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ABSTRACT

Four research projects were funded under the FY89 program, as well as an information transfer program. Two projects funded through the WWRC state grants program were submitted as matching. A short statement identifying each project follows:

A technique is presently being tested which will lower the alkalinity of solid waste materials from mining refinery processes to make them more susceptible to reclamation.

Uncertainty analysis and risk evaluation was performed on parameters of a dissolved oxygen (DO) water quality model which show that DO prediction depends on the classification of the stream and the use of a correct probability distribution.

Microorganisms which inhabit the rhizosphere are found to play a major role in the modification of the bioavailability of selenium.

An evaluation of potential toxicity effects of saline discharges from oil production operations on a portion of a stream system in Wyoming has indicated that these saline discharges significantly contribute to observed toxicity.

Matching-funds projects are: (a) the study of hydrologic, geomorphic and biologic responses of conveying municipal water through an ephemeral watercourse; and (b) the maintenance of a high mountain watershed observatory for the purposes of hydrologic, water quality, and climatologic research and educational instruction.

Information transfer was accomplished through field tours, professional papers, a newsletter, law journal publications, seminars and updating data and bibliographic information sources.

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WATER PROBLEMS AND ISSUES OF WYOMING

Wyoming's heritage stems from an abundance of natural resources. Vast areas of range and pastureland interspersed with fertile, irrigable stream valleys have enabled the agricultural and livestock industry to become a major driving force of the State's economy. The recreation and tourism industry thrives in Wyoming as visitors come to share the wealth of scenic beauty. 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 production.

Water is the key natural resource controlling the development of each of these facets of the State's economy. As the saying goes, "in Wyoming, water is life". The rancher could not survive our semi-arid climate without water for livestock and irrigation. Without our streams, lakes and reservoirs, the quality of the recreationists' experiences would be diminished. If the mineral industry is to continue to provide a major source of income in the State, water will be required. As our cities and towns continue to grow, adequate supplies of good quality water must be available.

Water availability and allocation for future agriculture, mineral extraction, industrial, recreation, 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, is a challenge in planning and implementation. Once available surface and groundwater supplies are utilized, their equitable distribution, conservation, and maintenance of quality become important legal and complex social issues.

The State of Wyoming is a water producing state to the Colorado River Basin, the Snake River Basin, and the Missouri River Basin. Approximately 15.5 million acre-feet of water are produced from snowfall and rain in Wyoming each year, with approximately 12 million acre-feet obligated for downstream use through compacts and decrees. Wyoming has embarked on a state supported water development program with the intended purpose of capturing for its use as much of the excess water produced as possible. 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.

To address the problems and generate needed information associated with water conservation, development, and re-use, a truly interdisciplinary effort, well-managed and coordinated, is essential. The Wyoming Water Research Center is organized to provide that effort and can call upon a diverse set of disciplinary expertise necessary to address key issues for the State and the region.

PROGRAM GOALS AND PRIORITIES

Effective administration and management of Wyoming's water resources depend upon an understanding of the economic and social effects related to water development and utilization and the numerous physical relationships explicit in the hydrologic cycle. Through research there must be a means of assessing the social and economic impacts emanating from water development projects so that the State can utilize its water resources to achieve social and economic goals that fit within a legal and institutional framework that can control and finance water development actions and programs. This also requires equitable administration of Wyoming's water law using a working knowledge of many hydrologic processes. The hydrologic processes necessary to explain or account for the yield and quality of water from precipitation and snowmelt, and the movement and fate of pollutants of this water from saturated topsoil to aquifers, and aquifers to stream channels, is important. Improvement in the efficiency of water administration and management and the effect that water conservation measures for irrigation and other water uses such as energy and mining have on social, economic and hydrologic issues, must be assessed in Wyoming.

The Wyoming Water Research 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 Research Center's Research Review and Priorities Committee, state and regional research priorities include, but are not restricted to, the following:

USGS PRIORITY RESEARCH AREAS (REGIONAL)

I. WATER QUANTITY

Water Distribution

Develop systems that are technically, economically, socially, and politically acceptable for the transfer of water from the areas of good supply to the areas of scarcity.

Dynamics of Ground Water/Surface Water Interaction

Develop and field test models explaining the ground and surface water interactions of different hydrologic areas of the region. This could include interactions involved in the processes of irrigation, flooding and recharge of ground water. It could include the importance and spatial variability of various parameters in the simulation models.

II. WATER QUALITY

Research in this area could include the fate and transport of agricultural chemicals as they move toward surface and ground water supplies. Such research might be on the adsorption mechanisms within the porous media, chemical reactions and degradation processes, flow characteristics of solutes and porous media, relative importance of the physical parameters in simulation models, methods for reducing the movement of contaminants, and application techniques.

III. INSTITUTIONAL RELATIONS

Research on the development of techniques to resolve conflicts among competing water was the most important in this category. This could include the refinement of institutional procedures of various water agencies as well as getting conflicting parties to accept and use each other's data.

IV. UTILIZATION AND CONSERVATION OF WATER

Enhancement of Water Use Efficiency

There could be research on more efficient systems for municipal, industrial and agricultural uses of water. This could include the development of techniques for producing the same amount of a product with less water, or more of the product with the same amount of or less water.

Improved Water Management

This could include the development of better management systems for municipal or irrigation use. Such systems might be those which better distribute the water or more efficiently manage it during peak demands. This could also include techniques for the reuse of water.

V. ECOLOGICAL/ENVIRONMENTAL RELATIONSHIPS

Instream Flow Needs

This research could include the instream flow needs for power generation, fish and wildlife management and recreational uses. It could be aimed at resolving the conflict between competing users of water.

Wetland Hydrology

Research here could establish the sensitivity to flow changes and multiple uses. It could establish the complementary relationships between farm ponds and natural wetlands. It could establish the importance of the wetlands as a hydrological resource.

Impact of Pollutants

Research in this topical area could include the chronic as well as acute effects of the various pollutants on the fish, wildlife and habitat vegetation.

WYOMING STATE RESEARCH PRIORITY AREAS

Specific research topic areas established by the WWRC Research Review and Priorities Committee include the following:

(Subject areas and subjects keyed with this symbol (*) were given a higher priority for funding consideration by the Research Review and Priorities Committee as long as the proposal had a satisfactory peer review.)

GROUND AND SURFACE WATER RESOURCES

*a. Water Quantity and Management

- Recharge mechanisms
- Groundwater/surface water interactions (water quality and quantity)
- Flow in the unsaturated zone
- Groundwater management
- Conveyance losses
- Weather modification potentials

b. Water Quality

- Groundwater contaminant assessment, transport and cleanup
- Assessment methods for non-point sources
- Atmospheric deposition

*c. Legal and Institutional Issues

- Groundwater/surface water interaction/ management
- Interstate conflicts
- Interbasin transfers
- Use transfers
- Water leasing or marketing
- Federal reserve rights

WATERSHED AND RIPARIAN ZONE MANAGEMENT

*a. Groundwater Storage

- Surface water hydrology effects
- Water rights
- Return flows and wetland creation
- Evapotranspiration

b. Surface Water Storage

- Headwater reservoirs
- Multiple reservoir management

*c. Non-Point Sources of Pollution

- Sedimentation
- Salinity
- Nutrients

d. Riparian Ecosystems

*- Economic valuation

WATER DEVELOPMENT AND CONSERVATION

*a. Improving Water Management

- Implications of climate change
- Measuring and estimation techniques for large river basins
- Flushing flow requirements
- Conservation techniques

*b. Legal and Institutional Issues

- Financing methods
- Use conflicts
- Conservation incentives
- Public dissemination
- Water leasing or marketing
- Weather modification

c. Environmental Relationships

- Instream flow
- Species of high state interest

d. Agricultural/Municipal/Industrial/Recreational Uses

*- Current consumptive use/loss estimates for Wyoming

Emphasis on these priorities provided a logical step-wise framework for addressing water research needs as stated previously for the State of Wyoming and the region. To demonstrate the Center's implementation of priority research, Figures 1 and 2 indicate how our projects relate to the various topics under major research priority areas.

Fiscal Year 1989

STATE OF WYOMING RESEARCH PRIORITIES

	Project 02 Development of a Chemical & Biological Method to Reclaim Alkaline Solid Wastes K.J. Reddy & S.E. Williams	Project 03 Uncertainty Analysis of Water Quality Models & Its Applications to Risk Assessment & Management Y.K. Tung S.D. Shih	Project 04 Transformation & Stimulated Plant Uptake of Selenium by Soil Micro-organisms S. Williams	Project 05 Assmt. of Potential Environmental Impact of Saline Oil-Field Discharges into Salt Cr. & the Powder River, WY H. Bergman	Project 06 Evaluation of an Alternative Conveyance Strategy for Municipal Water Q.Skinner & T. Wesche	Project 07 Snowy Range Observatory: Maintenance & Evaluation T. Wesche & Y.K. Tung
GROUND & SURFACE WATER RESOURCES						
Water Quantity & Management		X			X	X
Water Quality	X	X		X		X
Legal & Institutional						
WATERSHED & RIPARIAN ZONE MANAGEMENT						
Groundwater Storage					X	
Surface Water Storage						
Non-Point Sources of Pollution			X		X	X
Riparian Ecosystems			X		X	
WATER DEVELOPMENT & CONSERVATION						
Improving Water Mgmt.						
Legal & Institutional						
Environmental Relationships	X			X	X	
Multiple Uses					X	

Figure 1. State of Wyoming Research Priorities and Projects Funded by USGS Through the Wyoming Water Research Center.

Fiscal Year 1989

FEDERAL RESEARCH PRIORITIES

	Project 02 Development of a Chemical & Biological Method to Reclaim Alkaline Solid Wastes K.J. Reddy & S.E. Williams	**Project 03** Uncertainty Analysis of Water Quality Models & Its Applications to Risk Assessment & Management Y.K. Tung S.D. Shih	**Project 04** Transformation & Stimulated Plant Uptake of Selenium by Soil Micro-organisms S. Williams	**Project 05** Assmt. of Potential Environmental Impact of Saline Oil-Field Discharges into Salt Cr. & the Powder River, WY H. Bergman	**Project 06** Evaluation of an Alternative Conveyance Strategy for Municipal Water Q.Skinner & T. Wesche	**Project 07** Snowy Range Observatory: Maintenance & Evaluation T. Wesche & Y.K. Tung
WATER QUANTITY						
Water Distribution						
Dynamics of Ground/ Surface Water Interaction					X	X
WATER QUALITY	X	X		X		X
INSTITUTIONAL RELATIONS						
UTILIZATION AND CONSERVATION OF WATER						
Enhancement of Water Use Efficiency						
Improved Water Management						
ECOLOGICAL/ENVIRONMENTAL RELATIONSHIPS						
Instream Flow Needs					X	
Wetland Hydrology			X		X	
Impact of Pollutants	X	X	X	X		X

Figure 2. Federal Research Priorities and Projects Funded by USGS Through the Wyoming Water Research Center.

RESEARCH PROJECT SYNOPSES

SYNOPSIS

Project number: 02 Start: 6/89
End: 5/91

Title: Development of a chemical and biological method to reclaim alkaline solid wastes

Investigators:

Reddy, Katta J. and Williams, Stephen E.
University of Wyoming

COWRR: 05G **Congressional District:** First

Descriptors: Groundwater quality, pollution control, power plants, toxic substances, waste disposal

Problem and research objectives:

Fly ash is normally disposed of by temporary ponding (usually on site) followed by excavation and subsequent use as fill material, whereas spent shale is often disposed on the surface with a top soil cover. However, these disposal methods may not minimize contamination problems associated with these materials. Several researchers have expressed concern about the contamination of surface water and groundwater associated with fly ash and spent shale (Parker et al. 1979; Thesis et al. 1979; Garland et al. 1979; Harbert et al. 1979; Fransway and Wagenet, 1981; Wildung and Zachara, 1980; Stark and Redente, 1986; Rai et al. 1987). The alkaline nature of these materials also presents problems for successful reclamation efforts e.g., revegetation. Thus, there is a need for developing effective methods that minimize pollution of natural resources associated with these materials. The objectives of this research project are to:

A. Develop a method to lower the alkalinity of fly ash and spent shales by exposing these waste materials to CO_2 gas under pressure and in the presence of moisture (recarbonation).

B. Determine the effect of lowering alkalinity on solubility and availability of As, B, F, Mo, and Se in fly ash and spent shales.

C. Determine the biological activity of these waste materials. This will include determination of biological activity prior to lowering of alkalinity as well as post alkalinity moderation. Biological activity will include microbial activity and capacity of the waste material to support growth of introduced plants and microorganisms.

Methodology:

Objective A: Fly ash samples were collected from the Wheatland, Rock Springs, and Dave Johnson power plants in Wyoming. We are presently working with Lurgi, PPP6, and PPP3 spent shale samples under an ongoing geochemical modeling project. These spent shales and the above fly ash samples were used in this study.

A 30 cm dia. by 55 cm long reaction vessel was connected to a CO_2 gas tank through an H_2O chamber to saturate the CO_2 with H_2O. A pressure relief valve was inserted on top of the lid to release excess pressure from the vessel. A pressure gauge and a thermometer were installed on top of the lid to monitor pressure and temperature inside the vessel, respectively. Four stainless screens with filter papers were placed inside the vessel to hold samples. The gas outlet from the reaction vessel was vented into a fume hood.

Objective A consisted of these experiments with each material. In the first set of experiments a sample (50 to 100 g) of air dried fly ash, spent shale, and a mixture of fly ash and acid coal mine spoils was spread over the filter papers. Before connecting the gas outlet to the digital pressure gage, CO_2 gas from a gas tank bubbled through distilled H_2O, using a sparger, to purge the initial air from the reaction vessel. Approximately 5 psi pressure was applied to the sample during recarbonation. After 1h reaction time, the sample was removed and sufficient distilled H_2O added to the recarbonated sample to prepare a saturated paste. The saturated paste was allowed to equilibrate with atmospheric air until the pH of the paste stabilized. The pH of the paste was measured daily. When the pH of the paste was stabilized, the sample was used for subsequent solubility and availability experiments. In the second and third sets of experiments, the same procedure was used, but the pressure was increased up to 10 and 15 psi, respectively. All three sets of experiments were conducted in triplicate to obtain data for statistical analysis.

Objective B: Recarbonated samples from the previous experiments and unrecarbonated samples were X-rayed to examine mineral changes associated with recarbonation. We are in the process of conducting solubility and availability experiments.

Objective C: We are in the process of conducting biological experiments before and after lowering the alkalinity of fly ash and spent oil shales.

Principal findings and significance:

A CO_2 pressure vessel was designed as shown in Figure 1 to accomplish the recarbonation.

A 30 cm dia. by 55 cm long reaction vessel was connected to a CO_2 gas tank through an H_2O chamber to saturate the CO_2 with H_2O. A pressure relief valve was inserted on top of the lid to release excess pressure from the vessel. A pressure gauge and a thermometer were installed on top of the lid to monitor pressure and temperature inside the vessel, respectively. Four stainless screens with filter papers were placed inside the vessel to hold samples. The gas outlet from the reaction vessel was vented into a fume hood.

Alkaline solid waste samples such as fly ash (from different power plants in Wyoming) and spent oil shale were collected to lower their alkalinity. We also collected acid mine spoils from Glenrock Coal Company, Wyoming to lower their acidity. Alkaline and mixtures of acid mine spoils plus fly ash samples were mixed with different amounts of H_2O and reacted in the CO_2 pressure vessel. The preliminary findings (Table 1) suggest that the CO_2 pressure process is an effective means of reducing the alkalinity of fly ash, spent oil shales, and acidity of mixtures of acid mine spoils plus fly ash.

We are in the process of optimizing the CO_2 pressure technique for different alkaline and acidic solid wastes. We are also in the process of conducting chemical and biological studies of CO_2 pressure reacted samples.

Publications and professional presentations:

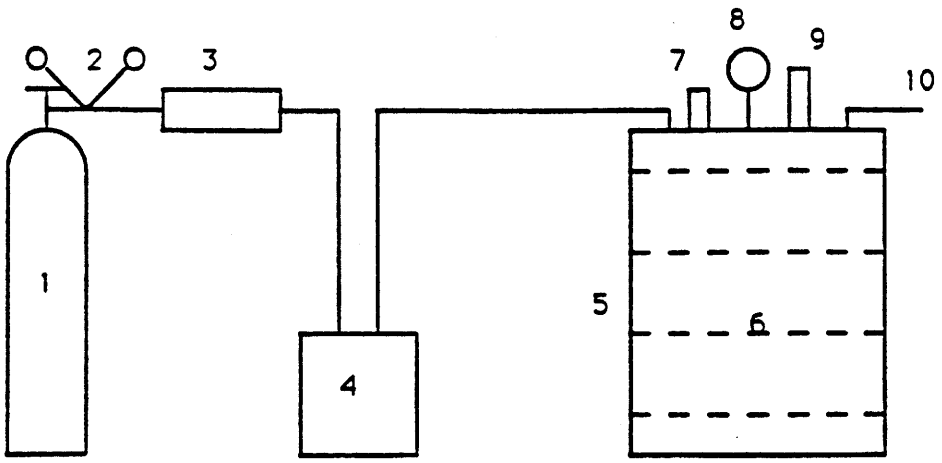
Reddy, K.J. 1990. Potential solid phases controlling the solubility of major and trace elements before and after lowering the pH of spent oil shales. Intnl. Conf. on Metals in Soils, Waters, Plants, and Animals. April 30-May 3, 1990. Orlando, FL.

M.S. theses:

None

Ph.D. dissertations:

None



1. CO_2 gas tank
2. Pressure regulator
3. Gas purifier
4. H_2O chamber
5. Reaction vessel
6. Stainless steel screen
7. Relief value
8. Pressure gauge
9. Thermometer
10. Gas outlet

Figure 1. A CO_2 pressure vessel designed to accomplish recarbonation.

Table 1. The effect of CO_2 pressure treatment at 25 psi for 1 hour on the pH of different fossil fuel solid wastes (100 g sample size).

Solid Waste	Treatment		pH**	
	Moisture (%)	Mixing* Ratio	BR	AR
Fly ash	15	---	12.50	8.00
Spent oil shale	20	---	12.10	8.50
Acid mine spoil	15	1:1	3.00	8.63

* 50 g of acid spoil and 50 g of fly ash

** pH measured in saturated paste

BR = before pressure treatment

AR = after pressure treatment

SYNOPSIS

Project Number: 03 Start: 6/88 End: 5/90

Title: Uncertainty Analysis of Water Quality Models and Its Applications to Risk Assessment and Management

Investigators: Tung, Yeou-Koung and Shih, Shagi-Di
University of Wyoming, Laramie

COWRR: 05G **Congressional District:** First

Descriptors: optimization, systems analysis, water quality modeling, statistics, water quality management, Streeter-Phelps Equation

Problem and research objectives:

Water quality models are frequently used to assist water resource engineers and planners assessing the impact of various proposed water quality management plans. Most water quality models used in planning processes are deterministic without considering the existence of uncertainties in water quality models. Information obtained from such deterministic models is limited in the sense that single-value system response is obtained from the model. In reality, because of the existence of various uncertainties in water quality modeling, the system response under a given input condition is random which can only be assessed by probabilistic approaches. The result of probabilistic analysis provides full spectrum of all possible system response that can be utilized to make much more sound decision in environmental management.

In addition, most commonly used BOD-DO models in water quality modeling do not consider or simply ignore the presence of dispersion which is a small-valued parameter. The inclusion of dispersion coefficient causes two major difficulties: (1) the governing partial differential equations are parabolic to which the analytical solution is difficulty to derive and (2) most numerical methods for solving such small-valued parameter problems tend to be unstable. Without considering dispersion coefficient in transport mechanism would result in error in pollutant concentration estimation.

The research objectives include the following:

1. Perform uncertainty analysis of parameters in water quality model on instream dissolved oxygen (DO) concentration prediction.

2. Assess the probability distribution of instream DO concentration for various classes of stream systems.

3. Develop procedure for evaluating the risk of violating water quality standards.

4. Use singular perturbation techniques to derive BOD and DO concentrations considering the presence of dispersion.

5. Analyze the effect of dispersion on the DO and BOD concentrations.

Methodology:

In addition to the water quality parameters in the traditional Streeter-Phelps equation, the DO-BOD model considered in the study included other oxygen sources and sinks that contribute to instream BOD and DO variations. The factors considered are: (1) removal of BOD by sedimentation or absorption; (2) addition of BOD along the stretch by the scour of bottom deposits; (3) addition of BOD along the stretch by local runoff; (4) addition of oxygen by photosynthetic action; (5) removal of oxygen by the respiration of plankton and attached plants.

To investigate the relative importance of water quality with uncertainty, streams are categorized into four classes: sluggish, low, medium, and high velocity, according to Chadderton et al. (1982).

Uncertainty analysis was done by the Mean-Value First-Order Second-Moment (MFOSM) method. Result of such uncertainty analysis provides information about the relative contribution of water quality parameters on the overall uncertainty in DO prediction. Correlations among water quality parameters are also considered in the investigation.

In assessing the probability distribution of DO concentration, Monte-Carlo simulation was employed. Various parametric probability distributions were used for stochastic water quality parameters and their effects on the distribution of DO concentration were examined. The goodness-of-fit procedure was used to identify the most appropriate distribution for the DO concentration.

Advanced FOSM was used to evaluated the probability of violating water quality standards. The method is capable of taking into account non-normality of and correlation among stochastic water quality parameters. It overcomes the disadvantages of MFOSM method especially when the water quality model is highly nonlinear which is the case for DO models. Comparisons were made regarding the accuracy of the two FOSM methods.

The solution scheme used for solving the Streeter-Phelps BOD-DO model with dispersion is the singular perturbation technique. The method involves the determination of inner and outer solutions to the parabolic partial differential equations. An efficient scheme was developed in this research which is mathematically more precise and accurate than what have been developed thus far.

Principal findings and significance:

In uncertainty analysis, the relative importance of stochastic water quality parameters in terms of their contribution to the total uncertainty in DO prediction depends on the classification of stream. This observation has implications on water quality sampling program design for purpose of reducing uncertainty in DO prediction.

With regard to the distribution of DO concentration, either normal or lognormal distribution, in a great majority of the cases, provides the best fit. However, the most appropriate distribution (normal or lognormal) depends on stream classification and types of oxygen source and sink terms in the water quality model. The use of the correct probability distribution for DO concentration has important effect on the accuracy of computing the probability of violating water quality standard.

Compared with the results from Monte-Carlo simulation, Advanced FOSM method provides more accurate calculation for the probability of violating water quality standards than the Mean-Value FOSM method. Computations involved in the Advanced FOSM method are more complex than those in the Mean-Value FOSM method. Judging from the environmental, ecological, social, and economic implications of such violation events, the ability to accurately assess violation probability given by the Advanced FOSM method should override its disadvantage due to computational complexity.

Various practically foreseeable initial and boundary conditions in BOD-DO modeling were considered and solutions developed. The results are useful and can be readily employed by engineers to assess the effect of waste discharge on stream water quality. Comparisons were made, under various conditions, for DO profiles with and without considering dispersion. The difference in some instances were quite significant.

Publications and professional presentations:

Tung, Y.K. and Hathhorn, W.E. 1990. Stochastic waste load allocation. Journal of Ecological Modelling., 51: 29-46.

Tung, Y.K. 1990. Evaluating the probability of violating dissolved oxygen standard. Journal of Ecological Modelling, 51: 193-204.

Tung, Y.K. Uncertainty analysis of DO models. Journal of Environmental Engineering, ASCE. (under review).

Shih, S.D. and Tung, Y.K. On Streeter-Phelps model by singular perturbation techniques. Journal on Applied Mathematics, SIAM. (under review).

Shih, S.D. and Tung, Y.K. Solutions of Streeter-Phelps dispersion model. (in preparation).

Shih, S.D. and Tung, Y.K. Sensitivity analysis of Streeter-Phelps dispersion model. (in preparation).

Hathhorn, W.E. and Tung, Y.K. 1989. Water quality assessment in stochastic stream environments. Proceedings of 1989 ASCE National Conference on Environmental Engineering, July 10-12, Austin, Texas.

M.S. theses:

None

Ph.D. dissertations:

None

SYNOPSIS

Project Number: 04 Start: 6/88
End: 12/90

Title: Transformation and Stimulated Plant Uptake of Selenium by Soil Microorganisms

Investigator: Williams, Stephen E.
University of Wyoming, Laramie

COWRR: 05B **Congressional District:** First

Descriptors: selenium, biological treatment, plant growth, soil chemistry, soil microbiology, toxic substances

Problem and research objectives:

The objectives of this research are (1) the enumeration and identification of bacteria and fungi in the rhizosphere which are capable of oxidizing selenides and elemental selenium to selenates and selenites; (2) evaluate the potential for mycorrhizal and non-mycorrhizal test plants to take up selenides, elemental selenium, selenites, and selenates; and (3) ascertain, in a controlled environment, the rate at which selenium can move from geologic parent material into test plants.

Wyoming is underlain with a significant amount of seleniferous formations. These formations weather into soils which in turn support plant growth. The interactions of the roots of the plants with the chemicals available in the soil and water influence the population of microorganisms in this zone. Selenium is an element of concern in these soils if it can be altered by the microorganisms into a form which is easy to be taken up by plants. Plant uptake of selenium enables it to enter the food chain, as it becomes available to animals as forage, and can be toxic if concentrated by the plant or plants known to be capable of this uptake of selenium.

The major concern of this research is that microorganisms that inhabit the rhizosphere will play a major role in the modification of the bioavailability of selenium and will determine the uptake of selenium by plants. Chemical transformations by bacteria which have been studied include nitrogen transformation from atmospheric nitrogen into bioavailable forms (nitrate and ammonium) and sulfur transformation by bacteria (in which they gain energy). Mycorrhizal fungi, which form a symbiotic relationship with plant roots of most land plants, are considered essential for the normal growth and development of the plants by enhancing plant uptake of nutrients and water. Understanding the

interrelationship of these types of microbes with selenium will enable better understanding of selenium activity within this ecosystem.

Methodology:

Field sites were located in Albany County and Natrona County. The site in Albany County was a seleniferous native rangeland site from which Astragalus bisulcatus and Astragalus pectinatus were harvested. The sites in Natrona County included two irrigated alfalfa fields and two rangeland sites which contained volunteer alfalfa.

Soil samples from these sites indicated that selenium was present. The soils were sampled for total selenium, DTPA-TEA extractable selenium, soil organic matter, pH, phosphorus, and electrical conductivity. Soils samples were frozen in order to identify soil microorganisms which could alter selenium. Plants from the area were sampled for selenium by obtaining roots and leaves of the Astragalus species and leaves of the alfalfa. Plant samples were analyzed throughout the growing season, and root samples were stained to determine the presence of v.a. mycorrhizae.

Principal findings and significance:

Accomplishments of this project to date include:

1. Sampling of A. bisulcatus and A. pectinatus plants from a site in southeastern Wyoming and determination of selenium content of these plants. Plants were also studied for v.a. mycorrhizae.

2. Sampling of numerous soil pits from the site in southeastern Wyoming and analyzing the soil for bacteria, fungi, and actinomycetes which alter selenium.

3. Studying the selenium content of alfalfa grown on seleniferous soils in the Kendrick Irrigation Project (Casper, Wy.) over a growing season.

4. A greenhouse project studying uptake of selenium (as Se elemental, Se^{+4} and Se^{+6} in accumulator species was performed and results are pending.

Publications and professional presentations:

Williams, Stephen E. Selenium content of two-grooved and tine-leaved milk vetches in native range soils as a function of time. To be presented at the American Society of Agronomy Annual Meeting (Soil Microbiology and Biochemistry Division) in San Antonio, Texas October 21-25, 1990.

Havener, Celeste. Influence of curing on selenium content of alfalfa grown on seleniferous soils. To be presented at the American Society of Agronomy Annual Meeting (Soil Microbiology and Biochemistry Division) in San Antonio, Texas October 21-25, 1990.

Williams, Stephen E. Influence of rhizosphere microorganisms on uptake of selenium by two-grooved and tine-leaved milkvetches. Presented at the American Society of Agronomy Annual Meeting (Soil Microbiology and Biochemistry Division) in Las Vegas, Nevada, October 15-17, 1989.

M.S. theses:

None

Ph.D. dissertations:

None

SYNOPSIS

Project Number: 05 Start: 6/88 End: 5/90

Title: Assessment of Potential Environmental Impact of Saline Oil-Field Discharges into Salt Creek and the Powder River, Wyoming

Investigator: Bergman, Harold L.
University of Wyoming, Laramie

COWRR: 05C **Congressional District:** First

Descriptors: toxic substances, brackish water, water quality control, industrial waste water

Problem and research objectives:

Discharge of co-produced water from oil fields is becoming a controversial issue in key oil producing regions of Wyoming and other western oil states. Concerns are based on potential effects of toxic and saline releases from oil production to ground and surface waters. The waters produced are typically high in total dissolved solids and may contain a variety of other inorganic and organic constituents, all of which have a potential for toxicity to freshwater organisms. Adverse impacts from these discharges could include effects on downstream water uses for wildlife, agriculture and municipalities.

Salt Creek, a major tributary of the Powder River in northeastern Wyoming, flows through a large oil-producing basin. To evaluate potential effects of oil-field discharges on Salt Creek and the Powder River we used acute and chronic toxicity tests with fish and invertebrates, and chemical analyses. The objectives of this study were to (1) estimate the ambient toxicity of Salt Creek and Powder River waters, (2) collect and extract river sediments for toxicity tests, (3) use Toxicity Identification Evaluation (TIE) procedures to identify the toxic fraction of water and/or sediments, and (4) conduct a qualitative survey of stream fauna upstream and downstream from oil-field discharges.

Methodology:

During Year 1 (1988-89) we collected water samples from three sites in Salt Creek and three sites in the Powder River during high (May), medium (October) and low (August) flow periods for the rivers. Each water sample was tested for effects on 7-day survival and growth of fathead minnows (Pimephales promelas) and 7-day survival and reproduction of

Ceriodaphnia dubia, an aquatic invertebrate. Chemical analyses included routine water chemistry parameters, major inorganic ions, ten trace elements, and reverse-phase high performance liquid chromatography (HPLC). Benthic macroinvertebrates were qualitatively sampled at each site and preserved for identification.

In Year 2 (1989-90), we collected water samples from two sites downstream from the oil-field discharges in September, and water and sediment samples at one site above and one below the discharges in February. We conducted acute toxicity tests on all water samples, sediment pore water and sediment extracts, and on a reconstituted salt solution containing major cations and anions at concentrations similar to toxic stream waters.

Two toxic stream water samples were examined using TIE procedures. Chemical analyses included routine water chemistry parameters, major inorganic ions, four trace elements, and HPLC analyses of water samples and sediment extracts, including samples that were trace-enriched for organics.

Principal findings and significance:

In Year 1 there were no significant effects on fathead minnow survival, compared to the upstream Salt Creek control, in any of the water samples from Salt Creek or the Powder River. Fathead minnow weights were significantly ($P < 0.05$) reduced at all sites during low flow, compared to the upstream control. No Ceriodaphnia survived in Salt Creek waters below the oil fields during any of the sampling periods, and during low flow, no Ceriodaphnia survived in ambient water samples from Salt Creek or from the Powder River below the confluence with Salt Creek, as far as 68 km downstream from the confluence. Diluting the toxic waters by 50% with reconstituted water reduced the toxicity in most cases. Where Ceriodaphnia survival was not affected, reproduction usually was not affected as well.

Concentrations of Na^+, K^+, Cl^-, HCO_3^- and CO_3^{2-} increased considerably in waters collected downstream of the oil field discharges, and pH values increased also. Regression analyses indicated that these parameters contributed significantly to the observed toxicity. None of the trace element or HPLC analyses revealed heavy metal or organic contaminants that could be identified as possible toxicants.

Physical habitat for benthic macroinvertebrates was very poor at most study sites, and the qualitative stream fauna survey did not reveal any obvious trends that could be correlated with oil-field discharges.

During Year 2 we performed acute tests only with Ceriodaphnia since it was the more sensitive species. No

Ceriodaphnia survived in the two samples collected below the oil fields in September. However, the water sample taken from one of these sites in February, and the sediment pore waters and water extracts of sediments from this same site, were not toxic.

None of the TIE manipulations performed on the toxic water samples from September reduced toxicity, suggesting that heavy metals, organics, ammonia and oxidizing agents were not causing the observed toxicity. Further, none of the HPLC analyses revealed any obvious contamination of stream waters or sediments with high molecular weight organic compounds. Salt water solutions, reconstituted to match the concentrations of major inorganic ions in the toxic stream water samples, caused nearly identical toxicity as the stream water. This together with negative HPLC and TIE results indicates toxicity of these samples was mainly due to the salt content.

Results of this study indicate that (1) production water discharges from the upper Salt Creek oil field are responsible for toxicity of surface water samples from Salt Creek and the Powder River to fathead minnows and Ceriodaphnia dubia, (2) toxicity increased as stream flow decreased, (3) toxicity could not be attributed to trace elements or organic compounds as measured in this study, and (4) the high salt content (i.e., major inorganic ions) of stream waters below the discharges appeared to be the main cause of the observed toxicity.

Publications and professional presentations:

Lamming, F.N., A.M. Boelter, D.R. Mount, J.D. Fernandez and H.L. Bergman. 1988. Effects of Saline Oil-Field Discharges into Surface Waters. Presented at the Ninth Annual Meeting of the Society of Environmental Toxicology and Chemistry. Arlington, VA. November 13-17.

Lamming, F.N., A.M. Boelter and H.L. Bergman. 1990. Assessment of Potential Environmental Impacts of Saline Oil-Field Discharges into Salt Creek and the Powder River, Wyoming: Year 1 Progress Report. Report No. G1600-05. U.S. Geological Survey, Department of the Interior.

Lamming, F.N., A.M. Boelter and H.L. Bergman. 1990. Assessment of Potential Environmental Impacts of Saline Oil-Field Discharges into Salt Creek and the Powder River, Wyoming. Presented at Petroleum Association of Wyoming/Wyoming Department of Environmental Quality Produced Water Seminar, Casper, WY. April 24-25.

Farag, A.M., A.M. Boelter, F.N. Lamming and H.L. Bergman. 1990. Use of Ambient Toxicity Tests to Assess Impacts of Saline Oil-Field Discharges into Salt Creek and the Powder River, Wyoming. To be presented at the Eleventh Annual Meeting of the Society of Environmental Toxicology and Chemistry, Arlington, VA. November 11-15.

Boelter, A.M., F.N. Lamming, A.M. Farag and H.L. Bergman. Environmental Effects of Saline Oil-Field Discharges on Surface Waters. (Manuscript in preparation).

M.S. thesis:

Lamming, F.N. Assessment of Potential Environmental Impacts of Saline Oil-Field Discharges into Salt Creek and the Powder River, Wyoming. (M.S. Thesis in preparation).

Ph.D. dissertation:

None

SYNOPSIS

Project Number: 06 Start: 6/88 End: 5/90

Title: Evaluation of an Alternative Conveyance Strategy for Municipal Water

Investigators: Skinner, Quentin D. and Wesche, Thomas A. University of Wyoming, Laramie

COWRR: 03D **Congressional District:** First

Descriptors: surface water, groundwater, streamflow augmentation, riparian vegetation, fisheries habitat, channel morphology, streams, conveyance systems

Problem and research objectives:

An alternative method for conveyance which to date has received little, if any, attention is the controlled release of diverted water into ephemeral watercourses, thereby creating a perennial stream with a flow regime similar to a spring-fed system. The City of Cheyenne, Wyoming is presently being required by the U.S. Forest Service, under advisement with the U.S. Fish and Wildlife Service and the Wyoming Game and Fish Department, to pursue such a conveyance strategy as one mitigation measure for its Stage II water development program. The intent is that, through this unique delivery system, municipal water can be used for aquatic and riparian resource enhancement. Little is known regarding the potential for success of this mitigative action.

As part of mitigation procedures for impacts caused by the Cheyenne Stage II water development project, the flow in a previously ephemeral watercourse on the east slope of the Laramie Range has been augmented to create a perennial stream. This mitigation strategy is being carried out in hopes of enhancing riparian and fisheries habitat. Over the past several years we have been conducting a comprehensive study to assess the results of this action on five miles of the South Fork of Middle Crow Creek and the feasibility of applying this strategy to other watersheds. Our project focuses on defining conveyance efficiency, channel development, groundwater storage, alteration of riparian vegetation, and formation of trout habitat. During the past year (July 1, 1989 to June 30, 1990), our objective has continued to be the evaluation of the hydrologic, hydraulic and ecologic response of the South Fork of Middle Crow Creek to streamflow augmentation.

Methodology:

During the past year, our continuing research efforts have focused on the following:

- Monthly water level measurements in the 234 wells which comprise our groundwater network along the five mile study reach;

- Operation of the six recording streamflow gages located throughout the research watershed;

- Measurement of the length of newly channelized reaches;

- Time-of-travel studies using fluorescent dyes to document annual changes in conveyance period;

- Resurvey of 47 valley bottom cross-sections to evaluate change by geologic, gradient and vegetative type;

- Vegetation sampling by plant community type (forest, shrub, herbaceous plants).

Principal findings and significance:

The project will be continuing during the next fiscal year with support from the USDA Forest Service. Recently, the South Fork research watershed has been designated a Forest Service "Riparian Demonstration Area". Findings after three years include the following:

1. Stream channel length has increased 50 percent, but still occupies only 35 percent of the total valley length within the study area.

2. In areas where a developed channel does not exist, water has spread across the valley floor, flooding the riparian zone to a depth of 2 to 5 inches.

3. The herbaceous plant species composition in the meadows is shifting from less water tolerant species, such as tufted hairgrass, to more water tolerant species, such as the sedges.

4. The proportion of bare ground has increased as much as 31 percent between years. This may increase the potential for accelerated channel development.

5. Suitable trout habitat in both stream and ponded areas has formed due to the enhanced flow. The ponds have been stocked with brook trout and now support a brook trout fishery.

Publications and professional presentations:

Henszey, R.J. 1988. Riparian zone changes caused by streamflow augmentation. Water Talk: An Interdisciplinary Seminar Series. November 9, 1988, University of Wyoming, Laramie. Sponsored by the Wyoming Water Research Center.

Henszey, R.J., S.W. Wolff, T.A. Wesche and Q.D. Skinner. 1988. Assessment of a flow enhancement project as a riparian and fishery habitat mitigation effort. In: Restoration, Creation, and Management of Wetland and Riparian Ecosystems in the American West. A symposium sponsored by the Rocky Mountain Chapter of the Society of Wetland Scientists, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and U.S. Bureau of Land Management. November 14-16, 1988, Denver, CO. (in press).

Wolff, S.W. 1988. Radio interview on "Insight", University of Wyoming state-wide broadcast, December.

Wolff, S.W., T.A. Wesche and W.A. Hubert. 1989. Stream channel and habitat changes due to flow augmentation. Regulated Rivers: Research and Management. Vol.4, 225-233.

Henszey, R.J., Q.D. Skinner and T.A. Wesche. Sedge, Tufted Hairgrass and Slimstem Reedgrass response after two years of streamflow augmentation. To be submitted to Regulated Rivers: Research and Management, Fall 1990. (In preparation).

Henszey, R.J. A simple, inexpensive device for measuring shallow groundwater levels. Journal of Soil and Water Conservation. (In review).

Henszey, R.J., T.A. Wesche and Q.D. Skinner. 1989. Creating a perennial stream from an ephemeral stream as mitigation for Cheyenne Stage II. Joint Meeting of the Wyoming Chapters of the Wildlife Society and Society of Range Management. Douglas, Wyoming.

Henszey, R.J., Q.D. Skinner and T.A. Wesche. 1990. Carex spp., Deschampsia cespitosa, and Calamagrostis neglecta response to four years of streamflow augmentation. Invited presentation, Ecological Society of America, Annual Meeting. Snowbird, UT.

Henszey, R.J., Q.D. Skinner, T.A. Wesche and S.W. Wolff. 1990. Modifying aquatic and riparian habitat with augmented streamflow in Wyoming. Society of Range Management, National Meeting. Reno, Nevada.

Henszey, R.J., Q.D. Skinner, T.A. Wesche and M.A. Smith. 1990. Sedge, tufted hairgrass and reedgrass response to four years of streamflow augmentation. Society of Range Management, National Meeting. Reno, Nevada.

Wesche, T.A. and Q.D. Skinner. 1990. The South Fork of Middle Crow Creek Research Demonstration Watershed. Invited presentation, Workshop on Management of Watershed Demonstration Areas. Oakland, CA.

Now that a channel is beginning to form, we anticipate additional use of the SFMCC as both a research demonstration and a teaching watershed. Presentations have been made to several Range Management watershed classes.

M.S. theses:

Henszey, R.J. 1988. Sedge, hairgrass, and reedgrass response after two years of streamflow augmentation. M.S. thesis, Department of Range Management, University of Wyoming.

Wolff, S.W. 1987. Evaluation of trout habitat formation due to flow enhancement in a previously ephemeral stream. M.S. Thesis, Department of Zoology, University of Wyoming.

Ph.D. dissertations:

While none were completed during the past year, Mr. Robert Henszey made significant progress on his research during the past year. Bob should complete his dissertation during FY91.

SYNOPSIS

Project Number: 07 Start: 6/88 End: 5/90

Title: Snowy Range Observatory: Maintenance and Evaluation

Investigators: Wesche, Thomas A. and Tung, Yeou-Koung
University of Wyoming, Laramie

COWRR: 02B **Congressional District:** First

Descriptors: hydrologic network, surface water, precipitation, watershed monitoring, streamflow, climatology, mountain lakes/streams, sedimentation, statistics

Problem and research objectives:

The Snowy Range Observatory (SRO) is a densely instrumented hydrologic research and educational watershed located in the Snowy Range Mountains 35 miles west of Laramie, WY. Centered in the 7.5 sq. mile Nash Fork Creek drainage of the Medicine Bow National Forest, the SRO has been maintained by WWRC and its predecessor WRRI since the mid-1960's. The network consists of 21 recording precipitation gages, 8 hygrothermographs, 6 anemometers and 7 streamflow gaging stations. Since its establishment, the SRO has served as the study area for a variety of hydrologic and ecologic research projects involving many departments and units at the University of Wyoming. Also, the Observatory has been used to educate over 100 graduate and undergraduate students in watershed data collection and analysis techniques.

During the past year, our objectives have been to:

1. Continue to operate and maintain the instrument network;

2. Conduct an analysis of historic monthly precipitation data to determine the best statistical procedure for estimating missing data;

3. Evaluate the precipitation network design to streamline the data collection system;

4. Continue to investigate sediment transport characteristics of steep, rough mountain stream channels;

5. Continue information transfer and education activities.

Methodology:

Maintenance of the SRO is conducted on a weekly basis throughout the water year. This work entails the routine servicing of all instrumentation, the annual recalibration of each instrument, equipment repair, and the updating of stage-discharge relations at each streamgage station. Field charts are reduced by student research assistants and all data are entered onto the Water Resources Data System maintained by WWRC on the University of Wyoming computer system.

The performance of four methods for estimating missing mean monthly precipitation data was evaluated. The methods tested were the Inverse Distance Weighting Method, the Optimal Weighting Method, the Cross Correlation Weighting Method, and the Variance Weighting Method. Data from nine precipitation gages for three different time periods were selected for this evaluation. Performance criteria were the root-mean-square-error and the mean-absolute error.

The goal of our study to streamline the SRO precipitation network design was to reduce maintenance/operation costs without significantly reducing hydrologic information content. First, a somewhat subjective selection of the reduced network was made based on the geographical locations of the existing stations as well as their accessability and aesthetic characteristics. Two reduced network configurations were considered, one having 15 stations and one having 12 stations. Contour maps for the means and variances of the monthly precipitation were then constructed for each month. The resulting contour maps based on the two reduced network designs were then statistically compared with those of all 21 stations.

A series of bedload and suspended load sediment samples are collected each year at each of the seven streamflow gaging stations using standard USGS procedures. Sampling is conducted during both the rising and falling limbs of the spring runoff hydrograph. These data are being used for the development and testing of sediment transport models applicable to steep, rough mountain stream channels in the Central Rocky Mountain region. These models will be used to evaluate instream flow regimes required below water development projects for channel maintenance and flushing purposes.

Principal findings and significance:

1. All SRO data for the project year have been collected as described above, with chart reduction and entry onto the WRDS nearly completed.

2. No single method was found to be consistently superior for estimating missing monthly precipitation data for

the SRO. Overall, however, the Linear Inverse Distance Weighting Method performed better than the other models tested.

3. Results of the network design study indicate that the differences in means between 15 and 21 stations or 12 and 21 stations are not statistically significant. As would be expected, our analysis shows that the more retained stations there are, the smaller errors that exist.

4. The development and testing of sediment transport models will not be completed until later in FY91. To date, the results of multivariate modelling using dimensionless hydrologic, hydraulic and geomorphic variables are encouraging.

5. Regarding information transfer and education, the SRO served as a field training site for the Wyoming Water Institute for Teachers during July of the past year. Also, 8 graduate and undergraduate students were employed and/or trained in watershed data collection and analysis throughout the project year.

Publications and professional presentations:

Since its establishment, the SRO has served as the study area for a variety of hydrologic, climatologic and biologic research projects involving many departments and units at the University of Wyoming. The results of this work have been detailed in 35 water resource series publications, 23 Master's theses and Ph.D. dissertations, and 58 journal articles and proceedings papers. Also, the SRO has been used to educate over 100 graduate and undergraduate students in watershed data collection and analysis techniques. It is presently within the study area of the Glacier Lakes Ecosystem Experimental Study Site of the U.S. Forest Service and University of Wyoming in cooperative research efforts on background studies of a pristine area to atmospheric deposition and transport.

Each year the data collected on the SRO have been reduced to a tabular form and entered on the WRDS database system for researchers and others to use who are interested in alpine watershed characteristics. The data are kept current.

Additional slides were taken of the Snowy Range Observatory and data collection procedures within the Observatory to enhance a slide series developed for both on- and off-campus groups.

The draft report regarding the significance of the Snowy Range Observatory in comparison to other Rocky Mountain

research and demonstration watersheds has been completed and is in final review.

M.S. Theses:

Choi, Joongkyu. 1990. Analysis of monthly precipitation and precipitation network design in the Snowy Range Observatory. M.S. Thesis, Department of Statistics, University of Wyoming, Laramie, WY. 134 p.

Ph.D. dissertations:

None

INFORMATION TRANSFER ACTIVITIES

June 1, 1989 - May 31, 1990

The Wyoming Water Research 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 June 1, 1989 through May 31, 1990 period have included: conducting, co-sponsoring and coordinating seminars, workshops and conferences on water resource issues and technological and management issues; the dissemination of water resource 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 the "Wyoming Hydrogram", WWDA "Water Flow Newsletter", and Land and Water Law Review.

WATER RESOURCE SEMINARS, WORKSHOPS AND CONFERENCES

The Wyoming Water Research Center conducted, co-sponsored and coordinated 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 encourage interagency coordination of water resource programs.

1. **Wyoming Water Resources Seminars:** The WWRC and University of Wyoming Cooperative Extension Service co-sponsored two regional **Water Resources Seminars** for the public. These seminars are held annually at community colleges around the state with presentations that address contemporary state and regional water issues. The 1990 Water Resources Seminars were held in Rock Springs, Wyoming

on April 5 and in Gillette, Wyoming on April 9. Issues addressed at the seminars included: the water supply outlook for the region, state water resource information systems, contemporary regional legal issues concerning water quantity and quality, weather modification, the state's proposed pesticide/groundwater management program, and impacts of proposed mining and coal gasification projects on water quantity and quality. Cooperating agencies in the seminar program included: Wyoming State Engineer's Office, USGS Cheyenne Office, Wyoming Water Development Commission, Joint Powers Water Board, USDA Soil Conservation Service, Wyoming Department of Environmental Quality, U.S. Department of the Interior, Bureau of Land Management, Wyoming Department of Agriculture, and Western Wyoming and Northern Wyoming Community Colleges.

2. **Wyoming Water Resources and Law Forum:** This annual information forum for state legislators was held February 14, 1990 and was co-sponsored by the Wyoming Legislative Services Office. Topics of discussion included Wyoming water law, interstate compacts and court decrees, Wyoming Water Development Commission studies and projects, North Platte and Wind River/Bighorn River management issues (federal reserved rights and interstate compacts), WWRC research projects and legislative/regulatory programs such as those proposed for underground storage tanks (the Water Pollution from Underground Storage Tank Correction Act of 1990 was subsequently passed by Wyoming legislators during the spring 1990 session).

3. **Water Talk Seminar Series:** This weekly series of presentations held during the fall and spring semesters on the UW campus provides a forum for information transfer and discussion of water resources related research conducted by UW and other university faculty and graduate students, as well as research conducted by federal and state agencies. Each of the 1989-1990 Water Talk seminars was videotaped and

copies of the videotapes were circulated to community colleges and federal and state agencies around the state. Video copies of the seminars are also maintained at the WWRC and distributed on request. Students in the water resources graduate program earn one hour credit by attending the seminars and are required to make a formal presentation of their thesis topic in the seminar program. Faculty working on research funded by WWRC are a regular part of the seminar series.

4. **Water Institute for Teachers:** A two-week Water Institute for Teachers (WIT) is held annually 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. The course is co-sponsored by the WWRC and UW Center for Teaching and Learning and is a combination of classroom sessions, hands-on activities and field trips. Participants earn two hours of credit. The WIT was held July 17-28, 1989.

5. **Groundwater Management Conference:** The Wyoming Water Research Center was a co-sponsor of the Groundwater Engineering and Management Conference, organized by the Colorado Water Resources Research Institute and Office of the State Engineer, held February 28 through March 1, 1990 in Denver, Colorado. A wide variety of regional groundwater issues and research results were discussed at the conference including: groundwater quality assessment, groundwater quality remediation, application of groundwater models, artificial recharge, data management and mapping, and aquifer management. The conference was attended by over 200 water resource specialists.

6. **Trelease Natural Resources and Water Law Symposium:** The Wyoming Water Research Center was a co-sponsor of the "Third Trelease Symposium on Natural

Resources and Water Law" held in Jackson, Wyoming, March 9-10, 1990. Discussion topics included federal reserved water right allocations, interagency management of the Yellowstone ecosystem, and the legal/regulatory potential for water right transfers in six western states.

COOPERATIVE EDUCATION AND RESEARCH EFFORTS

The Wyoming Water Research Center is working with state, regional and federal organizations to coordinate and improve the effectiveness of water resource education programs.

1. **Wyoming Water Quality Issues Task Force:** The WWRC associate director for information transfer is a member of the University of Wyoming, Cooperative Extension Service, Water Quality Issues Task Force. The purpose of this task force is to identify state water quality education needs and develop educational materials and workshops so that extension agents throughout the state will be able to provide the public with accurate and timely water quality information. Two task force meetings were held in the spring of 1990 to start this four year program.

2. **Coordination of Water Quality Education Programs:** Several agencies in Wyoming were developing independent nonpoint source water quality education programs. The Wyoming Water Research Center has initiated and is coordinating a memorandum of understanding with the agencies that have primary responsibility for nonpoint source water quality education programs. The Wyoming Department of Environmental Quality, Wyoming Department of Agriculture, Wyoming Association of Conservation Districts, USDA Soil Conservation Service Wyoming District, and University of Wyoming Cooperative Extension Service at a meeting on April 17, 1990 agreed in principle to a MOU on nonpoint source education. The MOU being drafted by the WWRC specifies each

organization's responsibilities and encourages interagency coordination of water quality education programs.

3. **GPAC Water Quality Task Force:** The WWRC associate director for information transfer is a member of the Great Plains Agricultural Council, Water Quality Task Force. Objectives of the task force include assessing the need for increased emphasis in water quality research, extension and technical assistance programs and evaluation of the impact of current and proposed state and federal regulatory options to reduce nonpoint source pollution. The task force is composed of representatives from universities in Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming, and USDA Soil Conservation Service, Economic Research Service, Animal & Plant Health Inspection Service, and Agricultural Research Service officials. The first meeting of the task force was held May 7-8, 1990. The study timetable calls for a draft report to be completed by March 1991.

INFORMATION TRANSFER PUBLICATIONS

The Wyoming Water Research Center uses several types of publications in its information transfer activities. Information transfer publications for the report period include newsletters, bulletins, journals and technical reports.

1. **Wyoming Hydrogram:** The **Wyoming Hydrogram** is a newsletter produced and distributed bi-monthly by the WWRC. The newsletter is sent to over 1,300 people 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 on upcoming water resource workshops and conferences.

2. **WWRC News:** One page of the "Wyoming Water Flow Newsletter", published monthly by the Wyoming Water Development Association, is dedicated to news, research and education programs of the Wyoming Water Research Center. Subscriptions to the WWDA "Water Flow Newsletter" total approximately 700.

3. **Wyoming Water Law: A Summary:** The Wyoming Water Research Center and UW Cooperative Extension Service, in cooperation with the Wyoming State Engineer's Office, jointly published an updated bulletin on Wyoming water law (January 1990).

4. **Land and Water Law Review:** The College of Law at the University of Wyoming produces a refereed law journal, Land and Water Law Review, on a semi-annual basis. Several articles on western water issues are published each year in this journal. Interpretation and evolution of water law is a fundamental component in the understanding, allocation and use of Wyoming's water resources. Publication costs for the journal are partially funded by the Wyoming Water Research Center. Titles and authors of water articles published this past year are listed below:

"Introduction: Down the Imperiled Colorado", Bruce Babbitt, Land and Water Law Review, 25(1): 1-9.

"Quantification of Federal Reserved Indian Water Rights, 'Practicably Irrigable Acreage' Under Fire: The Search for a Better Legal Standard", Wyoming vs. United States, Case Notes-Water Law, Land and Water Law Review, 25(2): 417-434.

INSTITUTIONAL-SUPPORTED PROFESSIONAL PUBLICATIONS

See Table 1.

TABLE 1. INSTITUTIONAL-SUPPORTED PROFESSIONAL PUBLICATIONS

Technical Reports

Mills, J.P. and P. Huntoon. 1989. Foreland Structure and Karstic Ground Water Circulation in the Eastern Gros Ventre Range, Wyoming. Technical Completion Report to the U.S. Department of Interior, Geological Survey (USGS G1600-02). 101 p. + maps.

Pochop, L., R. Marston, G. Kerr and M. Varuska. 1989. Long-Term Trends in Glacier and Snowmelt Runoff, Wind River Range, Wyoming. Report to Wyoming Water Research Center. 65 p.

Rahel, F.J. and M.A. Bozek. 1989. Habitat Requirements of Young Colorado River Cutthroat Trout (Oncorhynchus clarki pleuriticus) in Relation to Alterations in Streamflow. Report to Wyoming Water Research Center. 71 p.

Wesche, T.A. 1989. Sediment Transport Relations and Channel Maintenance Implications for Big Sandstone Creek. 1989. Report to the Wyoming Water Development Commission. 44 p.

Henszey, R.J., T.A. Wesche and Q.D. Skinner. 1989. Evaluation of the State-of-the-Art Streambank Stabilization. Report to Wyoming Department of Environmental Quality, Water Quality Division. 224 p.

Tung, Y.K., Y. Bao and V.R. Hasfurther. 1989. Selecting Appropriate Flood Design Frequencies for Drainage Basins in Wyoming. Interim Final Report to the Wyoming Highway Department. 119 p.

Kerr, G.L. and V.R. Hasfurther. 1989. Caid Lateral 256 Conveyance Loss Study. Report to the Wyoming State Engineer's Office. 31 p.

Wetstein, J.H., V.R. Hasfurther and G.L. Kerr. 1989. Irrigation Diversions and Return Flows - Pinedale. Report to the Wyoming Water Development Commission and the Wyoming Water Research Center. 312 p.

Crocker, T.D., B.A. Forster, S.E. Atkinson and J.F. Shogren. 1989. Valuing Groundwater Protection Benefits. Report to the Wyoming Water Research Center. 131 p.

Reddy, K.J., J.I. Drever and V.R. Hasfurther. 1989. Application of a Geochemical Model to the Prediction of the Chemistry of Extracts From Non-Recarbonated and Recarbonated Spent Shales. Report to the U.S. Department of Energy and Western Research Institute. 17 p.

TABLE 1. INSTITUTIONAL-SUPPORTED PROFESSIONAL PUBLICATIONS (cont.)

Journal Articles

Marcus, M.D. 1989. Limnological Properties of a Rocky Mountain Headwater Reservoir. Water Resources Bulletin: 25(1): 15-25.

Adams, J.C., M.S. Lytle, D.G. Dickman, D.H. Foster, J.P. Connell and W.R. Bressler. 1989. Comparison of Methods for Enumeration of Selected Coliforms Exposed to Ozone. Applied and Environmental Microbiology 55(1): 33-35.

Young, M.K., W.A. Hubert and T.A. Wesche. 1989. Evaluation of Variation in Permeability Measurements When Using the MARK VI Standpipe. Canadian Journal of Fisheries and Aquatic Sciences 46(2): 447-450.

Tung, Y.K. and W.E. Hathhorn. 1989. Determination of the Critical Locations in a Stochastic Stream Environment. Ecological Modelling 45: 43-61.

Tung, Y.K. and W.E. Hathhorn. 1989. Multiple-Objective Waste Load Allocation. Water Resources Management 3: 129-140.

Reddy, K.J. and V.R. Hasfurther. 1989. Solubility and Release of Fluorine and Molybdenum From Oil Shale Solid Wastes. Water Research 23(7): 833-836.

Lansey, K.E., N. Duan, L.W. Mays and Y.K. Tung. 1989. Water Distribution System Design Under Uncertainties. Journal of Water Resources Planning and Management 115(5): 630-645.

Allen, M.B. and M.C. Curran. 1989. Adaptive Local Grid Refinement Algorithms for Finite-Element Collocation. Numerical Methods for Partial Differential Equations 5: 121-132.

Marston, R.A. 1989. Particulate and Dissolved Losses of Nitrogen and Phosphorus From Forest and Agricultural Soils. Progress in Physical Geography 13(2): 234-259.

Wesche, T.A., D.W. Reiser, V.R. Hasfurther, W.A. Hubert and Q.D. Skinner. 1989. New Technique for Measuring Fine Sediment In Streams. North American Journal of Fisheries Management 9: 234-238.

Wolff, S.W., T.A. Wesche and W.A. Hubert. 1989. Stream Channel and Habitat Changes Due to Flow Augmentation. Regulated Rivers: Research and Management 4: 225-233.

Squillace, M. 1989. Water Marketing in Wyoming. Arizona Law Review 31(4): 865-904.

TABLE 1. INSTITUTIONAL-SUPPORTED PROFESSIONAL PUBLICATIONS (cont.)

Journal Articles (cont.)

Reiser, D.W., T.A. Wesche and C. Estes. 1989. Status of Instream Flow Legislation and Practices in North America. Fisheries 14(2): 22-29.

Hathhorn, W.E. and Y.K. Tung. 1989. Bi-Objective Analysis of Waste Load Allocation Using Fuzzy Linear Programming. Water Resources Management 3: 243-257.

Adams, J.C. and Q.D. Skinner. 1989. Bacteriological Aspects of a Mountain Watershed. Toxicity Assessment: An International Journal 4: 309-315.

Lytle, M.S., J.C. Adams, D.G. Dickman and W.R. Bressler. 1989. Use of Nutrient Response Techniques to Assess the Effectiveness of Chlorination of Rapid Sand Filter Gravel. Applied and Environmental Microbiology 55(1): 29-32.

Books & Chapters in Books

Mays, L.W., Y.K. Tung and M.J. Cullinane, Jr. 1989. Methods for Component Reliability Analysis. Chapter 6 in Reliability Analysis of Water Distribution Systems. New York, NY: American Society of Civil Engineers. pp. 163-189.

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Tung, Y.K., L.W. Mays and M.J. Cullinane, Jr. 1989. Reliability Analysis of Systems. Chapter 9 in Reliability Analysis of Water Distribution Systems. New York, NY: American Society of Civil Engineers. pp. 260-298.

Bouchart, F., N. Duan, I. Goulter, K.E. Lansey, L.W. Mays Y.C. Su and Y.K. Tung. 1989. Reliability-Optimization Based Models. Chapter 14 in Reliability Analysis of Water Distribution Systems. New York, NY: American Society of Civil Engineers. pp. 472-532.

Marston, R.A. 1989. Geomorphology. In Geography in America. Columbus, OH: Merrill Publishing Company. pp. 70-94.

TABLE 1. INSTITUTIONAL-SUPPORTED PROFESSIONAL PUBLICATIONS (cont.)

Symposia Proceedings

Marston, R.A., L.O. Pochop, G.L. Kerr and M.L. Varuska. 1989. Recent Trends in Glaciers and Glacier Runoff, Wind River Range, Wyoming. In Proceedings of the Symposium on Headwaters Hydrology, (W.W. Woessner and D.F. Potts, eds.), American Water Resources Association, June, 1989. pp. 159-169.

Lowry, S., Q.D. Skinner and J.J. Jacobs. 1989. Economic Value of Riparian Zones in Differing Channel Conditions in Wyoming. In Symposium Proceedings of the 42nd Annual Meeting of the Society for Range Management, Billings, MT, Feb. 21. pp. 187-239.

Tung, Y.K. 1989. Uncertainty on Travel Time in Kinematic Wave Channel Routing. In Proceedings of the International Conference for Centennial of Manning's Formula and Kuichling's Rational Formula, May 22-26, 1989, Charolottesville, VA. pp. 767-781.

Wetstein, J. and V. Hasfurther. 1989. Response of a Surface Aquifer to Flood Irrigation. In National Water Specialty Conference Proceedings, July 17-20, 1989, Newark, DE, Irrigation and Drainage Division, ASCE. pp. 367-374.

Hathhorn, W.E. and Y.K. Tung. 1989. Water Quality Assessment in a Stochastic Stream Environment. In Environmental Engineering, Proceedings of the 1989 Specialty Conference, July 10-12, 1989, Environmental Division, ASCE: 600-607.

Wesche, T.A. and W.A. Hubert. 1989. Relation of Geomorphology to Stream Habitat and Trout Standing Stock in Small Rocky Mountain Streams. In Proceedings of the Wild Trout IV Symposium, September 18-19, Yellowstone National Park, Wyoming. pp. 170-171.

Adams, J.C., M.S. Lytle, D.G. Dickman and W.R. Bressler. 1989. Effectiveness of Killing Bacteria on Rapid Sand Filter Material by Ozonation as Measured by the Direct Viable Count. In Ozone in Water Treatment, Vol. 1, Proceedings of the Ninth Ozone World Conference, June 3-9, New York, NY. pp. 472-481.

TABLE 1. INSTITUTIONAL-SUPPORTED PROFESSIONAL PUBLICATIONS (cont.)

Other

Price, R.E. (editor). 1989. Governor's Economic Development Field Tour of Fremont County, Wyoming: Tour Guide and Information Booklet. June 28-30, 1989. 103 p.

Reddy, K.J., J.I. Drever, M.E. Essington and W.L. Lindsay. 1989. Selection of Standard Free Energies of Formation for Use in Soil Chemistry. Technical Bulletin 134, Strontium Supplement, Agricultural Experiment Station, Department of Agronomy, Colorado State University. 24 pp.

Miller, M.M. 1989. Environment and Society in the Manaslu-Ganesh Region of the Central Nepal Himalaya. A Final Report of the 1987 Manaslu-Ganesh Expedition, University of Idaho, Foundation for Glacier and Environmental Research, R.A. Marston, (editor). 114 p.

SERVICE ACTIVITIES

Water Resources Data System

The Water Resources Data System (WRDS) is a computerized data storage and analysis system housing the largest single repository of hydrological and climatological data for the State of Wyoming. WRDS databases include: surface water quantity, water quality, climate, well levels, and snow course.

WRDS is set up primarily to assist state agencies; however, the service is also provided to federal, county, and municipal agencies, as well as university faculty, private firms and citizens. Requests are made for database retrievals, data loading, mapping and graphics, statistical analysis, limited custom programming, and accessing other data systems.

The Wyoming State Engineer's Office provides funds in the amount of $70,000 annually through a service contract with the Wyoming Water Research Center.

Wyoming Water Bibliography

As part of the Water Resources Data System, the WWRC continues to work with the State Library in Cheyenne to provide search and retrieval on the Wyoming Water Bibliography (WWB) for state agencies in addition to updating the database itself with state documents. This service project originated at the request of the Governor's Office and has grown to become the most comprehensive, multidisciplinary, computer-based bibliographic storage and retrieval system

regarding Wyoming's water resources. The WWB contains approximately 13,000 citations.

COOPERATIVE ARRANGEMENTS

ADMINISTRATION

As specified in its charter, the Wyoming Water Research Center has responsibility for 1) Service, 2) Extension, 3) Research, and 4) Instruction. The Director, in keeping with the Center's charter, and in cooperation with the State of Wyoming, has spent the majority of his time in organizing the following services.

1. **Service**

Service to State Agencies

- Continual liaison with state agency officials. Table 2 lists cooperating state agencies and Table 3 lists specific projects performed in response to state requests.
- Basic technology transfer to state agencies and Wyoming water users and managers.
- Serve as advisor to Wyoming Water Development Commission and review proposals for work from consultants.
- Continued attempts to integrate state and federal research programs.
- Interaction with State Legislature subcommittees (i.e., Select Water Committee).
- Participate in Governor's Selenium Work Group.
- Attend Governor's Water Forum.
- Attend meetings regarding specific research projects.

University Service

- Member, University of Wyoming Deans Council.
- Serve on University committees.
- Continued effort to apprise faculty members of research needs and opportunities in water-related research.
- Work with academic standards committee on Water Resources curriculum.

- Serve on appropriate graduate student committees.
- Serve on appropriate national and international technical review panels and committees.

TABLE 2: COOPERATING AGENCIES IN WYOMING

STATE:
Attorney General's Office
State Conservation Commission
Department of Agriculture
Department of Environmental Quality
Air, Land & Water Quality Divisions
Disaster and Civil Defense
Economic Development & Stabilization Board
Game & Fish Department
Governor's Office
Highway Department
Industrial Siting Administration
Legislative Services Office
Oil & Gas Conservation Commission
Recreation Commission
State Climatologist
State Engineer's Office
State Planning Coordinator's Office
Travel Commission
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 3. SERVICE-TO-STATE - FY1989

- Evaluation of Irrigation Diversions and Bank Storage Return Flows, Pinedale, Wyoming (Wyoming Water Development Commission and State Engineer's Office)
- Development of Methodology to Determine Flushing Flow Requirements for Channel Maintenance Purposes (Wyoming Water Development Commission, Wyoming Game and Fish, and U.S. Forest Service)
- Snowy Range Watershed Laboratory
- Riparian Zone Management, Muddy Creek, near Baggs, Wyoming (Ranchers, Water Quality Division of Department of Environmental Quality, U.S. Department of Agriculture, Bureau of Land Management, Soil Conservation Service)
- Enhancement of Aquatic/Riparian Ecosystems (Pole Mountain) (Wyoming Water Development Commission, Wyoming Game and Fish, and U.S. Forest Service)
- Climate Data Validation for Wyoming (State Engineer, Wyoming Water Development Commission and National Oceanic and Atmospheric Administration)
- Climatic Data Collection in Wyoming for Regional Climate Center in Lincoln, Nebraska (Farmers, Ranchers, Numerous State Agencies)
- Conveyance Losses in Natural Stream Channels (Wyoming Water Development Commission, State Engineer's Office, Board of Control)
- Compiling streamflow data for a portion of the State of Nebraska within the North Platte and Platte River Drainage (Wyoming State Engineer's Office, State Attorney General's Office)

Other

- Continued effort to be cognizant of regional and national water issues and research opportunities.
- Transfer of research results to appropriate users.

2. **Extension**

One of the four major missions of the WWRC involves extension activities. The WWRC believes in a strong water resources extension effort. The Associate Director for Extension and Information works in cooperation with the UW Agricultural Extension Service to develop expanded education programs among researchers conducting water-related research. It is our intention that both state and federal research results be packaged and presented in a useful and satisfactory manner to maximize the utilization of research effort and results.

Cokeville Elementary Research Project

In April, 1986, a researcher from the WWRC was invited to give a talk to a group of school children at Cokeville Elementary School in southwest Wyoming. The talk centered on scientific methods used in measuring weather and climate data (parameters), and subsequently resulted in a request by the students for hands-on experience in weather data collection.

A weather station (on loan from WWRC) which monitors precipitation and temperature data (minimum and maximum thermometers) was installed at the school during the summer of 1986. Data are continuing to be collected by the fifth and sixth grade students and submitted to the WWRC for input

into the University of Wyoming mainframe computer. Simple listings of the data are generated, in addition to plots of the data over time. All output is returned to the students.

Data generated from this station are also used to describe local weather conditions for the residents. The local Soil Conservation Service office helps maintain the station.

3. **Research**

- Federal Program FY89

Research accomplishments of the FY89 Federal Water Research Program were reviewed by the Director. The results of the projects sponsored with the FY89 monies have been provided to the Center's advisory committees and presented at professional meetings.

- Federal Program FY90

The Director solicited proposals under the FY90 Federal Water Research Program from interested faculty on campus and the seven community colleges. Proposals were received and reviewed by state agencies and regional Water Institute/ Centers--four were funded under the program; two were funded from state funds as match.

4. **Instruction**

The Wyoming Water Research Center is cooperating with academic departments throughout the campus to provide master of science degree programs which contain high quality multi-disciplinary training in water resources. The master of science degrees offered through these affiliations are

awarded as specialty options within the existing master of science programs currently housed within the sponsoring departments. The water resources emphasis will be acknowledged on the graduate transcript and thereby certify to potential employers that the candidate has completed an attractive, in-depth, multidisciplinary-course program in the broad area of water resources.

STATE CLIMATOLOGIST

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

SOIL 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 and modem. A computer account has been established on the SCS 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.

NATIONAL WATER DATA EXCHANGE

The WWRC serves as an assistance center for the National Water Data Exchange (NAWDEX) through a cooperative agreement for the purpose of helping users of water data identify and locate the data they need. The Center has access to several different data systems, including the Centralized Forecasting System (CFS) of the Soil Conservation Service; the Water Storage and Retrieval System (WATSTORE) and the Earth Science Data Directory (ESDD), both of the U.S. Geological Survey; the Storage and Retrieval System (STORET) of the U.S. Environmental Protection Agency; and the NAWDEX System itself.

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 seems to be working well. In 1982, the WWRC was restructured to 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 inputs of the Executive Office, the legislative branch of government, the academic community and the University administration (Table 4). 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 that 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.

A Citizens Water Issues Advisory Council (CWIAC) was formed in January 1984 and consists of members selected by the Governor (Table 5). The council was formulated to represent a) agriculture, b) recreation, c) municipalities, d) National Forest Service, Bureau of Land Management, Bureau of Reclamation, U.S. Fish and Wildlife Service, e) consulting engineers, f) State Legislature, g) industry, h) environmental interests, i) private citizens, j) legal profession, k) political action groups (e.g., League of Women Voters), l) Wyoming Higher Education System, and m) state agencies. The Council is charged with collecting input from constituencies, water experts within and outside the State, and other available sources, identifying water concerns and transmitting those concerns to the Research Review and Priorities Committee. The Council meets at least once a year.

TABLE 4

WYOMING WATER RESEARCH CENTER

RESEARCH REVIEW & PRIORITIES COMMITTEE

March, 1990

Governor Mike Sullivan
(ex officio)
State Capitol Building
Cheyenne, WY 82002
777-7434

Governor's Appointees:

Paul Schwieger (Chairman) (1983-1989)
Economic Development and Stabilization
Board, Water Division
Herschler Building
Cheyenne, WY 82002
777-7284

Dan Perdue
State Planning Coordinator[1]
Herschler Building
Cheyenne, WY 82002
777-7574

Myron Goodson (1988-1991)
Wyo. Water Development Commission
Box 429
Sundance, WY 82729
283-2407

Patrick O'Toole
Wyoming House of Representatives[1]
Box 26
Savery, WY 82332
383-2418

Jim Geringer
Wyoming Senate[1]
190 Preuit Road
Wheatland, WY 82201
322-9709

President Terry P. Roark
(ex officio)
Office of the President
University of Wyoming
766-4121

UW President's Appointees:

Steven P. Gloss (Exec. Sec.)
Director
Wyoming Water Research Center
Room 152, Vocational Annex
University of Wyoming
766-2143

Ralph DeVries[1]
Vice President for Research
Old Main
University of Wyoming
766-5353

Bill Gern (1988-1991)
Zoology & Physiology Dept.
Biological Sciences Building
University of Wyoming
766-4207

Quentin Skinner (1985-1988)
Range Management Department
Agriculture Bldg., Rm. 2028
University of Wyoming
766-4139

Victor Hasfurther[1]
State Climatologist
Wyoming Water Research Center
13th and Lewis Streets
Laramie, WY 82071
766-2143

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[1]Designated member of RRPC by Charter of WWRC.

TABLE 5

WYOMING WATER RESEARCH CENTER

CITIZENS WATER ISSUES ADVISORY COUNCIL

March, 1990

Walter Yose, Jr.
P.O. Box 94
LaBarge, WY 83123
386-2322

Russell Michael
Route #2
Torrington, WY 82240
788-1139

Jim Noble
Box 80
Cora, WY 82925
367-4553

Tom Hill
P.O. Box 6132
Laramie, WY 82070
745-3136

Cynthia Nunley
864 N. 4th
Lander, WY 82520
332-2442

James E. Kircher
U.S. Geological Survey
2617 E. Lincolnway, #B
Cheyenne, WY 82001-5662
772-2728

John Morris
10401 Experimental Farm Road
Cheyenne, WY 82009
634-7561

Beryl Churchill, Chairperson
RR3, 848 Road 10
Powell, WY 82435
754-4865

Steve F. Adams
Box 177
Baggs, WY 82321
324-7876

Doyl M. Fritz
Western Water Consultants, Inc.
Box 3016
Sheridan, WY 82801
672-0761

Dick Brown, Vice President
Pacific Power and Light Co.
P.O. Box 720
Casper, WY 82602
577-6901

Larry Wolfe
Holland and Hart
2020 Carey Avenue, Suite 500
Cheyenne, WY 82001
632-2160

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 1989 Program are indicated below.

TRAINING CATEGORY	ACADEMIC LEVEL				
FIELD OF STUDY	UNDER-GRADUATE	GRADUATE			
		MASTER'S DEGREE	PH.D. DEGREE	POST-PH.D.	TOTAL
Chemistry					
Agricultural Engineering					
Civil Engineering					
Environmental Engineering					
Geology					
Hydrology					
Agronomy					
Biology					
Ecology					
Fisheries, Wild-life & Forestry					
Computer Science					
Economics					
Geography					
Law					
Resource Planning					
Range Management		2			2
Other: (specify)					
Environmental Toxicology	2	2	1		5
Plant, Soil & Insect Sciences		1	1		2
Statistics		2			2
Mathematics		1			1
TOTAL	2	8	2		12