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Wyoming Water Resources Center
University of Wyoming
Laramie, WY 82071

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ABSTRACT

Three research projects were funded under the FY94 program, as well as information transfer activities. These three research projects relate to important water issues in the State of Wyoming and the region.

Modeling of Groundwater Transport and Biofilm Growth in Porous Media. This project will produce information on the behaviour of biofilms in porous media. This knowledge can then be used to design strategies for their use in preventing contamination of aquifers and also to clean them. This information will also be useful to the petroleum industry in enhanced oil recovery projects. In this project, numerical methods are used to simulate the interaction of water flow and biofilm growth and transport in a porous medium. The modeling of water flow is based on Darcy's law. The transport and dispersion equations model the movement of dissolved or suspended substances --- such as nutrients and microbes --- in the water. A local biofilm growth model that considers several types of bacteria and nutrients will be implemented. It is based on Monod kinetics together with attachment and detachment. The output of the biofilm growth model yields the size of the biofilm at the microscale, which can be used to compute changes in macroscale porosity and permeability via scale-up techniques. This information can then be used to determine the feasibility of using biofilms to act as local plugs and/or biodegrade contaminants.

Critical Groundwater Hydroperiods for Maintaining Riparian Plant Species. Today's water management reform efforts are using riparian wetland health as a central theme for promoting a change in the way water resources and rangelands are used and managed in the West.

These efforts require specific information to help predict how altered hydoperiods might affect riparian ecosystems. Resource managers also require this information to design hydroperiods for constructed and restored riparian wetlands. This study was designed to help address this immediate need for critical groundwater hydroperiods by comparing controlled experiments to field data from montane meadows in Southeastern Wyoming. These field data suggest that Nebraska sedge (Carex nebrascensis), tufted hairgrass (Deschampsia cespitosa) and Kentucky bluegrass (Poa pratensis) have different optimum hydroperiods. The overall objective of this study was to provide factual and reliable information on the critical plant tolerance of these three riparian species to the rate of water-level decline and the maximum water table depth by using simulated groundwater hydroperiods. Specific research objectives were to: 1) Evaluate the response of three important, but morphologically dissimilar, riparian plant species to specific groundwater hydroperiods designed to simulate dewatering of riparian zones, 2) Continue to describe the seasonal dynamics of surface water stage and groundwater elevation in subalpine and montane riparian wetlands, and 3) Compare depth to groundwater duration curves developed from periodic measurements with curves developed from continuous data.

River Bed Modification and Sediment Transport by Anchor Ice Events in Wyoming Rivers. Maintenance of river conditions and instream flows (or environmental flows) must be balanced against heavy demands for offstream water usage. There is a general understanding of

the instream flow requirements needed to assure the maintenance of fish and wildlife habitats. Minimum instream flows are needed to supply sufficient sediment transport to scour encroaching vegetation and to remove fine materials from the stream bed. However, recent observations that have beenmade on the Big Laramie River have shown that a heretofore largely ignored process may be very important in Wyoming rivers. High sediment transport rates resulting from daily detachment of anchor ice from the stream bed have been observed. Anchor ice is an accumulation of ice on the bed of a stream, under the flowing water. Wyoming has an ideal climate for extensive and repeated anchor ice formation. Clasts ranging from cobbles down to silts and clays have been observed in transport, with concomitant modification of the stream bed, both at the site of erosion and at the downstream site of deposition. Sediment transport by anchor ice has received little but anecdotal attention in the literature. Although this phenomenon is virtually unstudied, preliminary observations indicate that it has the potential to be a major modifier of the beds of Wyoming rivers.

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WATER PROBLEMS AND ISSUES OF WYOMING

Wyoming's development and economy have been focused around its abundance of natural resources. Beneath the land surface lie such mineral resources as coal, oil and gas, uranium, oil shale, trona, gypsum, and iron ore. Their abundance has enabled Wyoming to become a national leader in mineral and energy production. Vast areas of range and pastureland interspersed with fertile, irrigable stream valleys have also enabled the agricultural and livestock industry to become important components of the State's economy. The recreation and tourism industry thrives in Wyoming as visitors come to share its wealth of scenic beauty.

Wyoming is a net-water producing state to the Colorado River Basin, the Snake River Basin, the Great Basin, and the Missouri River Basin. Precipitation averages 14 inches per year, ranking Wyoming 48th in the nation, and ranges from 7 inches to about 40 inches. Approximately 15.5 million acre-feet of water are produced from snowfall and rain in Wyoming each year, and an additional 1.5-2.0 million acre feet flow into headwater streams from adjacent states. Approximately 12 million of this 17.0 million acre-feet are obligated for downstream use through compacts and decrees. Consumptive use of surface water in Wyoming is estimated at 2.8 million acre-feet per year. Over 93 percent of this use is by irrigated agriculture.

Water is a key resource controlling the development of each of the facets of Wyoming's economy. As the saying goes, "in Wyoming, water is life." The rancher or farmer could not survive our semi-arid climate without water for livestock and irrigation. Evapotranspiration exceeds rainfall in all of the state except the high mountain ranges. Without our streams, lakes and reservoirs, the quality of the recreationists' experiences would be diminished. The mineral industry will continue to provide a major share of the State's economy having both a need for water and potential impacts on its quality. Adequate supplies of good quality water must be available for our cities and towns to continue to grow. Wyoming has a state supported water development program with the intended purpose of capturing for its use as much of the excess water produced as possible, as well as improving and creating new water delivery systems within the state. Wyoming also has recognized instream flow rights for fisheries purposes.

Water quality, availability, and allocation for future agricultural, mineral extraction, industrial, recreational, and municipal purposes continue to be the center of water related problems in Wyoming. The future management of Wyoming's water resources, in compliance with existing interstate water compacts and decrees and water quality regulations, is a challenge in planning and implementation. After available surface and groundwater supplies are utilized, their equitable distribution, conservation, and maintenance of quality become important legal and complex social issues. The problems associated with the capture, diversion, dispersal, and re-use of these water resources are encompassing. In addition, being better able to forecast quantity and quality of water availability to downstream users is extremely important.

Groundwater is also a vital water source in Wyoming. The estimated annual recharge to groundwater aquifers is between 3-4 million acre-feet. Important aquifers include the Ogallala and Madison formations. Over 60 percent of the state's drinking water supplies come from groundwater and an estimated 0.5 million acre feet are pumped annually for irrigation. Potential groundwater quality impacts due to agricultural chemical use is a concern in many of the state's shallow alluvial aquifers. Oil and gas production and mineral extraction also have potential impacts on the quality of both ground and surface waters.

PROGRAM GOALS AND PRIORITIES

The Wyoming Water Resources Center (WWRC) is a program which integrates water resources research activities among numerous colleges and departments across the University. The WWRC was created in 1982 in a joint effort involving the University, the Wyoming legislature, and the Governor's office. Previously, the WWRC existed as the Water Resources Research Institute (WRRI).

The WRRI was originally established by the University of Wyoming Board of Trustees through actions taken in November 1964 and January 1965. In April 1965, the WRRI (and the University) began participation in the federal water research program administered by the U.S. Department of the Interior by agreeing to "accept and comply with such provisions as may be determined by the Secretary pursuant to Section 303 of the Water Research Act of 1964 (P.L. 88-379)." This legislation has been reauthorized by Congress about every five years and the WWRC still participates in this program as a part of its overall scope of activities.

The WWRC has a charter which provides for the principles of its operation and structure. Its purpose is to both sponsor and conduct multidisciplinary research related to the management and preservation of Wyoming's water resources. The WWRC was established to operate in a firm partnership with state agencies charged with major responsibilities for water resources and to serve as a point of focus and coordination for water research efforts at UW and with related programs carried on by other universities and state and federal agencies.

The WWRC structure includes a Director responsible for program development and implementation who reports to the Vice-President for Research. The Director also serves as Executive Secretary to the WWRC Research Review and Priorities Committee (RRPC) which is appointed by the University President and the Governor. The RRPC is comprised of state legislators, state agency representatives, university faculty and members from the public. The WWRC consists of faculty members jointly appointed between the Center and various academic departments as well as research specialists who, along with joint faculty, work in conjunction with cooperating faculty at UW and other institutions. Although the primary mission of the WWRC is research and service, the Center also participates actively in extension and information transfer activities as well as joint graduate degree programs with several departments on campus.

Beginning with the inception of the WWRC, the University received a line item in its biennial budget from the legislature which provided the principal support for the Center. The "base" budget for the WWRC is completed by the receipt of approximately $100k annually from the federal WRRI program. This base funding has provided an infrastructure for the WWRC enabling it to compete effectively for additional external research funding. Although the line item funds received by UW previously came from the state general fund, beginning in FY 89-90, and continuing to FY 95-96, those funds have been allocated from one of the state's water development accounts. The WWRC also receives an annual contract through the Wyoming Water Development Office to operate the Water Resources Data System.

In summary, the Wyoming Water Resources Center provides a focal point for the coordination and conduct of water resources research and education in the State. Direct linkages exist in the Center's structure between state agencies, the University, and citizen groups responsible for, or interested in, water resources. In addition, the Center is involved in numerous regional, national and international activities. The Wyoming Water Resources Center is part of both the Colorado and Missouri river basin regional organizations with other Water Resources Research Institutes. In compliance with the USGS guidelines, and in consultation with state

water officials and the Wyoming Water Resources Center's Research Review and Priorities Committee, state and regional research priorities are addressed. Oversight by the Research Review and Priorities Committee and careful administration of the research program insure the best quality and most cost effective means of obtaining information relevant to Wyoming's water resource management.

Section 104 Objectives

The Wyoming Water Resources Center uses its Section 104 funds in a manner consistent with the distribution of funds in the overall program of the Center. That is to say, 104 funds are not directed toward a particular area of emphasis. The only exception to that generalization is that 104 funds are not used for so-called "state service projects" which tend to be quite applied in nature. The federal grant is an integral part of our research program on water quality issues related to both surface and groundwater impacts resulting from the extractive industries and questions related to hydrologic and economic considerations involving the distribution and consumptive use of surface water.

Research:	54%	Education:	18%
Information Transfer:	14%	Administration:	14%

The following outline of topics represents areas of research for which proposals were solicited in FY 94.

I. WATER QUANTITY
II. WATER QUALITY
III. INSTITUTIONAL WATER PROBLEMS
IV. UTILIZATION AND CONSERVATION OF WATER
V. ENERGY-WATER RELATIONS
VI. ECOLOGICAL/ENVIRONMENTAL RELATIONSHIPS IN WATER RESOURCES

RESEARCH PROJECT SYNOPSES

SYPNOSIS

Project Number: 02

Start: 07/94
End: 06/96

Title: River Bed Modification and Sediment Transport by Anchor Ice Events in Wyoming Rivers

Investigators: Humphrey, Neil F. and Wiley, Michael T.,
University of Wyoming, Laramie

Focus Category: SED

Congressional District: First

Descriptors: ice, suspended sediments, sedimentation, river beds, heat budget, thermodynamics, education, rivers.

Problem and Research Objectives:

Maintenance of river conditions and instream flows (or environmental flows) must be balanced against heavy demands for offstream water usage. We currently have a general understanding of the instream flow requirements needed to assure the maintenance of fish and wildlife habitats. Minimum instream flows are needed to supply sufficient sediment transport to scour encroaching vegetation and to remove fine materials from the stream bed. However, recent observations that we have made on the Big Laramie River have shown that a heretofore largely ignored process may be very important in Wyoming rivers. We have observed high sediment transport rates resulting from daily detachment of anchor ice from the stream bed. Anchor ice is an accumulation of ice on the bed of a stream, under the flowing water. Wyoming has an ideal climate for extensive and repeated anchor ice formation. Clasts ranging from cobbles down to silts and clays have been observed in transport, with concomitant modification of the stream bed, both at the site of erosion and at the downstream site of deposition. Sediment transport by anchor ice has received little but anecdotal attention in the literature. Although this phenomenon is virtually unstudied, we believe from our preliminary observations that it has the potential to be a major modifier of the beds of Wyoming rivers.

Many studies have noted that the formation and subsequent release of anchor ice results in sediment transport. However, no one has ever tried to quantify the ice-induced transport in a fluvial setting. The primary goal of this study is to quantify the amount and size distribution of sediment transported by anchor ice in order to determine the importance of anchor ice as a sediment transport mechanism. In order to accomplish this, we propose to study ice formation along a reach of a single small stream. Five questions will be considered: (1) How often does anchor ice form during freezeup? (2) How much anchor ice forms, or how much of the bottom of a stream is affected by anchor ice? (3) What is the sediment concentration in released anchor ice? (4) What is the size distribution of sediment incorporated into anchor ice? (5) How far is sediment transported once the

anchor ice is released from the bottom? By answering these five questions, we will be able to estimate the amount of anchor-ice induced sediment transport. Once such an estimate is made, it will be compared to estimates of sediment transport under ice-free conditions to determine if anchor ice accounts for a significant portion of the total sediment transport in the river.

The size distribution of the transported and redeposited sediment will be observed to allow an assessment of the modification of bed surface conditions by anchor ice events. It should be noted that even if anchor ice transport turns out to be of secondary importance in terms of total sediment transport, it may still be an important process in bed modification since it redistributes sediment in a manner unrelated to flow competence.

A secondary goal of the study will be to determine the meteorological conditions that lead to the formation of anchor ice.

Methodology:

Data collected and observations made during the winter 1994-95 field season are described below in the section on Principal Findings and Significance. Some preliminary processing and interpretation of this information has already been done, but much work remains. Sieve analysis of the sediment recovered from anchor ice samples will be carried out at the Surficial Processes Laboratory (Dept. of Geology and Geophysics) at the University of Wyoming. Temperature logs acquired will be correlated with other climate logs and field notes in an effort to better understand the conditions necessary for anchor ice formation.

A critical part of the study is to measure flow, discharge and sediment flux in the Big Laramie River during ice-free conditions. This information will be used to make an assessment of the relative importance of anchor-ice sediment transport. Observations made during the past 2 winters lead us to the conclusion that the frequency and extent of anchor ice formation vary dramatically from year to year. Consequently, we feel it is very important to make additional winter observations of anchor ice sediment transport as well.

To date, we have not attempted to measure distance of transport by anchor ice. During the 1995-96 field season, we will attempt to do this by tracking pebbles with attached radio transmitters. This radio tracking technology has been developed by a graduate student (Diane Brien) working on a different project on the North Platte River. The equipment is in-hand, although additional transmitters may be needed as replacements.

Principal Findings and Significance:

Field work for this project began in mid-October of 1994 with regular observations of two reaches of the Big Laramie River. Reach 1 is located on the west side of Laramie, WY, from approximately 800 m upstream of the Garfield Street bridge to about 200 m downstream of the same bridge. Reach 2 is located 3 miles west of Laramie off State Highway 230 at the Monolith Ranch public fishing access site. Here, a river length of about 500 m adjacent to the parking lot was monitored.

In late October, air and water temperature monitoring stations were established at both sites. Hobo

data loggers were used for this purpose, with resolutions of 0.16°° C (water) and 0.26° C (air). Rare and volumetrically small occurrences of anchor ice were observed at this time. Regular formation of significant amounts of anchor ice began in mid to late November. Typically, anchor ice was observed to form in 2 different settings: at the downstream ends of rapidly flowing stretches of open water, and in areas of shallow rapids.

In addition to continuous temperature logging and the recording of qualitative observations, the following work has been done:

1) A stream profile was measured 70 m downstream from the Garfield Street bridge.
2) Sketch maps of surface ice cover and anchor ice occurrence were drawn (selected days only).
3) Estimates of average anchor ice thickness were recorded.
4) Anchor ice samples were taken, both floating and grounded.
5) Sediment concentration was determined for samples collected.
6) Estimates of volume of anchor ice/unit time floating downstream past a fixed point were made.
7) Water level of the river was recorded (most days).

From analysis of data collected during the 1994-95 winter field season, we can calculate that an average of 110 kg of sediment were carried past our observation point by released anchor ice following a typical night of anchor-ice formation. This value must be considered a minimum, because it does not include anchor ice floating by unobserved (such as high density masses moving by beneath the water surface and out of sight, or masses floating by beneath surface ice cover along the stream banks). Even this minimum value, however, is comparable to the bed load carried by other streams of similar size in Wyoming during normal summer flow (Wesche, 1991). The average sediment contraction in 30 anchor ice samples collected was determined to be .022 g sediment/ml ice.

The amount of sediment transported by anchor ice in a given winter is obviously a function of the number of days on which anchor ice forms. Observations made of the Big Laramie River during November 1993 showed that anchor ice formed on 10 of 14 nights before a solid ice cover formed and remained for the rest of the winter. In contrast, warm weather that characterized the winter of 1994-95 prevented formation of a solid ice cover. Consequently, significant formation of anchor ice occurred on 44 of 78 nights between Nov. 27,1994 and Feb. 12, 1995. Examination of temperature logs for this period of time shows a strong correlation between daily low temperature and formation of anchor ice, regardless of other obvious meteorological conditions (such as cloud cover or wind). The critical temperature for substantial anchor ice formation seems to be about -5° C. These observations should prove useful in calculating a reasonable range and an average value for seasonal sediment transport.

Another purpose of this study is to gain a better understanding of the processes involved in anchor ice formation and the concomitant sediment entrainment/transport. Some key observations worthy of reporting here are:

1) Sediment was commonly observed to be uniformly distributed throughout anchor ice masses, indicating continuous sediment inclusion during ice formation.
2) Released anchor ice will often float downstream only as far as the next frozen stretch of river, where it may accumulate and freeze when the temperature drops again. Other masses may float

along beneath surface ice for some distance before stopping and freezing in place beneath the surface ice cover. These processes can produce surface ice containing substantial quantities of sediment held in storage until a thaw cycle occurs and initiates additional transport.

SYNOPSIS

Project Number: 03

Start: 06/94 (actual)
End: 05/97 (expected)

Title: Modeling of Groundwater Transport and Biofilm Growth in Porous Media

Investigators: Myron Allen, Benito Chen and Renduo Zhang,
University of Wyoming, Laramie

Focus Categories: MOD, GW, ST

Congressional District: First

Descriptors: mathematical models, groundwater modeling, fluid flow, bacteria, groundwater quality, biological control.

Problem and research objectives:

This project will produce information on the behaviour of biofilms in porous media. This knowledge can then be used to design strategies for their use in preventing contamination of aquifers and also to clean them. This information will also be useful to the petroleum industry in enhanced oil recovery projects.

In this project we are using numerical methods to simulate the interaction of water flow and biofilm growth and transport in a porous medium. The modeling of water flow is based on Darcy's law. The transport and dispersion equations model the movement of dissolved or suspended substances --- such as nutrients and microbes --- in the water.

A local biofilm growth model that considers several types of bacteria and nutrients will be implemented. It is based on Monod kinetics together with attachment and detachment.

The output of the biofilm growth model yields the size of the biofilm at the microscale, which we can use to compute changes in macroscale porosity and permeability via scale-up techniques. This information can then be used to determine the feasibility of using biofilms to act as local plugs and/or biodegrade contaminants.

Methodology:

The model that we are using is described by coupled nonlinear partial differential equations involving flow transport of nutrients and microorganisms, pressure, and biofilm growth. Solving these equations numerically involves the treatment of sharp fronts, heterogeneities, physical dispersion, and time-scale effects. All of these difficulties must be handled in a robust and computationally efficient fashion. The algorithm we have implemented is as follows :

(1) From the pressure equation, accurate Darcy velocities and pressure are calculated using a mixed finite element /MFE/ procedure, (2) A finite element modified method of characteristics /FE-MMOC/ is used to treat each of the transport /concentration/ equations. (3) The biofilm growth equations are based on Monod kinetics with attachment and detachment, and may have a transport diffusion part.

The pressure appears in the concentration only through its velocity field, and it is appropriate to choose a numerical method that approximates the velocity directly. MFE method is attractive for modeling flows in porous media since it can yield pressures and velocities having comparable accuracy. In solving the resulting discrete equations, however, poor matrix conditions can arise. To overcome that problem we use a matrix splitting iterative scheme applying the multigrid ideas.

The form of the solute transport equation ranges from parabolic to almost hyperbolic depending on the ratio of advection to dispersion. When advection is the dominant transport process, most numerical procedures exhibit some combination of excessive nonphysical oscillations and excessive numerical diffusion. The FE-MMOC method minimizes those problems by taking time steps in the direction of flow, along the characteristics of the velocity field of the total fluid. The overall advantages of the FE-MMOC method include minimum numerical oscillation or grid orientation problems under steep concentration simulations. Compare to the other transport procedures, large time step can be taken without lose of accuracy or stability. Among other advantages of the FE-MMOC procedure is that the algebraic system is symmetric and positive definite, which is an ideal system for the linear iterative algebraic solver.

In order to be able to determine the effect of biofilm growth on permeability and porosity, we use a percolation model. Percolation theory has developed over the past two decades as a way of dealing with flow through disordered systems. A hypothetical system of interconnected pipes or wires is set up. There are two physical laws governing the system. One is that the sum of the pressure drops around a closed circuit is equal to zero. The other is that the sum of the flows into a node is equal to zero. The conduits are assumed to be cylindrical pipes with radii determined by a lognormal probability distribution. Poiseuille flow is assumed in each conduit, or pipe. That means that for a given pressure head drop across a pipe, the flow rate is proportional to the fourth power of the radius. The pressure drop across the system, from one side to the other, is fixed. Then the pressure head values at each node are solved for using an iterative SOR technique. Then the flow through each conduit is computed, and the flow through the system is determined. The permeability is calculated using Darcy's Law. A method has been devised for modeling solute transport through a grid. Each pipe is divided up into a number of "cells". The concentrations of one or more solutes may be tracked, as a function of time, in each cell. The number of cells in a pipe is chosen as to minimize the amount of numerical diffusion introduced into the system. The radius and volumetric flow rate through a pipe are known. Plug flow of the solute is assumed during one time step. Then complete mixing is assumed in each cell. Complete mixing of all flows into a given node is also assumed. The number of cells in a pipe is chosen so that the product of the volumetric flow rate and the time step are as close as possible to the volume of a cell without exceding the volume of a cell.

Principal findings and significance:

This is a continuing project. To date the main results are: A code for solving the flow and transport of a solute using the mixed finite element method together with the modified method of characteristics, was written in Fortran. The correctness and accuracy of all models was analyzed through a comparison with some analytical solutions. The set of numerical experiments confirm the ability of FE-MMOC procedure to produce good numerical solutions and show good agreement with theoretical convergence results, compared with the other approaches alone. We are in the process of adding the biofilm.

With respect to the percolation model, two types of grids have been investigated in 2-D: A square grid, and a hexagonal, or honeycomb shaped grid. Flow through a grid is directly proportional to the pressure head drop across the grid, and to the number of nodes in a plane perpendicular to the direction of flow. Flow is inversely proportional to the number of nodes in a plane parallel to the direction of flow. Two factors are observed concerning the lognormal distribution of the pipe radii. Flow through the grid is proportional to the fourth power of mean pipe radius. Flow is decreased as the standard deviation of the distribution of pipe radii is increased. A simple cubic grid has been investigated in 3-D. Similar results are observable.

The method described above for the transport problem, tracks the concentrations of nutrients in all of the cells. It also makes it possible to track the concentrations of bacteria in solution, and the amounts of adsorbed bacteria in each cell. That means that after the flow and transport problems are solved, some type of reaction kinetics may be used to determine the growth of bacteria and depletion of nutrients in each cell. The amount of adsorbed bacteria may be determined using some type of isotherm for equilibrium adsorption, or some kind of kinetic relationship for rate controlled adsorption. A death rate for bacteria may also be incorporated.

At the moment we have results that have been tested and verified for the flow and transport parts of the problem. These are the more challenging parts. We still need to incorporate the biofilm and couple everything and this part will be done during the continuation of the project.

This project will help understand the behaviour of biofilms in porous media. This knowledge can then be applied to the control and cleaning of contaminants in aquifers . Biofilms are also useful to the petroleum industry in enhanced oil recovery projects.

SYNOPSIS

Project Number: 04

Start: 07/01/94
End: 06/30/95

Title: Critical Groundwater Hydroperiods for Maintaining Riparian Plant Species

Investigators: Henszey, Robert J. and Skinner, Quentin D., University of Wyoming, Department of Rangeland Ecology and Watershed Management, Laramie

Focus Categories: WL

Congressional District: First

Descriptors: riparian vegetation, wetlands, plant-water relationships, plant stress, surface-groundwater relationships, reclamation, instream flow

Problem and research objectives:

Today's water management reform efforts are using riparian wetland health as a central theme for promoting a change in the way water resources and rangelands are used and managed in the West. These efforts require specific information to help predict how altered hydoperiods might affect riparian ecosystems. Resource managers also require this information to design hydroperiods for constructed and restored riparian wetlands.

Our study was designed to help address this immediate need for critical groundwater hydroperiods by comparing controlled experiments to field data from montane meadows in Southeastern Wyoming. These field data suggest that Nebraska sedge (Carex nebrascensis), tufted hairgrass (Deschampsia cespitosa) and Kentucky bluegrass (Poa pratensis) have different optimum hydroperiods. The overall objective of our study was to provide factual and reliable information on the critical plant tolerance of these three riparian species to the rate of water-level decline and the maximum water table depth by using simulated groundwater hydroperiods. Specific research objectives were to: 1) Evaluate the response of three important, but morphologically dissimilar, riparian plant species to specific groundwater hydroperiods designed to simulate dewatering of riparian zones, 2) Continue to describe the seasonal dynamics of surface water stage and groundwater elevation in subalpine and montane riparian wetlands, and 3) Compare depth to groundwater duration curves developed from periodic measurements with curves developed from continuous data.

Methodology:

Plants were tested in 3x10 cm by 3 m tall columns that were filled with silica sand. This sand allows the water table to be adjusted to a specific level, while minimizing the confounding effects of the capillary fringe and residual moisture above the water table. Plants were then watered by reverse column irrigation with a 50% modified Hoglands solution. A clear plexiglass

front on each column was used to observe and measure root extension during the experiment. Four groundwater decline rates (0, 2, 4, 6 cm · day^{-1}) with an initial level at the surface, and three maximum groundwater depths (1, 2, 3 m) were used to simulate natural hydroperiods, as well as hydroperiods that might be expected from streamflow diversions. The experiment was conducted in a randomized design with a 4x3x3 factorial treatment structure (4 groundwater decline rates, 3 maximum depths, and 3 plant species). The plant response to various hydrologic regimes will be determined by the following attributes: above and below ground biomass, average leaf length, root density, and maximum root depth. These data will also be used to develop depth-to-groundwater suitability curves which will be compared to curves developed from field data.

Principal findings and significance:

The first phase of the study concentrated on building the Tall-Column Plant Growth Facility at the University of Wyoming. This Facility can accommodate 90, 3 m-tall columns at one time. The columns were constructed of a 6 mm black acrylic with a clear acrylic front for the nondestructive observation and measurement of the roots during the experiment. The clear acrylic front is removable so below ground biomass can be measured at the end of the experiment. A removable black-plastic layer covers the front to shield light from the roots. Three, 2.4 m grow lights were constructed for the facility. Each light fixture has 8 very high output (VHO) fluorescent bulbs and 16, 60-watt incandescent bulbs. The grow lights are controlled by four electric circuits with timers that provide four light intensities to simulate the cycle of daylight (dawn, full daylight, dusk). A system was developed to raise and lower the lights to adjust the light intensities to 500-700μ mol·s^{-1}·m^2 on the plants. A 250 gallon tank along was installed to provide the nutrient solution for the plants. The first of three replicates (27 columns) was planted in March 1995, with additional columns planted with the appropriate species as water-tight columns were achieved. All three replicated were in progress by August 1995, and the experiment should be completed by January 1996. Data analysis will be completed by March 1996. Time and space has also allowed us to expand the initial experiment to include a 1 cm · day^{-1} groundwater decline rate.

Preliminary results suggest that Nebraska sedge tolerates a groundwater level between 0 and -48 cm; tufted hairgrass tolerates a groundwater level between 0 and -60 cm; and Kentucky bluegrass tolerates a groundwater level between 0 and -1.5 m. Results from the first of three replicates suggests that both tufted hairgrass and Kentucky bluegrass had the greatest above ground biomass and leaf growth with the water level at the surface. This differs from results observed in the field, but other investigators indicate that competition for light may limit the growth of these plants in sedge dominated communities. In the Tall-Column Plant Facility there is no competition for light, nutrients, or vertical space between the species. A M.S. thesis will be completed by a Todd Yeager, a Rangeland Ecology and Watershed Management graduate student at the University of Wyoming.

INFORMATION TRANSFER ACTIVITIES

June 1, 1994 - May 31, 1995

The Wyoming Water Resources Center uses several networks to inform the people of Wyoming, as well as neighboring states and regions, of what the WWRC is doing in education, research, and interagency cooperation to better manage and protect Wyoming's, and the nation's, water resources. Information transfer activities of the WWRC during the period June 1, 1994 through May 31, 1995 have included: conducting, co-sponsoring and coordinating seminars, workshops and conferences on water resource issues and technological and management issues; the dissemination of water resources research results in technical reports, professional journals and presentations at conferences; coordination and participation in University of Wyoming, federal, and state agency water quality education efforts; and publication of research and education programs, research results and information transfer activities in newsletters and bulletins.

A. WATER RESOURCES SEMINARS, WORKSHOPS AND CONFERENCES:

The Wyoming Water Resources Center conducted, co-sponsored, coordinated, and attended numerous seminars, workshops and conferences to provide and enhance the information transfer of water resources research results, education programs and instructional materials, discussion of state and regional water resource issues, and interagency coordination of water resource programs.

1. **WY-AWRA Summer Symposium**: The WWRC co-sponsored the American Water Resources Association's (AWRA) Annual Summer Symposium in Jackson Hole, Wyoming, on June 26-29, 1994. The title of the conference was "Effects of Human-Induced Changes on Hydrologic Systems." A WWRC Associate Professor gave a presentation and chaired two sessions of the conference. Topics discussed included: climate change, national and state water rights and policy, geomorphology of rivers and streams, precipitation and runoff, and selenium studies. Participation was the largest in the history of the AWRA symposia. More than 400 participants represented academia, government, and the private sector from 45 states and Canada, France, Greece, Mexico, Scotland, and Switzerland.

2. **Wyoming Wetlands Workshops**: The WWRC provided assistance to the Wyoming Riparian Association and the Wyoming Stock Growers Association and to promote wetlands workshops held in Torrington, Wyoming and Riverton, Wyoming during February, 1995. A wide range of topics regarding wetlands were addressed. Organizations making presentations included: WWRC, State Engineer's Office, Wyoming Game and Fish Department, Wyoming Association of Conservation Districts, Wyoming Department of Environmental Quality, Wyoming Riparian Association, and various farmers and landowners.

3. **Wyoming Water Resources Seminar**: The WWRC and the University of Wyoming Cooperative Extension Service, in cooperation with the Converse County Conservation District, sponsored a regional Water Resources Seminar for the public. These seminars are held annually with presentations that address contemporary state and regional water issues. The 1994 Water

Resources Seminar was held in Douglas, Wyoming. Topics discussed included water quality awareness for the North Platte River watershed, non-point source pollution overview, Section 404/Dredge and Fill Permits, pesticides and groundwater, and wetlands banking in Wyoming. Organizations represented at the seminars included the WWRC, Wyoming Department of Environmental Quality, Wyoming Association of Conservation Districts, United States Army Corps of Engineers, Wyoming Water Rural Water Association, and the University of Wyoming.

4. **American Water Resources Association-Wyoming State Section**: The American Water Resources Association, in conjunction with the WWRC, held its seventh annual Wyoming State Section meeting on November 2-3, 1994 at the University of Wyoming in Laramie. This meeting addressed such issues as water quality, ground water, agricultural hydrology, the Powder River Basin cumulative hydrologic impact assessment, the Tie Hack Reservoir permitting process, recreation and aquatic habitat, and mining hydrology. The 1994 winner of the best graduate student paper/presentation was a graduate student in the UW Plant, Soil, and Insect Sciences Department enrolled in the water resources option.

5. **11th Annual World Food Day**: The WWRC co-sponsored the 11th annual World Food Day teleconference and local discussion group on October 14, 1994. The theme for the conference was "Sharing Water: Farms, Cities, and Ecosystems." Local panelists discussed a wide variety of topics including pollution, water policies and compacts, and water management. Panelists that took part in the local discussion included representatives of the UW Department of Zoology and Physiology, UW Department of Political Science, UW College of Law, Wyoming Cooperative Extension Service, Wyoming Department of Agriculture, and the Wyoming State Engineer's Office.

6. **Wyoming Legislative Water Resources and Law Forum**: The WWRC sponsored the Wyoming Legislative Water Resources and Law forum on January 9, 1995. Presenters included representatives of the Wyoming Water Development Office, Wyoming Department of Environmental Quality, Wyoming Game and Fish Department, State Department of Agriculture, and the Wyoming State Engineer's Office. The seminar helps acquaint new legislators with agencies and laws concerning water resources. About 30 state legislators attended the forum.

7. **Wyoming Water Development Association Annual Meeting**: The WWRC Director, Information and Education Coordinator, and two former associate directors attended the Wyoming Water Development Association annual meeting in Casper on October 26-28, 1994. A "Meet the Candidates" forum included candidates Jim Geringer and Craig Thomas. Kathy Karpan spoke by telephone, and most other candidates sent representatives. Topics that were addressed by speakers included federal-state relationships, wellhead protection, North Platte River litigation, federal regulations, Colorado River issues, and other water-related concerns.

8. **Wyoming Association of Conservation Districts Annual Convention**: The Wyoming Association of Conservation Districts held its 49th Annual Convention on November 14-17, 1994 in Riverton, Wyoming. The WWRC Information and Education Coordinator attended the conference and featured the WWRC display board. Some of the topics that were addressed included various roles in range management; local, state, and federal roles in land management; range reform; the Clean Water Act; the Endangered Species Act; the future of Wyoming's state land trust; forestry relationships; and leadership skills.

9. **National Geodata Forum**: The WWRC Geographic Information System (GIS) Coordinator attended the National Geodata Forum on May 7-10, 1995, in Crystal City, Virginia. Sponsored by the Federal geographic Data Committee, the forum centered on integrating federal, state, local, and private efforts in development of the National Spatial Data Infrastructure (NSDI). A main component of the NSDI is the National Geospatial Data Clearinghouse, a distributed electronically connected network of geospatial data producers, managers, and users.

10. **ESRI (ARC/INFO) Users Group**: The WWRC GIS Coordinator and two GIS Research Associates attended the 1995 ESRI (ARC/INFO) Users Group meeting in Palm Springs, California, on May 20-26, 1995. The WWRC presented results of a collaborative mapping project completed last fall with the Office of the Wyoming State Archeologist, as well as a poster map portraying available USFWS National Wetlands Inventory data for Wyoming. Also presented was research related to the Wyoming Gap Analysis Program.

11. **International Conference on the Biochemistry of Trace Elements**: A WWRC senior research scientist and a Plant, Soil, and Insect Sciences/Water Resources graduate student attended the third International Conference on the Biochemistry of Trace Elements in Paris, France on May 15-19, 1995. The graduate student featured a poster display on his research project, In-Situ Immobilization of Contaminants with Calcite.

12. **Workshop on Computer Applications in Water Management**: The WWRC co-sponsored the Workshop on Computer Applications in Water Management in Fort Collins, Colorado on May 23-24, 1995. A WWRC GIS research associate and the WWRC Water Resources Data System (WRDS) Coordinator attended the workshop. In addition to attending both the field scale and watershed scale workshops, WWRC staff also participated in the Watershed scale field-trip to the Northern Colorado Water Conservation District Office and facilities, and presented a poster on Advanced Computer Technologies at the WWRC at the workshop and resource fair.

13. **Greybull School District's Success Through Area Resources (STAR) Laboratories**: The WWRC Information and Education Coordinator, along with a Wyoming Riparian Association (WRA) board member, toured the Greybull School District's Success Through Area Resources (STAR) Laboratories as part of the WRA annual spring meeting on April 21, 1995. As part of a hands-on outdoor learining environment, the School District purchased a 20 acre tract of land to use as a natural classroom lab. From uplands to the riaprian areas along Shell Creek, the lab has tremendous potential as a teaching resource.

B. COOPERATIVE EDUCATION AND RESEARCH EFFORTS:

1. In terms of **Geographic Information Systems** and other advanced computer data processing and visualization systems, the WWRC offers education and training including several short courses in ARC/INFO and ArcView software and other courses which target industry and agency software cliental applications.

2. **Minority High School Student Research Apprentice Program**: During the 1994-1995 school year, the WWRC participated in the Minority High School Student Research Apprentice Program (MHSSRAP). The program provides high school minority students and teachers

throughout the country the opportunity to conduct research work with the University of Wyoming. During the eight-week program, students worked on health-related science research projects with professors from various departments. Besides learning to work on the research projects independently, students also wrote a final paper and gave a presentation to all of the participants. A WWRC senior research scientist sponsored separate research projects with three participants in the program. Respectively, the subjects studied were: developing a method to measure selenium compounds in surface coal mine overburden materials, a preliminary evaluation of the remediation of contaminants in the vadose zone by CO2 injection, and the removal of nitrates from contaminated groundwater in a bench scale reactor. Aside from the research work, all participants toured and learned about UW's various science departments and programs. The primary goal of the program is to encourage minority students to continue their education after graduation and raise their interests in the sciences.

3. **1994-1995 Willard C. and Elaine N. Rhoads Scholarships for Graduate Studies in Water Reources**: Two University of Wyoming students received the Rhoads Scholarship for the 1994-95 school year. The scholarship honor the late Willard C. Rhoads who was a long-time member of the Wyoming Water Development Commission and had served on the Research Review and Priorities Committee for the WWRC. Recipients are selected on the basis of demonstrated academic achievement, recommendations from graduate faculty advisers, enrollment for at least nine hours of credit for two semesters and a written statement of academic and career goals.

4. **Water Institute for Teachers**: The WWRC sponsored the annual Water Institute for Teachers (WIT) at the University of Wyoming on July 5-15, 1994. Coordinators of the institute were the WWRC Information and Education Coordinator and an Associate Research Scientist from the Wyoming Institute for the Development of Teaching. The workshop is held to provide elementary and secondary school teachers an opportunity to learn more about Wyoming's water resources and about water resources concepts and activities that can be incorporated into their classroom instruction. Classroom discussions and activities covered the topics of water management and measurement, water quality and pollution, and stream habitat. Field trips allowed participants to visit the WWRC Snowy Range Observatory where they were taught about climate, instrumentation, and measurements and to tour the Cheyenne water supply reservoirs and associated wastewater treatment plants. A roundtable discussion was held which discussed water resources, law, and policy and included representatives from the State Senate, State Engineer's Office, State Attorney General's Office, Wyoming Water Development Commission, Powder River Basin Resource Council, and Thunder Basin Coal Company. A United States Senator also participated via telephone.

C. INFORMATION TRANSFER PUBLICATIONS

1. **WWRC News Releases**: The following news releases prepared by the University of Wyoming News Service were made available state-wide.

Research Proposals Due at Wyoming Water Resources Center
State Water Resources Meeting in Laramie
Wyoming Water Research Projects Funded for Fiscal 1995
Legislators/Guests Participate in Biennial Legislator's Day at UW

Scholarship Awards Given at Annual Water Resource Meeting
Water Institute for Teachers
WWRC Announces Water Education Poster Contest
UW Students Receive Rhoads Scholarships
Governor Presents Awards to 1994-95 Poster Contest Winners
EPSCoR Project Leads to Product Development

2. **WWRC Research Briefs**: Information briefs on WWRC research are being produced and distributed in Wyoming and nationwide through newsletter mailings and at water resource organization meetings. Two briefs were published in 1994-95:

a) Removal of Nitrate from Ground Water Utilizing A Chemical Reduction Process: A Preliminary Evaluation.

b) Depth-to-Groundwater Relationships for Three Riparian Species/Assemblages in Southeastern Wyoming. RB94-01.

3. **Wyoming Hydrogram**: The Wyoming Hydrogram is a newsletter produced and distributed bi-monthly by the WWRC. The newsletter is sent to over 1,800 individuals and organizations in Wyoming and throughout the United States. Features of the newsletter include contemporary state, regional and national water resources news and issues (e.g. education programs, legislative updates, water data availability, etc); WWRC faculty research activities and research briefs; and notices of upcoming water resources workshops and conferences.

4. **WWRC Fact Sheet**: The WWRC Fact Sheet describing the research, education, information transfer, and state service project activities of the Wyoming Water Resources Center was updated and distributed to individuals desiring information about the WWRC.

5. **Graduate Education in Water Resources**: A brochure describing opportunities in Graduate Education in Water Resources at the University of Wyoming was updated and disseminated to UW departments, students, community colleges, agencies, organizations, and other universities nationwide.

6. **WWRC Public Information and Education Exhibits**

a. Invited exhibit on UW-Wyoming Water Resources Center research, education, and service programs for display at the University of Wyoming Visitor's Center.
b. Exhibit display at the Wyoming State Capitol Building in Cheyenne during the 1994 Legislative session
c. Wyoming Section American Water Resources Association Annual Meeting. Graduate student in Range Management/Water Resources, received the best student presentation award. November 2-3, 1994.

7. **1994-95 School-Year Powell Water Education Calendar**: The Powell Water Education calendar features full-color pictures of the 1993 posters and poster contest winners, water facts, and water experiments. Calendar sponsors include: WWRC, Amax Coal Company, Holly Sugar

Corporation, Powder River Basin Resources Council, U.S. Department of Agriculture-Working Group on Water Quality, Bureau of Reclamation, U.S. Environmental Protection Agency, International Office for Water Education, National Water Information Clearinghouse, Wyoming Department of Education, Wyoming Game And Fish Department, Wyoming State Engineer's Office, Wyoming State Section-AWRA, and the Wyoming Water Development Commission.

D. SERVICE ACTIVITIES

1. **WWRC's World-Wide Web Access**: The Wyoming Water Resources Center became accessible through the Internet via the World Wide Web (WWW) during FY 94. Some of the information available includes the WWRC fact sheet, links to servers operated by the units of the Center (Water Resources Data System, Geographic Information System, and Wyoming Initiative), and pointers to other water-related sites on the Web. Since its establishment, the Web site has been visited by persons located worldwide. Accesses have increased dramatically since the site went online in October of 1994. A popular choice of users has been the Natural Resources Conservation Service (NRCS) monthly and weekly snow surveys and forecasts which are posted in the Web environment by WRDS through a cooperative agreement with the NRCS. Included in this posting are the Monday Morning Snowpack Reports for Wyoming and the monthly Wyoming Basin Outlook Reports. Additional cooperative efforts between WRDS and the National Weather Service in Cheyenne, Wyoming have led to the posting of monthly climatic data and analyses for the state, as well as hydrologic forecasts. The data are presented in both tabular and graphic formats and include monthly precipitation by basin, local climatological summaries, and spring flood forecasts. Development is underway to make the Wyoming Water Bibliography and its more than 13,000 citations on Wyoming's water resources searchable via the Web.

2. The **Wyoming Initiative** provides a framework for hydrologic data exchange, access to data, data sharing, and scientific applications for Wyoming's surface and groundwater as it relates to coal production statewide. By updating the computer modeling system with current mine information, this also allows for a consistent way of updating the Cumulative Hydrologic Impact Assessment and facilitate timely permitting of mines.

3. **Water Resources Data System**: Operated by WWRC, with funding from the Wyoming Water Development Commission, the Water Resources Data System (WRDS) is a clearinghouse of water resources information for the State of Wyoming. WRDS offers a wide variety of products and services to its users including retrievals for water resources information from in-house databases, CD-ROM products, and alternate data systems from across the region and/or country via the Internet. Additional sources of information available to requesters include numerous federal and state water resource publications, microfiche, reports, and historical documents. WRDS also maintains the Wyoming Water Bibliography, a bibliographic database dealing with the development, management, and use of Wyoming's water resources.

4. **Geographic Information Systems**: The WWRC has taken the lead in the state by developing a state-of-the-art GIS computer lab. The initial WWRC project has involved mapping ground water vulnerability, first for Goshen County, and then for the rest of the state. Other on-going and future projects at the WWRC include: underground injection well mapping, surface water rights mapping, compilation of digital map sources for Wyoming Water Division II, mapping

of archeology sites at South Pass City, agricultural nonpoint source surface water quality modeling, development of a geographical decision support tool for the Forest Service's common water unit parameters, and cumulative hydrologic impact modeling in the Powder River Basin.

COOPERATIVE ARRANGEMENTS

ADMINISTRATION

As specified in its charter, the Wyoming Water Resources Center has responsibility for: 1) Service, 2) Research, 3) Information Transfer, and 4) Education. The Director and Associate Director, in keeping with the Center's charter, and in cooperation with the State of Wyoming, have spent the majority of their time in organizing the following services.

1. Service

Service to State and Federal Agencies

- Continual liaison with state agency officials. Table 1 lists cooperating state and federal agencies and Table 2 lists specific projects performed in response to state requests.
- Basic technology transfer to state and federal agencies and Wyoming water users and managers.
- Serve as advisors to Wyoming Water Development Commission and review proposals for work from consultants.
- Continue to integrate state and federal research programs.
- Interaction with State Legislature subcommittees (i.e., Select Water Committee).
- Attend Governor's Water Forum.
- Attend meetings regarding specific research projects.
- Administer UW research for Wyoming Department of Environmental Quality Nonpoint Source Pollution Program.

University Service

- Member, University of Wyoming Deans Council.
- Serve on University Committees (e.g., Women and Minority Faculty Hiring Committee).
- Serve on Steering Committee for Abandoned Mine Lands Research Program.
- Continued effort to apprise faculty members of research needs and opportunities in water-related research.

- Work with academic standards committee on interdisciplinary Master of Science/Water Resources curriculum.
- Serve on appropriate graduate student committees.
- Serve on appropriate national and international technical review panels and committees.
- Serve on School for Environment and Natural Resources Committee.

Other

- Continued effort to be cognizant of regional and national water issues and research opportunities.
- Director served as Vice-President of Powell Consortium
- Director served as President of National Institutes for Water Resources and President NIWR Board of Directors.
- Serve as delegates to Universities Council on Water Resources.
- Transfer of research results to appropriate users.

TABLE 1: COOPERATING STATE AND FEDERAL AGENCIES IN WYOMING

STATE

Attorney General's Office
Department of Agriculture
Department of Commerce
    Division of Economic and Community Development
    Division of Parks and Cultural Resources
    Division of Tourism and State Marketing
Department of Environmental Quality
    Air, Land & Water Quality Divisions
Department of Transportation
Emergency Management Agency
Game and Fish Department
Governor's Office
Industrial Siting Administration
Legislative Services Office
Oil and Gas Commission
State Climatologist
State Engineer's Office
State Library
State Planning Coordinator's Office
Wyoming Water Development Commission
Wyoming Geological Survey

FEDERAL

U.S. Geological Survey
U.S. Department of Energy
U.S. Soil Conservation Service
U.S. Bureau of Reclamation
U.S. Forest Service
U.S. Bureau of Land Management
U.S. Fish and Wildlife Service
Environmental Protection Agency
Office of Surface Mining

TABLE 2: SERVICE-TO-STATE - FY 94

Research Projects Performed in Response to Wyoming State Agency Requests

Predicting extreme precipitation events and floods in Wyoming will allow cost effective procedures to be developed to assist in risk assessment, risk-based design, and evaluation of hydraulic structures. This research is being conducted of the **Wyoming Department of Transportation** and the **Wyoming State Engineer's Office.**

Through the WWRC's **Geographic Information Systems** lab, a digital water use inventory is being developed for the Tongue River Basin in Wyoming (Water Division 2) to demonstrate the flexible data storage, retrieval, and updating capabilities of a Geographic Information System. The Wyoming State Engineer's Office is the principal agency cooperator on the project.

Seismic reflection and ground-penetrating radar will be used to image the shallow water subsurface. With this approach, nitrate contamination problems in Torrington and land-use problems in Laramie can be better understood. This technique has already been used successfully in Laramie and at F.E. Warren Air Force Base in Cheyenne.

Wyoming landowners and citizens in **Goshen County** are assisting in the **Citizen Monitoring Network** for Nitrates and Pesticide in Groundwater of Goshen County, Wyoming. The project involves citizens who assist in the collecting and monitoring of groundwater samples for nitrates and the pesticides aldicarb and atrazine. This project will also help in developing Best Management Practices that are capable of preventing the degradation of quality groundwater.

Instream or conveyance losses of water being transported within natural stream systems in Wyoming will be quantified and computer models will be developed to accurately predict losses for management recommendations. Transfers in point-or-use, which need approval from **the State Board of Control**, require this type of information.

In working with the **Wyoming Water Development Commission**, the WWRC has completed a project that helps evaluate small water development project areas for planning and possible future development within the guidelines and laws of the state and federal government.

Groundwater sensors are being developed for specific metal ions, anions, and oxygen. Once developed, these will provide a low cost alternative to Wyoming towns and cities for the monitoring of contaminants in water supplies.

A centralized repository for water quality data collected by city, county, state, and federal agencies throughout Wyoming will be established and housed at the WWRC. This project was requested by several state and federal agencies and will result in the most up-to-date and complete information possible on water quality in the WWRC's **Water Resources Data System.**

2. Research

- Federal Program FY 94

Research accomplishments of the FY 94 Federal Water Research Program were reviewed by the Director. The results of these projects have been provided to the Center's advisory committees and presented at professional meetings.

- Federal Program FY 95

The Director solicited proposals under the FY 95 Federal Water Research Program from interested faculty on campus and the seven community colleges. Proposals were received and reviewed by state agencies and regional university personnel through the Water Institute Directors in the region--three were funded under the program.

3. Information Transfer

One of the four major missions of the WWRC involves information transfer activities. Information transfer programs are developed among researchers conducting water-related research in cooperation with other UW departments, state agencies and public interest groups. The Center provides an avenue to exchange and disseminate research results and water related information.

4. Education

The WWRC coordinates a joint interdisciplinary Water Resources Master of Science degree program with ten department sin four colleges at UW. Students receive a broad background in water in addition to their chosen field of specialization. Currently, more than 30 students are enrolled in this program campus-wide. This graduate education effort and our research program provides training for over 80 students each year. Many of these students have found employment in Wyoming industry and in state and federal government.

STATE CLIMATOLOGIST

The State Climatologist is housed within the Wyoming Water Resources Center. This individual is expected to serve the public and the Wyoming Water Resources Center by directing existing statewide climatological programs and services and by assisting academic researchers involved with meteorology-related work.

ENVIRONMENTAL PROTECTION AGENCY

The WWRC has an agreement with the Environmental Protection Agency permitting access to the agency's national computer center mainframe computer. Specific applications which have been validated for WWRC use include STORET, the water quality storage and retrieval system of the EPA, and FRDS, the Federal Reporting Data System which houses information on public water supply systems. Both databases are accessed on a routine basis and serve to augment data already housed at the WWRC.

NATURAL RESOURCES CONSERVATION SERVICE

The WWRC has an agreement with the Soil Conservation Service permitting access to the Centralized Forecasting System (CFS) in Portland, Oregon by WRDS personnel via microcomputer

has been accessed regularly in responding to requests for data during the year. Additionally, the system has proved to be a valuable source of information to WWRC researchers and staff.

U.S. GEOLOGICAL SURVEY

The WWRC serves as an assistance center for the National Water Data Exchange (NAWDEX), an organization of the U.S. Geological Survey, through a cooperative agreement for the purpose of helping users of water data identify and locate the data they need. The Center has also entered into an agreement with the USGS for access to the Water Storage and Retrieval System (WATSTORE) and the Earth Science Data Directory (ESDD).

WWRC ADVISORY STRUCTURE

The organizational structure and operational procedures of the WWRC for a high degree of accountability and relevance to state and regional water research include a Research Review and Priorities Committee (RRPC) appointed by the Governor of the State of Wyoming and the President of the University of Wyoming. The membership was designed to reflect the interests and input of the Executive Office, the legislative branch of government, the academic community, the State Climatologist, citizens representing each of the state's four administrative water divisions, and the University administration (Table 3). The Committee meets at least twice annually to discuss WWRC activities and research priorities and to approve projects presented.

Prior to presentation of projects to the Advisory Committee, a review process which includes relevant state agencies, in addition to scientific peer review, has been completed. This process has insured good science directed toward issues meaningful to water research needs in the state and the region.

WYOMING WATER RESOURCES CENTER
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April 1994

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PUBLICATIONS

Publications completed as a result of work funded under Section 104

CITATION	Supporting Section 104 Project Number
1. Article in Refereed Scientific Journals Wiley, Michael, and Humphrey, Neil, 1995, Anchor Ice in Cold Regions: A Significant Sediment Transport Process, Journal of Geophysical Research, (in preparation).	G-2056-02
2. Book Chapters	
3. Dissertations	
4. Water Resource Research Institute Reports	
5. Conference Proceedings	
6. Other Publications	

TRAINING ACCOMPLISHMENTS

Shown by fields of study and training levels indicated, the number of students participating in projects financed in part through the Fiscal Year 1994 Program are indicated below.

Training Category	Academic Level				
Field of Study	Undergraduate	Master's Degree	Ph.D. Degree	Post-Doc	TOTAL
Chemistry					
Engineering:					
Agriculture					
Civil					
Environmental					
Soils					
Systems					
*Other					
Geology			1		1
Hydrology	1				1
Agronomy					
Biology					
Ecology/Range Management	2	2	1		5
Fisheries, Wildlife & Forestry					
Computer Science					
Economics					
Geography					
Law					
Resources Planning		1			1
Other* Mathematics		1	2		3
TOTAL	3	4	4		11

POSTGRADUATE EMPLOYMENT

None

Student	Degree			Employer				
				Government				
	BS	MS	Ph.D.	Federal	State	Local	Private Sector	College or University
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								