone Compact. As you hit it pretty hard during irrigation season you're not going to be penalized by it as long as your flows are at a minimum. So I don't know the answer totally to your question, but I don't believe there is a relevancy. Nobody else discussing it has brought up any evidence on it.

QUESTION: What was the title on that last publication?

ANSWER: The last publication was Water Management in Transition, 1985 and published by the Freshwater Society.

QUESTION: Would you comment briefly on the possible transfer of waters from the Clarks Fork and Gooseberry and other streams.

ANSWER: Your hitting too many of them for me. Let's take Clarks Fork first. Clarks Fork has, I don't know how many, 60 or 80,000 acre feet a year easily. If you filed on it tomorrow you would probably have a pretty good permit if you could find some use down the road. I can't give you any comment because I don't know who would use it in Wyoming. Users are a little scarce these days on almost all our projects and I think that's one of the reasons the Governor probably didn't fund the Little Big Horn concept one more time. If you are thinking of selling downstream water or getting some exchange of some type for Wyoming benefit, then I think Clarks Fork is where the new action is.

Now Gooseberry I'm not familiar enough with. It's a tributary to the Big Horn isn't it?

Right. I know there was some discussion about a big, involved project where you transfer water from one basin to the next basin to the next and go all the way along the basin.

That's an ongoing discussion and it is a possibility.

Will that help alleviation of the downstream shortage?

The only downstream shortages from there might occur in Montana. There are none in Wyoming there. The shortage I'm concerned about is way upstream from there rather than downstream. Way upstream on the Wind.

QUESTION: We've heard some comments from Chief Justice Berger, suggesting that we should have another court somewhere between the Circuit Courts and the United States Supreme Court to take care of some of the matters that the Supreme Court can't get to because of the work load. Would you suggest the possibility of using a Special Master routine for water matters as a possible solution to that problem the Supreme Court has since you've had experience both in the Division 3 and on the U.S./Canadian border?

ANSWER: Your question is an excellent one and I'd be happy to answer it if you give me about three hours and give Don about an hour in the process and any other lawyer in the house.

The Special Master concept is used by lots of courts all over America and some states have past laws without use of Special Masters. The states that don't use the Special Master device usually have about one half again as many judges as the other states because they simply need them. You just can't do a case of immense complexity and still take care of your day-in, day-out work. That is the reason for the Special Masters concept. Whether Chief Justice Berger is right in his wanting of a new level of courts, I'm not competent to answer because I don't know what percentage water litigation is of those massive amounts waiting to be heard by the U.S. Supreme Court.

We are becoming a litigious nation; that bothers me. I wish we wouldn't be suing each other quite so much. I wish we didn't have to pay so much for malpractice and I wish the doctors would be free to do more exploratory surgery without fear of, "My God, am I going to get sued if I have a look at this appendix." You know this sort of thing. We are litigious and how we're ever going to get rid of it I can't know, but I hate to see it.

Last week I saw a publication in American Bankers Association quoting the executives of WASAW for having cancelled the liability coverage for all of the employees of the Bank of America for some horrendous losses. This official said, "All banks now in America, large and small, are rotten through and through." Now that's quite a statement to make in the face of one or two troubles in one part of the country and who is an insurance man to talk about a banker. So that's the era we're in now and I am reluctant to see another level of courts created because I would like to see society turn another direction really.

QUESTION: In the enabling funding legislation for the Central Arizona Project, Colorado signed on the basis that the funding for some of the previously authorized projects would go ahead. Those have been consistently denied ever since the Carter administration. What is your viewpoint on the pre-established role of federal funding for some of those which appear to be an obligation.

ANSWER: I think it has a right to be diminished as it was in every other state. I don't know what percentage of the lining of the canals going on now is federal but the authority for that act went back to 1966. I voted for that act about July of 1966. I was immediately pounced upon by Floyd Bishop, Cliff Hanson and all the other Republicans in Wyoming. I lost that election by 1900 votes, but that's another story. I didn't effect Wyoming water one iota, but it was a hot political potato and that is one of those things that goes on in life.

I don't think that it should have any effect on them if they are moving ahead with programs that have been authorized and appropriated. Arizona is going to have some real problems getting any more water and that is why they are looking all over the place. Litigation is inevitable on this business of exporting water. The U.S. Supreme Court is going to have to say sooner or later and it's going to have to speak specifically on each set of facts. It can't rule on Galloway, San Diego County, Colorado and have that apply to Minnesota a year later. Each case will bring up its own adjudication.

I am ready to wind up ladies and gentlemen. I will say, in conclusion, that Wyoming has to find some way to continue to attract people to live within our boundaries. I think skiing has been one of the greatest things that has ever happened to keep Wyoming people happy. I know it made my winters here joyous for many, many years. I think that if we can find ways to make life more enjoyable in the winter, provide employment, of course, and improve our education facilities, Wyoming can find more and more people and thereby utilize more and more of its own water. I would even ask Wyoming to look at some of the dumps for middle level uranium waste. That may shock some of you environmentalists, but we made millions of dollars in this state mining uranium for 40 years. Is it morally right that we should now say we are too proud to dig a hole some place and put some spent fuel shells there that won't bother anybody if its done right? I don't think that is the way to live either. That could improve our economy quite a lot, but even mention something like that now if you are in public office means that you are tired of public office. Since I am retired I can now mention it. Thanks very much.

CONCLUDING REMARKS

CONCLUDING REMARKS

Robert W. Brocksen

What I've gleaned from this day and a half of meetings is that we haven't necessarily been approaching our concerns with the appropriate research or looking down the pike as to what it is we really expect. A common theme among the various presentations is that we needed the ability to anticipate the consequences of our actions. That is asking a lot. You heard from Mr. Roncalio this morning that those expectations are generally couched in what the law is today and what compacts exist today, but they may change tomorrow or next year. The fundamental challenge of research, of course, is to be very perceptive; we not only need to know how to do something, but we need to know what will happen when we commit ourselves and our resources to a course of action.

Closely related to this theme is our incomplete ability to foresee the future. We know the drought cycle will return, but we don't know when. We know the demand for development of Wyoming energy reserves will return, but we really don't know when. Research does not necessarily enable us to predict the future, but research can help us influence the future and our ability to cope with it. If our research efforts are directed by reasoned anticipation of problems, if we are not always being reactive to the moment, we will be better prepared to effectively address those problems. If our research efforts are guided by an idea of what we want for our future, or what we want our future to be, then we stand a chance of realizing that future.

So down to a few specifics. Mr. Bourret talked about the need to know what a drought cycle will cost us. Mr. Odasz asked how will our current system of priority rights influence the distribution of these impacts. Mr. Budd, Mr. Noe, Mr. Bourret, Mr. Marrs, Mr. Wolfe, Mr. Christopulos, all acknowledge that we need to know how much water we have. This is a double question, of course, concerning both physical yield and legal rights. Mr. Wiley, Mr. Sando, Mr. Galbraith and Mr. Naftz, suggested we need a much better understanding of how to protect the quality of our water resources. So we have a theme here of questions that require answers. I think, however, we have to come to some kind of accommodation among ourselves as to how we approach retrieving those answers and what we expect that those answers might give us for the future of Wyoming.

The Wyoming Water Research Center, in conjunction with the University of Wyoming and the state and federal agencies that are associated with water resources in this State, I think, are committed to attempt to address these questions, but we need your constituency and your help in guiding us toward what it is you feel you're looking toward.

Those are my parting remarks. I would ask then, in reverse order, only in the interest of fairness, that we begin with Bob

Wiley and we'll have an expunction on the environmental point of view.

SUMMARY REMARKS

Bob Wiley

I think that if anything has come out of our meeting here, it is that, as Teno Roncalio pointed out, water is a very complex issue, not only from the environmental point of view, which I am supposed to represent, but from the developmental point of view, irrigation, the whole gamit of water interests. The only way that we can, all of us, understand these issues is to work together, recognizing that all the interests, and I said this yesterday, must cooperate and then realize that some of our old ideas about water are probably going to have to change to meet modern trends. What that means is that all the interests are probably going to receive some partial satisfaction but no one interest is going to be completely satisfied. That means, in terms of what we always think about, California is going to get some of our water but they are not going to get it all. We will maintain some and we will use some and we will probably lose some, as well.

I think that the research efforts that the Water Center is currently involved in, so far as environmental kinds of things, will lead to a better understanding, at least on our part of what the needs of the streams of the State are. I appreciate the points of view expressed by the gentleman that spoke about the catchment issue, those sorts of things. I think that there is probably a need for even a workshop to discuss and educate all of us to what the issue of an instream flow is. Maybe Dr. Brocksen would want to take that on since he is an impartial observer. My impartiality is probably questionable on that issue. That is pretty much how I see the workshop from a very limited point of view. Thanks.

Bob Brocksen:

I would like to expand very briefly on a point that Bob made. I have said this over the last couple of years, but I want to reemphasize the fact that the Water Center at the University of Wyoming is an objective set of people and researchers. Our job is to generate information and hopefully that information will be of value in decision making, but we are not advocates and we do not address policy issues. We simply generate information that should be germain to those issues.

SUMMARY REMARKS

Larry Bourret

I guess our role is to tell you if we have changed our minds any. There were a number of good presentations and I only missed a few. I don't think my mind was changed very much.

I think I will ask Quentin Skinner to come to our annual meeting to make the presentation on Range Management's wildland watershed research effort because the agriculture people will be very interested in that one. I do notice though that Quentin finished up his presentation by saying that they needed to know more about cost and returns. We are going to be very interested in that, Quentin. Right now, as Representative Roncalio said, the bankers aren't loaning us much money, so anything that you force us to do, has to show a positive cash flow or we won't be able to to it.

The information on the Salt River, I think, indicates that when we make those kinds of changes, we also need to recognize the changes that are going to take place downstream. I saw a presentation about a year ago on damage downstream from the increased flows during the high flow part of the year and now I have seen the other part. What we have done, I guess, is gone out and made changes upstream and now we have the SCS downstream trying to solve the problem we created with the upstream effort. I think that is just an example of the complexity of water. The more I learn about water the more I find I need to learn. It gets very, very complex.

On the presentations on water development by Warren Morton and Grant Parker, I didn't change my mind a bit. Not a single bit. I think that yesterday, when I was up here talking, I said that we had a lot of water in some years as high flow years and on an average year we still had quite a bit of water. In low flow years we did not have much. I also said that at different seasons of the year we had a lot, and other seasons we didn't. When I was sitting here listening to those two presentations I thought about another approach to this. That is, it is not only the time, meaning the year and season, it is the place. We have all that water in Boysen, Fontenelle and Lake DeSmit and these other places and if it was where it was needed, it would have been used already, I think. So we also have the problem of the place. If you take a look at some of the better lands of Wyoming, you find some of the better lands in Wyoming are down in this country, but there isn't much water down here. That is why we are pumping those wells over at Pine Bluffs. I guess I would have to agree with Representative Roncalio's point on underground pumping; I think that there is no way in the world we are going to do anything but get into trouble with that. He said 40 years, I don't believe it will be that long. I think that we need to ask ourselves what we are doing there. That then puts more pressure on the development of our surface water. And I think we need to take a good hard look at those two situations. I was the county agent in Laramie County when they first started having drawdown problems over there and they are extending the underground water control area more every five years, which means the problem is just getting bigger and it is going to continue to get bigger and bigger. More wells are being drilled outside the area. That is going to influence the area that is in the control area, if that water is going in that direction, and it sure is. It's going west to east.

Another thing that I think affects the water development issue is this that the law of gravity still is in effect and that water is going to flow out of here. If we have a mountain range in between the need and the flow, we are going to have to solve that problem by reversing the law of gravity through some kind of a project. I did say yesterday that we need to plan, and I still feel that way. We need to find out what we have and what the needs are as close as we can. But as far as waiting until the demand is here, that is the same thing I said yesterday on Interstate 80.

Now I want to go back to the final speaker, Representative Roncalio. He didn't change my mind at all. He just reinforced it. I think that we are going to have to continue to look at every possibility we can on storage and also use because it is one thing to store it and another thing to use it. We have to get them both tied together. But I think that instead of backing off, we should be more aggressive because I think we are talking about the "use it or lose it" theory versus the "value of the Compacts." I have people who tell me the Compacts are so valid legally that there is no question. I will tell you what, I have seen a lot of things that have been so valid legally that I was wrong on that I don't buy that story entirely. Courts are going to decide that issue and they are going to do it, not on what we think, they are going to do it on the basis of what is presented in the courts at that time. Regardless of what you think, this is my opinion--the courts are going to count the number of people and the amount that is actually being consumptively used at the time they go to court. That is what is going to decide who ends up with that water and that is my opinion. Maybe that won't be decided for 30 or 40 years, but I think that is the way it is going to be. Now I am not an advocate of the leasing situation, but maybe we should return this and call it "lease it and lose it" or "lose it." Maybe we can't, in the end, put all that water to use. So, in the end, I believe, knowing what I know right now, we might lose it. On the proposition of "lease it and lose it", I think if we ever lease it we will lose it. That is why we need to know what water we have, what our needs are going to be, and pin every bit of it down that we can. Then we need to decide which way we are going to lose the rest of it, because I think that is what is going to happen. Thank you.

SUMMARY REMARKS

Bill Budd

I will be very brief in just summarizing what I tried to say yesterday. Reemphasizing that I don't profess to be an expert in water issues, I have talked to people at the State and in the industry that I represent and some of the others to get the information I have. I don't think that industry is a threat to existing water users in Wyoming, nor do I think they ever will be. I think that agriculture, municipalities, recreation, wildlife, most every need will always have a superior right to industry.

The good thing about that is that, I think, industry has the money, the wherewithal, and will do the planning so that before any industrial plants are developed one of the things known in advance will be that water is there and that they will have the right to that water, or they won't develop the industry. In most instances, the industry can go where the water is. This is not the only place where coal is lying underground or any of the other mineral resources, so industry has some options to go other places. I do not feel that they will be a threat to existing water uses or uses in the future or that will be taking water away from municipalities or agriculture.

I think that industry does have concern, rightfully so, in this State for what might happen to them from a legislative point of view. Without having taken any position whatsoever on whether the coal slurry was a good idea or not, I think the fact that you had a legislature that passed a law and an industry that had a right to expect that law to last for a while, who went out and spent millions of dollars and then you had a legislature in a very few years that came back and started talking repeal of the law, would give all industry cause for concern to know that any future water that they had was in some way protected from that kind of action. I think that about summarizes what I have to say about the industry. Thank you.

SUMMARY REMARKS

Herman Noe

Well I won't keep you long because Larry Bourret said everything that I would have to say. I would just be repeating it. I just remind you that as we have heard here earlier, that water is life and it is prosperity and that I think we'd best use it wisely and develop it wisely if we're going to have it for our future. Thank you.

CONCLUSION

Robert W. Brocksen

This is going to be the conclusion of our Wyoming Water '85 Symposium. I think that we just have to take this next moment to acknowledge the superior job that Steve Mizell, Don Brosz, Vic Hasfurther, Tom Wesche and Pam Murdock have done in putting together a program that is reflective of the complexity of the issues that surround water but also in putting together a program that was really able to point out that most of us are talking the same kind of turkey here, and that we do want to do some positive things, and positive things are being done.

That concludes the Symposium. I wish you all safe travel. Please stay in touch with us in the future.

APPENDIX I.
FUNDING
WATER RESEARCH

CHALLENGES, OPPORTUNITIES AND REALITIES OF SECURING FINANCIAL SUPPORT FOR WATER RESEARCH

Robert Jenkins
Office of Research
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INTRODUCTION

It is a pleasure for me to be here and to participate in Wyoming Water '85. I saw the Water Center come into being, and it is a pleasure to see the progress it makes yearly. I believe that it begins to fill the expectations than many in State Government, the University, the Wyoming Legislature and the public sector had held for it. The measure of success it achieves is a tribute to the efforts of a host of individuals. Many of the key players are here with us tonight and the direct and indirect support the Center has received is appreciated on many fronts.

Thirty years ago today I was flood irrigating. Before you conclude that I have a fantastic recall, I should explain that I know I was irrigating because I was always irrigating. We irrigated something from May to October. In the Cache Valley of northern Utah we flood irrigated 60 acres of alfalfa, 30 acres of sugar beets, 20 acres of field and sweet corn, 20-30 acres of peas, 100 acres of grains and pasture whenever we could. We were at the end of the west Cashe Canal that started above Preston, Idaho, approximately 30 miles away. I learned very early about the divinity of water masters and the frailty of human honesty when a stream of water was involved. I remember the dreaded ditching--which I think drove me from the farm, and trying to irrigate where we had too much fall and where we had to push water to every dry knoll, dragging canvas dams around in the dark and wearing boots most of the day. You see before you an irrigator in exile--by the way, we never said irrigation, we simply watered everything. So much for nostalgia. I should turn to my assigned task which is to visit the matter of funding water research.

Let me begin our brief look at the matter of support for water research by scoping the problem just a little. The national renewable supply of water is about 1,400 billion gallons/day for the conterminous 48 states. Approximately 380 billion gallons/day, about 30 percent, of freshwater is withdrawn for use by the Nation's homes, farms and industries, and about 280 billion gallons/day is returned to streams (75 percent of that utilized), usually carrying with it large amounts of wastes that must be attended to. We should remember that freshwater withdrawals for all uses doubled between 1950 and 1980 and that the next doubling could take only until 1995. As a nation, our fresh water supply is abundant; we use only 30 percent of the available supply and consumptive use accounts for less than 10 percent of that available. But every locality, large or small, ranch or metropolis, has water problems of some sort. The ability to solve these problems is a function of the governmental ability to develop and manage water in the face of changing demands. Development and management bring us abruptly to the matter of research. Our ability to develop and manage water effectively depends upon the quality, breadth and depth of our knowledge on an enormous range of water parameters.

I would maintain that our knowledge is simply inadequate to guarantee optimum water development/management scenarios. We do not know enough about (1) the short-term and long-term vulnerability of surface-supplies and shallow ground-water supplies to drought; (2) the reliability of quality supplies as competitors and multiple-use increases; (3) the actuality of ground-water supply changes; (4) the control of surface water pollution, especially nonpoint sources of pollution; (5) contamination of ground-water supplies and the mitigation of existing sources of pollution, such as waste sites; (6) the full effects of acidic precipitation; (7) chronic problems of flooding; (8) the impacts of continued resource impacts of continued resource development (EOR, mining, low-head hydropower) on water resources; and (9) the development of refinements in laws concerning water allocation and reallocation procedures. Certainly there are other holes in our information base, but these examples describe a pretty healthy research agenda. I think that everyone who understands "water" agrees with the need for research, but like the 5 blind men of Hinustan and the elephant, the perception of the problem depends on where you are, what you do and what Mother Nature does, usually and unusually.

The generally acknowledged need is our opportunity, shaping the agenda is our challenge and recognizing the relationship between the opportunity (need), the description of the agenda and the source of the funding is our reality. And so there you are, the challenge, opportunity and reality of water research funding--what a nice place to stop! But I can't resist the temptation to be more responsible. Wyoming is our appropriate focus, and I would like to move to further acquittal of my responsibility by dealing with water and Wyoming.

Perhaps the overriding water issue in Wyoming is best viewed as the fundamental water/development choice. Should water policy be shaped by development or should development be shaped by water policy? Or, perhaps, can we have it both ways? Most indications are that we believe we can perform an interesting sleight-of-hand and preserve the pristine and pleasant while proceeding to develop the State's economy. Hopefully, such an effort will be realized. It is clear that population will continue to shift to arid and semiarid regions of the country, including Wyoming. Attendant to the addition of people are enhanced water needs for municipal, industrial and recreational purposes.

Certainly the competition for water will only intensify, leading to conflicts over allocations and complicated negotiations for scarce supplies. With a finite ground and surface water resource, reuse and recycling will become more and more necessary, exacerbating the effects of man's disturbances of the natural water cycle and the quality of water. At the same time, the increased volume and variety of wastes generated by increased industrialization of our state will certainly effect the useability of the water supply in some areas and could even preclude recycling in others.

The State probably has within its boundaries and within the confines of compacts and decrees sufficient water for all reasonable, foreseeable needs, although the distribution in space and time will always present problems. Such an assumption is based on the expectations that the water resource continues to be renewable/reuseable and that there are perhaps improvements of real significance possible in the reallocation process and even the relocation process.

It is clear that the State must call on all prudence in addressing water resource problems and that it must not rely on a single technology or developmental scenario. Experiences gained on many fronts over the last 50 years have shown that relying on a single technology or institutional device can be counterproductive. Massive attacks on what appeared to be obvious problems have been launched and vast sums of money expended, only to learn that the wrong approach was taken. For example, the U.S. has spent more than $15 billion on flood control in the last 50 years, but average annual flood damage expressed in constant dollars is continuing to increase. Dams, levees and channels were not the answer; it has become clear that a comprehensive program in land-use planning was required as well.

Similarly, the Nation's fragmented, single focus approach to environmental problems has legislated independent attacks on air and water pollution without proper consideration of how such approaches might effect the land, or more important from the viewpoint of water resources, how well they will affect the quality of ground water reserves. For example, prohibition of the disposal of wastes by burning or in water has led to disposal on land with concomitant buildup of pollutants in the soil. Because of the slow movement of contaminants in underground water, rates typically measured in cm or meters per year, the full effects of some of the control policies that have been set may not be felt for decades or even centuries. Contaminants entering the ground water system are flushed out slowly, if at all; remediation may be both technically and economically impossible. Once contaminated, ground water may remain contaminated for tens, hundreds, or even thousands of years; and its use as potable water may be precluded for all practical purposes. As we pour money on troubled water--we must be ever aware that we do so at the risk of creating new, subtle and untractable problems.

Most of us agree that it is not only the length (quantity of life) that is important, but also the quality of life; in fact, humans usually choose quality over quantity. In a generally arid state like Wyoming, the quality of life is inextricably tied to the water resource. As I am sure you have detected, I believe that there are not two principal problems in water resources--quantity and quality. Quantity is totally linked to quality, although there may be an exception or two, such as when water is used as a vehicle. We are reminded of the ancient mariner, "water, water everywhere..." none of us would accept such a fate for Wyoming. A most notable example of problems resulting in extraordinary recycling-reuse concerns the Kansas community of Chanute on the Neso River. In 1956, the Neso ran dry and so the City dammed the River below the sewage outfall and backed the flow up to the water intake. For five months the community recycled its sewage a dozen times. An unusual example, but variations on this event are likely to be more common in the future. Protection of water quality must be among our highest water resource priorities.

The problems of water quality affect not only human health but also the health of the water systems that support a wide variety of plant and animal life that inhabits lakes, reservoirs, rivers and creeks. It is in these bodies of water that changes in quality are most evident. The reality of the problem is dramatically demonstrated by the sterile lakes and streams of northern New York State.

Essentially every water use is dependent upon quality. Obviously wildlife, recreation, and human health are impacted early and sometimes subtly, and other uses are not immune. Developments in our state add threats to water quality. Acid rain has spread rapidly across the United States. By the early 1970s, acid rain had intensified in the 12 northeastern states and extended westward to effect all of eastern North America except for the southern tip of Florida and northern areas of Canada. In the western U.S., acid rain has come to the mountain areas of the Continental Divide. More people, more combustion will certainly increase the problem. The fact that some acidity has natural sources and perhaps even sources in the mideast does not excuse us from addressing the problem in every conceivable way. That rain has an inherent acidity and that the world may have seen cycles of atmospheric acidity with consequent ecological calamities is of very little comfort to me, especially when we have the ability to nullify further increases in acidity--as we do.

Intensified agriculture increases nutrient, dissolved solids, and toxic loads of water in the State. Eutrophication, salination, and toxicity are phenomena related to agricultural technologies that represent consequences of agriculture's struggle to make ends meet. Nevertheless, we must avoid the temptation to point fingers and deal cooperatively with the full range of problems.

We really have not faced the problems associated with people-places, our developing urban areas. The contributions of urban development to contamination in storm water runoff can be appreciated from the units of measurement that are often used to identify this pollution: pounds of pollution per curb mile of street or per square mile of development. Sediments and associated toxic materials, biodegradable organic material, nutrients, oils and greases, asbestos and heavy metals are identified in runoff water. Dustfalls on major cities amount to hundreds of tons/square mile/year which, in storm sewer runoff, can translate to hundreds of mgs/liter. The increases in the concentrations of heavy metals in streams draining from urban areas is as much as 10 times above normal background levels. The year 2000 may see three times the population of the 60s-70s. Because of Wyoming's sporadic precipitation patterns and concentrated water resource, the contamination from urban areas may be greatly exaggerated.

Clearly our knowing is way ahead of our doing in many areas. In many cases we must bite the bullet and deal with priorities. In some cases we simply don't know enough to intelligently establish priorities. There is a real need for multidisciplinary research. Wyoming has organized an interdisciplinary center to deal with water problems. Hopefully, the Wyoming Water Research Center will accomplish well-planned research designed to preserve the Wyoming water resource. The Wyoming Water Research Center was instituted as a means to develop a base of information, through a broad spectrum of research, wherein decision makers would find data pertinent to the examination of water issues and the advice necessary for all interested entities to develop a comprehensive and dynamic water policy for the State.

As a body of researchers and policy makers interested in Wyoming's water future, we have recognized the need to know more about water, evidence the WWRC. We all recognize that this need for information has provided the opportunity through the Water Center, through other projects with state agencies and the federal government, to do research. Our challenges are three: to maintain our equilibrium in the research we propose so that we continually build the first principles knowledge base necessary for applied research--we must say this over and over; the research community, in particular the University, must maintain its integrity as an independent source of critical inquiry, immune from vested interest, expedience and political whims; and, finally, the research community must find better ways of bringing industry, government and citizens groups together as supporters of research. We do not have an easy task, but the future of Wyoming will certainly depend upon the preservation, development and management of the great water resource present here today. And none of these foregoing activities will succeed optimally without sound and comprehensive research. We have an enormous challenge but one that will be met if we discard our sacred territories and work together for the future of the State.

Let me finish by providing an interesting insight on the geneology of water. The total quantity of water on earth is about 1.5×10^{21} quarts. Each 1.5 quarts contains about $50{,}000 \times 20^{21}$ molecules. In the course of two thousand years the oceans of all surface waters have become well-mixed. Any quart of water today, therefore, contains about 50,000 molecules from any given quart of water at the time of Julius Caesar. About 30,000 liters of water passed through the Great Caesar in his lifetime.

So to paraphrase Hamlet:

> Imperious Caesar dead and turned to clay
> Might stop a hole to keep the wind away.
> Of Caesar water, molecules in the sink;
> A many million dwell in your every drink.

Thank you again for the opportunity to share thoughts on water issues facing the State and to discuss briefly the relationships between those issues, the public interest and a fundable research agenda.

APPENDIX II.
SYMPOSIUM
PROGRAM

WYOMING WATER '85

A Symposium on Water Resource Problems and Research in Wyoming

Agriculture Auditorium
University of Wyoming

THURSDAY, May 2, 1985

Session 1: INTRODUCTION
Victor Hasfurther, Chairperson

8:30 Welcome to the University of Wyoming
Donald Veal, President, University of Wyoming

8:40 Introduction to WYOMING WATER '85
Robert Brocksen, Director, Wyoming Water Research Center

Session 2: WATER ISSUES AND PROBLEMS
Donald Brosz, Chairperson

8:50 The Industrial Viewpoint
Bill Budd - Wyoming Mining Association

9:10 The Municipal Viewpoint
Herman Noe - Cheyenne Board of Public Utilities

9:30 The Agricultural Viewpoint
Larry Bourret - Wyoming Farm Bureau Federation

9:50 The Environmental Viewpoint
Bob Wiley - Wyoming Game and Fish Department

10:10 Break

Session 3: WATER ECONOMICS
Paul Schwieger, Chairperson

10:30 USDA Water Information Management for Economic Research
John Green - U.S. Department of Agriculture

10:50 Water Conservation: Relief for the Taxpayers
Frank Odasz - Consulting Chemical Engineer
Larry Harms - Casper Parks and Recreation Department

11:10 An Analysis of Alternative Management Strategies for Irrigators Facing Rising Electrical Rates and Declining Groundwater Tables
Jim Jacobs and Jeanette Oster - Dept. of Agricultural Economics, University of Wyoming
Roger Mann - Colorado State University

11:30 Lunch - on your own

Session 4: WATER MANAGEMENT
George Christopulos, Chairperson

1:00 Snowpack Estimates from Satellite Imagery and Relationship to Spring Melt Patterns
Ronald Marrs - Dept. Geology & Geophysics, Univ. Wyo.

1:20 Range Management's Wildland Watershed Research Effort
Quentin Skinner - Dept. Range Management, Univ. Wyo.

1:40 Effects of Increased Irrigation Efficiences on Salt River Streamflow
Steve Sando and Donald Brosz - Dept. of Agricultural Engineering, University of Wyoming
John Borrelli, Agricultural Engineering, Texas Tech Univ.

Session 5: WATER LAW
Victoria Huntoon, Chairperson

2:00 Wyoming Groundwater Quality Laws as Applied to Longstanding Pollution Sources
Larry Wolfe - Wyoming State Attorney General's Office

2:20 Preventive Law for Water Developers and Owners: Representing the Owner During Pre-Construction Phase
Raymond Hunkins - Jones, Jones, Vines & Hunkins, Inc.

2:40 Water Right Administration in Wyoming
George Christopulos - Wyoming State Engineer

3:00 Break

Session 6: WATER DEVELOPMENT
Michael Purcell, Chairperson

3:20 Wyoming Oil and Water
Warren Morton

3:40 Water Development: Water Use and Conservation
Grant Parker - Powder River Basin Resource Council

4:00 Augmentation of Casper's Municipal Water Supply Through Control of Irrigation Canal Losses
Kathleen Flaccus and Leslie K. Horsch - Casper Alcova Irrigation District

Session 7: WATER QUALITY
Harold Bergman, Chairperson

4:20 Acid Deposition Studies in the Wind River Mountains
Alan Galbraith - U.S. Forest Service

4:40 Geochemistry of Postmining Ground Water at the Cordero Coal Mine, Northeastern Wyoming
Dave Naftz - U.S. Geological Survey

5:00 Adjourn

BANQUET SESSION:

6:00 No-host Cocktail Hour
7:00 Dinner
8:00 Challenges, Opportunities and Realities of Securing Water Research Support
Robert Jenkins - Office of Research, Univ. Wyo.

FRIDAY, May 3, 1985

Session 7 (Continued): WATER QUALITY

8:30 Changes in Bacterial Water Quality in the Nash Fork Hydrologic Watershed After 10 Years
Michael Hussey, Quentin Skinner and John Adams - Dept. of Range Management, University of Wyoming

Session 8: GROUND WATER
Steve Mizell, Chairperson

8:50 Modeling Contaminant Flows in Unsaturated Soils
Myron Allen and Carolyn Murphy - Dept. of Mathematics, University of Wyoming

9:10 An Example of Solute Transport in Low Permeability Aquifers -- Abandoned Oil-Shale Retort near Rock Springs, Wyoming
Kent Glover - U.S. Geological Survey

9:30 Snow Fence Fetch Influence on Soil Properties
W. R. Pope and Steve Williams - Dept. of Plant Science, University of Wyoming

9:50 Break

Session 9: FEDERAL ROLE
Robert Brocksen, Chairperson

10:00 Federal-State Relationships in Water Development Projects
Teno Roncalio

Session 10: SUMMARY

10:30 Panel Dicussion

12:00 Adjourn

APPENDIX III.
ATTENDEES LIST

WYOMING WATER '85
A SYMPOSIUM ON WATER RESOURCE PROBLEMS AND RESEARCH IN WYOMING
COLLEGE OF AGRICULTURE, UNIVERSITY OF WYOMING, LARAMIE, WYOMING
MAY 2-3, 1985

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