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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 FY95 program, as well as information transfer activities. These three research projects relate to important water issues in the State of Wyoming and the region.

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 been made 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.

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.

TABLE OF CONTENTS

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 97-98, 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 95.

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 was 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 proposed to study ice formation along a reach of a single small stream. Five questions were 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 was 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.

Winter 1995-96 field work

Based on our findings in the 1994-95 field season, the 1995-96 field program was designed to address two main issues. The first issue was to further delineate areal and temporal extent of the anchor ice events. The second issue was to make thermal measurements to allow modeling of the anchor ice process.

The focus of field monitoring of anchor ice in the 1995-96 field season was the determination of the locations and extent of anchor ice events. The section of the Laramie River downstream of Jelm, and upstream of Laramie was observed both on foot and from the air during the winter (air time was donated).

A thermistor string was imbedded in the bed of the Laramie river about 7 miles above Laramie on a straight stretch of the river. Nine thermistors in a vertical column monitored the water temperature and the sub ground water temperatures throughout the winter. The thermistor string and datalogger were unfortunately destroyed in the spring floods. The initial data from the temperature profile indicate that the thermal regime in the near bed region of the stream is dominated by a slow influx of water at slightly above freezing from the surrounding ground water flow. Although the water flow is minor, the heat content is significant and should maintain the river bed at temperatures slightly above freezing. This result indicates quite strongly that the anchor ice must form from direct contact of super-cooled frazil ice with the bed. The influx of heat to the bed does, however, identify the releasing mechanism, which leads to the release and transport of sediment during anchor ice release events. A model is being constructed which uses this information to estimate the parameter space in which anchor ice can form. We are expecting to be able to construct a 3 parameter graph, using the variables of, degree of turbulence (Reynolds number), surface cooling rate, and frazil ice size, to predict the formation of anchor ice and subsequent sediment transport events. We will not have sufficient data to fully parameterize our model, however we hope to be able to identify the necessary data that must be included in such a model.

SYNOPSIS

Project Number: 03

Start: 06/94 (actual)
End: 05/96 (actual)

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 be used to design strategies for using biofilms to prevent and remediate aquifer contamination. The information will also be useful to the petroleum industry in enhanced oil recovery projects.

In this project we use numerical methods to simulate the interaction of water flow and biofilm growth and transport in a porous medium. We examine three scales: the microscale, appropriate for individual pores; the mesoscale, which involves networks of pores; and the macroscale, in which water flow is modeled using Darcy's law. At each scale, transport equations model the movement and reaction of dissolved or suspended substances -- such as nutrients and microbes -- in the water.

At the microscale, we use a biofilm growth model that considers several types of bacteria and nutrients. This model incorporates Monod growth kinetics and the attachment and detachment of biofilms. The local model predicts the size of the biofilm at the microscale, which we can incorporate into the mesoscale model. The purpose of the mesoscale model is to analyze effects of biofilm growth on the porosity and permeability of the porous medium. We then use this information in the macroscale model, which is appropriate for predictions at the bench and field scales. Ultimately, macroscale models can be used to determine the feasibility of using biofilms to act as biobarriers and possibly to biodegrade contaminants.

Methodology:

The microscale model is based on Navier-Stokes flow in an irregular conduit, representing a single pore in the medium. Accompanying this flow is the transport of nutrients and microbes and the growth of biofilm along the pore walls. The main features of this model were established when the project began.

In the mesoscale model, we treat the porous medium as a system of conduits connected at nodes. Each conduit is a cylindrical pipe with Poiseuille flow. The conduit radii are random, obeying a lognormal probability distribution. Given an overall pressure drop across the network, we solve for pressure at each node using successive overrelaxation. We then compute the flow in each conduit and thus in the overall network. Finally, we calculate the network's permeability using Darcy's Law.

The mesoscale model includes a model of solute transport through the network. We divide each conduit into cells, tracking the concentrations of nutrients and microbes in each cell. We choose number of cells in each conduit to minimize numerical diffusion, based on conduit radii and volumetric flow rates determined from the flow calculations.

The macroscopic model is based on coupled, nonlinear partial differential equations describing flow and transport of nutrients and microorganisms, changes in water pressure, and biofilm growth. Solving these equations numerically requires the efficient, robust treatment of sharp fronts, heterogeneities, physical dispersion, and time-scale disparities.

The algorithm is as follows:

(1) Solve the pressure equation for Darcy velocity and pressure, using a mixed finite element (MFE) procedure.

(2) Use a modified method of characteristics (MMOC) to solve the transport equations.

(3) Solve the biofilm growth equations, which model the growth kinetics, attachment, detachment, and possibly transport in the biofilm.

Since the pressure equation affects the transport only through fluid velocity, the MFE method is attractive here, since it can yield accurate velocities. In solving the MFE equations, however, poorly conditioned matrix equations arise. We overcome this problem using an iterative scheme based on multigrid ideas.

The transport equations involve a different set of numerical problems. When advection is the dominant transport mechanism, most numerical schemes exhibit nonphysical oscillations or excessive numerical diffusion near sharp fronts. MMOC approximations minimize these problems by timestepping along the flow directions. Advantages of the MMOC approach include (a) better resolution of fronts, (b) reduced grid-orientation bias, and more efficient linear algebra, since the resulting matrix equations are symmetric and positive definite.

Principal findings and significance:

This project started in June 1994. This report covers mainly the second year of the project, from June 1995 to May 1996. During the past year, we worked on three related tasks:

(1) Mesoscale studies, involving scale-up of microscale results to obtain macroscale relations between biomass and porosity and permeability of the porous medium;

(2) A one-dimensional study of the physical, mathematical, and computational aspects of macroscale transport via reaction-diffusion equations;

(3) Macroscale simulation of flow, transport and bioreaction.

Mesoscale studies:

In this task we used the network model to determine how permeability varies with concentration of biofilm. We solved the model on networks having different sizes and distributions of radii to determine the permeabilities of biofilm-free media. Transport simulations, conducted to see how fast solute moves across the biofilm-free media, revealed fingering effects. These become pronounced as the variance of the pipe radii increases.

We developed two models of biofilm growth in the network. The first, an "unstructured model," contains only bacteria and nutrients. All bacteria is adsorbed uniformly within a given computational cell, and all nutrients are in solution. The second, "structured" model contains nutrients, bacteria and extracellular polymeric substances (EPS), which bind the bacteria in a biofilm. Bacteria and EPS may be either adsorbed or in solution. Bacteria obey Monod kinetics and undergo non-equilibrium adsorption. The model accounts for death of bacteria and sloughing of the biofilm.

The conduit radii change as bacteria grow and adsorb onto the surface. This changes flow rates in the conduits, so we iterate on the flow equation to determine flow rates consistent with the radii. Using this computer model, we have computed changes in permeability as a function of time and space as well as concentrations of bacteria, nutrients, and EPS.

Transport study:

This task involves the investigation of the how reaction terms affect the advection-diffusion-reaction equation. The results of this task are used in the third task, which involves integration of transport solvers into a macroscopic model of flow and transport of biofilm and nutrients.

To investigate the population dynamics of microbes, we first examined populations that vary in time but not space. These models isolate the interaction between bacteria and nutrient from the effects of transport. Among the models tested were the Lotka-Volterra model, Monod kinetics, and Michaelis-Menten laws. We then added advection and diffusion, keeping the reaction terms intact. Calculations using zero diffusion, zero advection, and both effects verified the accuracy of the numerics.

We also verified that the numerics can reproduce important structures arising in many reaction-diffusion equations. The model supports traveling waves, stable equilibria and limit cycles, and pattern formation in the spatial distribution of nutrients and microbes, all of which may prove important in biobarrier design.

Macroscale Simulation:

The third task was the development of a macroscopic model that incorporates biofilm growth and its effects on the flow. The model consists of three parts: water flow, bacteria and pollutant transport, and growth of bacteria and its effects on flow and transport.

In groundwater aquifers, advection-diffusion-reaction equations model the transport and fate of adsorbing contaminants and microbe-nutrient systems. As discussed earlier, numerical difficulties arise when advection, associated with the velocity field, dominates the transport.

To solve the solute transport equation we used a two-dimensional finite element technique based on the modified method of characteristics (MMOC), in some cases including streamline or velocity-weighted diffusion. The MMOC can capture most of the advective transport in the timesteping scheme. Also, the resulting matrix equation is symmetric and positive definite, which allows the use of efficient algebraic solvers. However, spurious oscillations near sharp concentration fronts can trigger severe instabilities.

A cheap and popular way to suppress oscillations is to add numerical diffusion, as in the streamline diffusion method. While these techniques are widely used for nonreactive transport, we found that they cause serious problems when reactions with treshholds are present. In particular, sharp fronts in numerical solutions can smear out too fast, distorting the numerical solution significantly. In problems involving nonlinear reactions, either type of error - oscillations or numerical diffusion - can lead to qualitatively incorrect numerical predictions.

These findings suggest that, in this setting, it is crucial to use sufficiently fine spatial grids to avoid oscillations without introducing artificial diffusion. However, the added computational effort needed for such grids makes simulations more time consuming.

SYNOPSIS

Project Number: 04

Start: 07//94
End: 05/96

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 hydroperiods 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 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 partensis*) 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 hydroperiods. Specific research objectives were to: 1) Evaluate the response of three important, but morphologically dissimilar, riparian plant species to specific hydroperiods designed to simulate dewatering of riparian zones, and 2) Develop hydroperiod suitability curves and design hydroperiod duration curves for each riparian plant species and then to compare these curves to curves developed from field data.

Methodology:

Plants were tested in 3×10 cm by 3 m-tall columns filled with commercial-grade coarse silica sand. This sand allowed the water table to be adjusted to a specific level, while minimizing the capillary fringe and the soil moisture above the water table. Plants were watered with a 50% Hoagland's solution by reverse column irrigation, which provides water from the bottom of the column to maintain the water table. This eliminated the need to re-irrigate the soil profile when adjusting water levels. A removable clear acrylic front on each column was used to observe and

measure root extension during the experiment, and to take below ground biomass measurements at the end of the experiment. The clear front was covered with a sheet of black plastic, except when making root observations, to simulate darkness below ground. The experiment consisted of five water-table decline rates (0, 1, 2, 4, 6 $cm \cdot day^{-1}$) to four maximum depths (0, 1, 2, 3 m). Impossible treatment combinations were not tested (e.g., 0 $cm \cdot day^{-1}$ to 1, 2, or 3 m). The treatment period was for 120 days with three replicates of each treatment combination for each species. Plant response was evaluated by measuring the percentage of live leaves at 10-day intervals during the experiment, and the above and below ground biomass at the conclusion of the experiment.

Principal findings and significance:

The Tall Column Plant-Growth Facility at the University of Wyoming was constructed for this experiment. This Facility can accommodate 90, 3-m tall columns at one time, and has three, 2.4 m-long grow lights that provide 500-700 $\mu mol \cdot s^{-1} \cdot m^2$ of light within 15-30 cm of each fixture. The light fixtures used a combination of very high output fluorescent lights and 60-watt incandescent bulbs attached to automatic timers to control light intensity and duration. The timers were set to provide 14 hours of light per day, at four intensities to simulate dawn, full daylight, and dusk. Air circulation was provided to reduce the vapor boundary around the leaves. Results from this study suggest all three species cannot survive for more than 20 days if the water table drops below about 40 cm during the growing season. Since the water table alone was unable to maintain these species, other hydrologic and soil factors may be involved in the maintenance of riparian plant communities. These other sources, such as precipitation, should be considered when water allocations are considered for riparian habitat improvement.

All three species produced the most above and below ground biomass when the water level was maintained at the surface. Their roots, however, were unable to extend fast or deep enough to maintain plant growth when the water level was lowered at the rates and depths tested. Water content in the rooting zone above the water table was typically less than 3%, suggesting that the plants utilized all the available water before they senesced. Kentucky bluegrass developed more roots than the other two species when the water table was lowered quickly (4 and 6 $cm \cdot day^{-1}$). This relatively more "aggressive" root development to obtain soil moisture with falling water tables might suggest why Kentucky bluegrass appears to have a competitive advantage over tufted hairgrass and Nebraska sedge when water tables decline quickly.

The hydroperiod suitability curves based on the percentage of live leaves suggests that Kentucky bluegrass is less sensitive to the water table than Nebraska sedge, with tufted hairgrass as an intermediate. These results are similar to those observed under natural conditions, but only the Nebraska sedge suitability curves were similar to the curves developed from field data. Results from our controlled study suggests that the water level should be maintained at the surface throughout the growing season, while the filed data suggest that the water table can drop below 1.79 m by the end of the growing season for tufted hairgrass.

Based on the results and experiences from this study, we propose the following recommendations for further investigation or consideration:

1. A study should be conducted with a fine-textured soil to assess the importance of the capillary fringe, and to obtain quantifiable, physiological-optimum plant response curves when the capillary rise is not restricted.

2. Plant stress during the experiment might be better correlated to the effects of dewatering on plant survival by measuring the physiological attributes of leaf photosynthesis and transpiration.

3. Future studies should be conducted where competition among species can be introduced along environmental gradients within a laboratory setting, and the plant response tested against field studies.

4. Continuous hydrologic data from an array of field sites should be collected to establish a long term database in order to monitor and further understand riparian dynamics in relation to water table fluctuations and other hydrologic and soil factors.

INFORMATION TRANSFER ACTIVITIES

June 1, 1995 - May 31, 1996

The Wyoming Water Resources Center (WWRC) 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, 1995 through May 31, 1996 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 RESOURCE SEMINARS, WORKSHOPS AND CONFERENCES:

The WWRC 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. **American Society for Surface Mining and Reclamation Annual Meeting**: This meeting was held June 3-8, 1995 in Gillette, Wyoming and was attended by several Water Center staff including: Katta. J. Reddy, Ken Voos and Jeff Hamerlinck. Recent research efforts were discussed.

2. **Second Annual Water Information Management System Workshop**: This conference, co-sponsored by the Wyoming State Engineer's Office, U.S. Bureau of Reclamation, and the Western States Water Council was held June 12-14, 1995 in Cheyenne. More than 80 representatives from federal and state water agencies were in attendance, including the WWRC's Water Resources Data System (WRDS) and Geographic Information System (GIS) personnel. Barry Lawrence gave a presentation on WRDS and its capabilities with special emphasis on cooperative data posting and database migration into the World Wide Web environment. WRDS also gave a poster display at this conference.

3. **Muddy Creek Governor's Tour**: The WWRC participated in this tour hosted by the Little Snake River Conservation District and the Bureau of Land Management as prior water quantity and quality research was conducted in this area by WWRC personnel. Approximately 110 people were in attendance.

4. **Western Society of Soil Science Annual Meeting**: K.J. Reddy was actively involved in setting the agenda for this meeting held June 18-23, 1995 at the University of British Columbia in Vancouver, Canada. The program was entitled "Soil Contaminants: Reactions, Mobility, and Remediation." Papers highlighting WWRC research were presented.

5. **Water Resources Seminar**: This seminar entitled "Groundwater Management and Pollution Prevention in Goshen County" was held September 8-9, 1995 at Eastern Wyoming Community College in Torrington, Wyoming. The seminar was co-sponsored by the WWRC and Wyoming Department of Environmental Quality - Water Quality Division. Forty individuals were in attendance during the first day's presentations. Day two of the seminar was a hands-on demonstration of ArcView 2.0 for resource managers and determination of groundwater vulnerability mapping.

6. **Economic Development Meeting**: This meeting was held September 11, 1995 at the Antelope Truck Stop near Burns, Wyoming with City Council members in attendance from the Wyoming towns of Burns, Albin, and Pine Bluffs. A presentation was given by the WWRC Information and Education Coordinator concerning WWRC activities and capabilities and how we might assist, using WRDS and GIS, in their efforts to promote the diversion of water into Lodgepole Creek which they hope would eventually help to recharge their groundwater aquifers.

7. **Environmental and Natural Resources Research and Policy Forum**: Poster displays concerning WWRC water quality research were highlighted at this forum held September 5, 1995 at the University of Wyoming.

8. **1995 Rocky Mountain Groundwater Conference**: This conference entitled "Science and Policy: Who's Driving Groundwater Cleanup" was co-sponsored by the WWRC in cooperation with the Montana Water Resources Center, Center for Biofilm Engineering, Montana State University, Groundwater Research Cluster, and University of Wyoming. The conference was held October 4-6, 1995 at the Snow King Resort in Jackson Hole, Wyoming. Topics included: plenary and wrap-up sessions on the science-versus-policy debate and what are realistic technology goals and cleanup expectations; options for regulatory and cleanup policy; monitoring technologies; mathematical modeling; fate and transport; and bioavailability.

9. **Annual Meeting of Soil Science Society of Agronomy**: This meeting was held in St. Louis, Missouri October 29-November 3, 1995. K.J. Reddy was author or co-author for several presentations and was co-organizer and co-chairman of the symposium "Chemistry and Restoration of Disturbed Lands" for 1995 Soils and Environmental Quality Division presentations.

10. **American Water Resources Association - Wyoming State Section 8th Annual Meeting**: The AWRA - Wyoming State Section, in conjunction with the WWRC, held its eighth annual Wyoming State Section meeting on November 1-2, 1995 at the University of Wyoming in Laramie. This meeting is designed to be a forum for graduate and undergraduate student research presentations. In addition, panel sessions concerning the Crown Butte Mine and the state's 3-brick proposal were held. A poster display was established pertaining to the WWRC's WRDS. Todd D. Yeager, Project Graduate Assistant, tied for best graduate student paper with his presentation of the preliminary project results of this project at the Wyoming Section of the American Water Resources Association annual meeting.

11. **Wyoming Water Development Association Annual Meeting**: This meeting, held November 8-9, 1995 in Sheridan, Wyoming, centered on the theme "Making a Difference". The

Water Center poster display "Water Center Sponsored Programs and Projects With Possible Benefit to Landowners" was in place during the meeting. Sections on WRDS and GIS and also project information including conveyance loss, citizens monitoring network, vegetation stubble height, large ungulate herbivory on willow, riparian management handbook, and WWRC involvement in the Powell Consortium were included in the poster display. WWRC Research, Review, and Priorities Committee member Beryl Churchill was honored for her many years of service to the Center.

12. **Wyoming Association of Conservation Districts 50th Annual Convention**: The Wyoming Association of Conservation Districts held its 50th Annual Convention on November 14-16, 1995 in Rock Springs, Wyoming. The WWRC Information and Education Coordinator attended the conference and featured the WWRC display board highlighting WWRC programs and activities with benefits to landowners. A presentation was given to members interested in water quality concerning the WWRC's WRDS and GIS.

13. **Governor's Conference on Natural Resources and the Environment**: The WWRC poster display was established at this conference held December 14-15, 1995 in Casper. Handouts concerning WWRC activities and publications were made available and approximately 300 people were in attendance.

14. **State Water Forum Meeting**: The special presentation of the January, 1996 State Water Forum Meeting was on the WWRC's WRDS as given by Barry Lawrence (WRDS coordinator). The presentation covered the WRDS databases, alternate systems accessed, and cooperative data posting efforts with federal and state agencies in Wyoming. On-line World Wide Web access via the Internet was featured as was the recently migrated WRDS water quality database. Twenty-seven individuals attended the first morning presentation, while thirteen attended the second presentation held that afternoon.

15. **Wyoming Conservation Connection Annual Meeting**: Held January 26, 1996 at the University of Wyoming, this meeting was attended by the WWRC's Information and Education Coordinator. Approximately 35 people were in attendance and the Statewide Integrated Conservation and Education Program (SICEP), a program supported by the WWRC, was discussed.

16. **Wyoming Legislative Water Resources Forum**: The WWRC sponsored the Wyoming Legislative Water Resources and Law forum again on February 19, 1996. The seminar, held annually, is designed to acquaint new legislators with agencies and laws concerning water resources. Directors of the Wyoming Water Development Office, Wyoming State Engineer's Office, Wyoming Department of Environmental Quality, and Wyoming Game and Fish are regular speakers at this forum.

17. **Carbon County Planning Office**: The WWRC facilitated a meeting February 7, 1996 to discuss the possibility of using GIS and WRDS data in ways to assist county planners in Carbon County and throughout the state. In attendance were Carbon County planners, Wyoming Water Development Office and WWRC personnel.

18. **Wyoming Riparian Association Meeting**: University of Wyoming riparian area research was highlighted at this meeting hosted by the Water Center at UW on February 8-9, 1996. Presentations concerning large ungulate herbivory on willow, riparian vegetation height requirements, Big Horn River research, vegetation column study research results, riparian management handbook development, and wetland/GIS mapping were given. A tour of the Department of Rangeland Ecology and Watershed Management's Watershed Simulation Laboratory was conducted. The meeting was open to the public and all Wyoming Riparian Association members.

19. **Legislative Technology Session (GIS/WWW) Showcase**: Demonstrations of the WWRC's WRDS and GIS units and respective capabilities were given February 22-23, 1996 in Cheyenne as part of the Legislative Technology Session Showcase sponsored by the Wyoming State Engineer's Office and the Wyoming Geographic Information Advisory Council. Approximately 200 people visited the two-day session, including Wyoming state legislators and the Governor. Through on-line Internet access, the WRDS unit demonstrated the WWRC's website, cooperative data posting efforts, and the water quality on-line system. The center's GIS unit displayed groundwater vulnerability mapping project results.

20. **Wyoming Geological Association Meeting**: The March 22, 1996 meeting in Casper of the Wyoming Geological Association featured a presentation by Barry Lawrence on WRDS. Held at the Wheeler Auditorium at Casper College, the session included an overview of the WRDS system (databases, CD-Rom products, and alternate systems), cooperative data posting on the World Wide Web, and the newly migrated water quality on-line database. On-line demonstrations were performed for a crowd in excess of 50 persons followed by a question and answer session.

21. **Wyoming Information Summit**: This conference, promoted by the Wyoming Rural Development Council, was held April 17-18, 1996 at the Headwaters Convention and Arts Center in Dubois, Wyoming. The conference was designed to give those attending links to providers of information enhancing information access for Wyoming's populace across the state. The Water Center had information and education displays established and computer demonstrations highlighting GIS and WRDS data for conference registrants.

22. **Third Annual Water Information Management System Workshop**: Sponsored by the Western States Water Council and the Arizona Water Board, this conference was held in Phoenix, Arizona May 15-17, 1996. Barry Lawrence, WRDS coordinator, gave a presentation on WRDS with emphasis on World Wide Web activities, including cooperative data posting and the water quality on-line system. More than fifty water resource professionals from the Western U.S. were in attendance.

23. **American Society for Surface Mining and Reclamation National Meeting**: Jeff Hamerlinck was a workshop instructor at this meeting held in Knoxville, Tennessee May 18-23, 1996. The workshop center around Geographic Information Science (GIS) applications in mining and reclamation.

24. **Northwest Glaciology Meeting**. Paper presented by Neil Humphrey, UW Department of Geology and Geophysics on research conducted on river bed modification.

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 June - August 1995, 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 two participants (a student and teacher) in this year's program. 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. **Minority High School Student Research Apprentice Program** - The Water Center participated in this program in cooperation with the University of Wyoming's Minority Affairs Office by conducting a tour of the WWRC and talking of WWRC capabilities and activities June 13, 1995. This program provides hands-on training and experience to minority high school students (Grades 10-12), science teachers (K-12), and any prospective science teachers.

4. Stacy Gonzales, **Minority High School Student Apprentice,** assisted our project team during the summer of 1995 with the daily operation of the Tall-Column Plant Growth Facility and at our montane and subalpine field sites.

5. Thirty-five undergraduate students from the UW College of Agriculture toured **the Tall-Column Plant Growth Facility** as part of their exposure to different programs offered at the University of Wyoming.

6. Tours of the **Tall-Column Plant Growth Facility** were given to 23 representatives from the Republic of Turkey, East Anatolia Watershed Training Project.

7. Tour of the **Tall-Column Plant Growth Facility** was also given to 25 representatives from the University of South Dakota, Department of Ecology.

8. **Math Science Initiative Project** - The Water Center participated in this program designed to provide experience in hands-on scientific and mathematical applications in laboratory research. This program is also oriented towards high school age students and

encourages students to pursue careers in the math and sciences fields. Students participated actively in research from June 27 - July 25 at the University of Wyoming. K.J. Reddy had two students working with him on his water quality related projects during this time period.

9. **1995-1996 Willard C. and Elaine N. Rhoads Scholarships for Graduate Studies in Water Resources**: Two University of Wyoming (UW) students received the Rhoads Scholarship for the 1995-96 school year. One student is enrolled in the Department of Rangeland Ecology and Watershed Management and the other is enrolled in the Geology Department at UW. The scholarship honors 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.

10. **Field Trip With the Basic Beginnings Class**: The Water Center Information and Education Coordinator talked about weather stations, climate and streamflow monitoring in the WWRC's Snowy Range Observatory. Twenty kids, ages 6-12 were in attendance on July 24, 1996.

11. **Statewide Integrated Conservation and Education Program (SICEP)**: The WWRC contributed funds for teacher workshops promoting SICEP held in Tongue River and Platte County. The SICEP teaching materials contain revised water-related activities, many from the WYO K-6 Water Curriculum as previously developed by UW's Natural Science Program personnel in cooperation with the Water Center.

12. **"Hydroexplorer 2 - the Colorado River Run" Computer Game**: The Water Center has cooperated with the Water Education Foundation (WEF) located in Berkeley, California to develop this computer game oriented towards junior high age students. The game was developed by the WEF and is on the market at this time.

13. **St. Laurence School in Laramie**: Discussions were held concerning grant preparation for U.S. West grant solicitation to derive funds for water education materials.

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.

News Releases

- Photos (2) of Wyoming State Legislators and UW Trustees and Faculty (2/28/95): 85 Legislators and guests participated in biennial Legislators' Day activities at the University of Wyoming (WWRC facilities were toured by the group).

- Call for Papers at Groundwater Conference (8/18/95): "Science and Policy - Who's Driving Groundwater Management", 25th Annual Rocky Mountain Groundwater Conference theme, Oct. 4-6, Jackson, Wyoming.

- Groundwater Management Seminar in Torrington (8/30/95): Groundwater Management and Pollution Prevention in Goshen County", topic of free public seminar in Torrington, Wyoming.

- Applications Due for Rhoads Scholarship (3/27/96): Announcement of Willard C. and Elaine N. Rhoads Scholarship for Graduate Students in Water Resources at the University of Wyoming.

- Elementary School Children Win Water Education Poster Contest (6/6//96): Photo with Wyoming Governor and each award recipient was circulated to hometown newspapers along with statewide circulation of cover story.

- UW Students Receive Rhoads Scholarships in Water Resources(5/29/96): Three University of Wyoming students are recipients of 1995-96 Willard C. and Elaine N. Rhoads Scholarship for Graduate Studies in Water Resources. Photo with students, faculty advisors and WWRC Director and Associate Director.

- Research Proposals Due at Wyoming Water Resources Center (12/95): In addition to announcing availability of funds for FY 97 research projects, a new student research funding category was described.

- Research Project Funding for FY 97 - Wyoming Water Resources Center (6/27/96). Short synopsis of each of 13 funded research projects.

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. One brief was published in 1995-96:

a) The Influence of Channel and Riparian Zone Types on Muddy Creek's Water Discharge and Sediment Transport (1986-1991). RB95-01.

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. **Wetlands Fact Sheets**: Two fact sheets pertaining to Wyoming's Wetlands have been produced and are in the review process now. These are: "Wetlands in Wyoming" and "Wetland Banking in Wyoming."

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 1995 Legislative session
c. Wyoming Section American Water Resources Association annual meeting
d. Wyoming Association of Conservation Districts annual meeting
e. Wyoming Water Development Association annual meeting
f. Wyoming Riparian Association winter meeting
g. Governor's Conference on Natural Resources and the Environment
h. Wyoming Information Summit
i. Legislative Technology Session Showcasing GIS and the World Wide Web

7. **1995-96 School-Year Powell Water Education Calendar**: The Powell Water Education calendar features full-color pictures of the 1995 posters and poster contest winners, water facts, and water experiments. Posters were generated based on the contest theme "The Power of Water." Calendar sponsors include: WWRC, Wyoming State Engineer's Office, Wyoming Water Development Commission, Bureau of Reclamation, Wyoming State Section-AWRA, Wyoming Cooperative Extension Service, Wyoming Council of Trout Unlimited, Kennecott Energy Company, Energy Laboratories, Inc., Kiewitt Mining Group, Western Water Consultants, an anonymous donor, and five individual donors.

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 95. Some of the information available includes the WWRC fact sheet, research briefs, upcoming event notices, 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. A popular choice of users is still the Natural Resources Conservation Service (NRCS) daily and weekly snow surveys and monthly forecasts which are posted in the Web environment by WRDS through a cooperative agreement with the NRCS. Included in this posting are daily basin reports, 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, ablation plots, and spring flood forecasts. The Wyoming Water Bibliography and its more than 13,000 citations on Wyoming's water resources is now searchable via the Web. The WRDS Water Quality database

has been migrated and is available in a limited Beta-test manner through the web. WRDS data pages continue to receive in excess of 4,000 accesses per month.

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. Updating the computer modeling system with current mine information provides a consistent way of updating the Cumulative Hydrologic Impact Assessment and facilitates 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. WRDS cooperative data posting has led to increased data dissemination to the public.

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: public water system well mapping, underground injection well mapping, surface water rights mapping, Colorado River Cutthroat Trout inventory and assessment, compilation of digital map sources for Wyoming Water Division II and the Snake River Basin, mapping of archeology sites at South Pass City, and cumulative hydrologic impact assessment 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., Institute for Environment and Natural Resource, School for Environment and Natural Resources, 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.
- University representative to the Wyoming Geographic Information Advisory Council.
- WWRC GIS Coordinator is lead delegate for University of Wyoming membership to University Consortium for Geographic Information Science (UCGIS).

Other

- Continued effort to be cognizant of regional and national water issues and research opportunities.
- Director served as President of Powell Consortium
- Director served as Past President of National Institutes for Water Resources and Past President NIWR Board of Directors.
- Serve as delegates to Universities Council on Water Resources.
- Transfer of research results to appropriate users.
- Board member of the Wyoming Riparian Association and Technical Assistance sub-committee chair.

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 95

Research Projects Performed in Response to Wyoming State Agency Requests

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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 resource 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** assisted in the **Citizen Monitoring Network** for Nitrates and Pesticide in Groundwater of Goshen County, Wyoming. The project involved citizens who assisted in the collection 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 95

Research accomplishments of the FY 95 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 96

The Director solicited proposals under the FY 96 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 departments in 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.

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 SDWIS, the Safe Drinking Water Information 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 Natural Resources Conservation Service permitting access to the Centralized Forecasting System (CFS) in Portland, Oregon by WRDS personnel via microcomputer and modem. A computer account has been established on the NRCS mainframe

for WRDS use and 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). Additional access has been granted to WRDS to the National Water Information System (NWIS) in Wyoming and four surrounding states.

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.

Table 3

WYOMING WATER RESOURCES CENTER
RESEARCH REVIEW AND PRIORITIES COMMITTEE
January 1996

Governor Jim Geringer (*ex officio*) C
State Capitol Building
Cheyenne, Wyoming 82002 777-7434

Steve F. Adams (1995-1998) G
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Box 177
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Bill Gern, Vice-President P
Research Office
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Cynthia Lummis G
Governor's Office
State Capitol Building
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Cynthia Nunley (1995-1998) G
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Rodney "Pete" Anderson (1993-1997) G
Wyoming House of Representatives
1070 Albin Road
Pine Bluffs, Wyoming 82082 245-3201

Mike Purcell (1992-1995) G
Wyoming Water Development Office
Herschler Building
Cheyenne, Wyoming 82002 777-7626

Pete Maxfield (1995-1996) G
Wyoming Senate
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G = Governor appointees
P = UW President appointees
C = Member by Charter

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
Liu, B., M.B. Allen, H. Kojouharov and B. Chen, 1996, Finite-element solution of reaction-diffusion equations with advection, in Computational Methods in Water Resources XI, Computational Mechanics Publications, Southampton, UK, 10 pages.	G-2056-03
Yeager, T.D., R.J. Henszey, and Q.D. Skinner. (in preparation). Critical groundwater hydroperiods for maintaining riparian plant species. Wetlands.	G-2056-04
2. Book Chapters	
3. Dissertations	
Li, Lingxia, 1996, Mathematics of the growth and transport of biofilm-forming bacteria and their consumption of nutrients in porous media, MS Thesis, Department of Mathematics, University of Wyoming, Laramie, WY, 75 pages.	G-2056-03
Suchomel, Brian, 1996, Network model of flow, transport and biofilm effects in porous media, Ph.D. Dissertation, Mathematics, University of Wyoming, Laramie, WY, 256 pages.	G-2056-03
Yeager, T.D. 1996. Critical groundwater hydroperiods for maintaining riparian plant species. M.S. Thesis, Department of Rangeland Ecology and Watershed Management, University of Wyoming, Laramie. 52 pp.	G-2056-04
4. Water Resource Research Institute Reports	
Yeager, T.D., R.J. Henszey, and Q.D. Skinner. 1996. Critical groundwater hydroperiods for maintaining riparian plant species. Wyoming Water Resources Center Technical Report, University of Wyoming, Laramie, Wyoming. 52 pp.	G-2056-04

CITATION	Supporting Section 104 Project Number
5. Conference Proceedings	
Suchomel, Brian, 1996, Microscopic level model of flow and transport in porous media with biofilm effects and scale-up, in Proceedings of the Sixteenth Annual American Geophysical Union Hydrology Days, Hydrology Days Publications, Atherton, CA, 12 pages.	G-2056-03
Yeager, T.D. and R.J. Henszey. 1996. Designing hydroperiods for riparian wetlands in Wyoming and the implications for Platte River management. Abstract *In*: 1996 Platte River Basin Ecosystem Symposium, 27 February 1996, Kearney, NE. pp. 11-12. Sponsored by University of Nebraska Cooperative Extension, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and University Nebraska Water Center.	G-2056-04
Yeager, T.D., R.J Henszey, and Q.D. Skinner. 1996. Critical groundwater hydroperiods for maintaining three riparian plant species. *In*: Abstracts, 49th Annual Meeting of The Society for Range Management, 10-15 February 1996, Wichita, KS. p. 87.	G-2056-04
Henszey, R.J., Q.D. Skinner, and T.A. Wesche. 1996. Depth-to-groundwater relationships for three riparian plant species/assemblages in southeastern Wyoming. *In*: Abstracts, 49th Annual Meeting of The Society for Range Management, 10-15 February 1996, Wichita, KS. pp. 33-34.	G-2056-04
Yeager, T.D., R.J. Henszey, and Q.D. Skinner. 1995. Critical groundwater hydroperiods for maintaining three riparian plant species. *In*: Eighth Annual Conference of the American Water Resources Association, Wyoming Section. November 1-2, 1995, Laramie, WY. In cooperation with the Wyoming Water Resources Center. 3 pp. (unnumbered).	G-2056-04
Henszey, R.J., Q.D. Skinner, and T.A. Wesche. 1995. Designing hydroperiods for riparian-wetlands with hydroperiod suitability curves. *In*: Eighth Annual Conference of the American Water Resources Association, Wyoming Section. November 1-2, 1995, Laramie, WY. In cooperation with the Wyoming Water Resources Center. 2 pp. (unnumbered).	G-2056-04
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 1995 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		2
Hydrology	1				1
Agronomy					
Biology					
Ecology/Range Management	3	2	1		6
Fisheries, Wildlife & Forestry					
Computer Science					
Economics					
Geography					
Law					
Resources Planning	1				1
Other* Mathematics	2	1	2		5
TOTAL	7	4	4		15

POSTGRADUATE EMPLOYMENT

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