FISCAL YEAR 1990 PROGRAM REPORT

Wyoming Water Research Center

UNIVERSITY OF WYOMING

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by

Wyoming Water Research Center
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Laramie, WY 82071

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ABSTRACT

Four research projects were directly funded under the FY90 program, as well as information transfer activities. Two research projects were funded through the WWRC state grants program as part of the matching contribution. These six research projects relate to important water issues in the region and the State of Wyoming.

Reaction of CO_2 under pressure in fly ash and spent oil shale waste materials was shown to lower the pH of the materials and effectively reduced the concentrations of toxic elements (As, B, F, Mn and Se) as well as increasing the native population of microbes.

Movement of aldicarb through the unsaturated zone and in the groundwater of an agricultural area of Wyoming indicates that aldicarb itself is not persistent, but that the sulfoxide and sulfone metabolities of aldicarb may be quite persistent.

V.A. mycorrhizal fungi are found to be high in number in target plant species that have a high relative uptake of selenium compared to other low selenium uptake plant species and microorganisms are found which modify the bioavailability of selenium.

A solute transport process in water bodies which can be described mathematically by a nonclassical convection-dispersion model proved an excellent approximation for small dispersion and defined functional relationships for the time-distribution of pollutant concentrations.

Model(s) for estimating evapotranspiration for vegetation commonly irrigated in Wyoming are presently being compared in this two-year study for development of a consumptive use and irrigation water requirement manual for Wyoming.

A set of water education curriculum materials for elementary schools in Wyoming have been developed that will require intensive workshops and personnel with water knowledge to test the materials during the third year of this project.

Information transfer was accomplished through professional papers, a newsletter, research briefs, seminars and conferences, a water institute for teachers, extension efforts and database user information available through the WWRC.

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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 ground-water 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 were addressed.

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 seemed to be of most importance 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 or less amount of 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

Proposals were solicited in the following six areas in addition to a general list of research priorities contained in WWRC RFP-90-7.

WWRC-RFP-90-1. Hydrologic and Water Quality Impacts of Coalbed Methane Production in Wyoming

Project proposals in this area should examine the potential water-related problems associated with coalbed methane production in the state. Particular attention should be paid to describing the geologic setting for the activity, magnitude of groundwater depletion, preferred water use or disposal opportunities, potential water quality problems, impacts to existing groundwater users and techniques to evaluate these impacts. A geohydrologic model may be developed. Investigators should demonstrate awareness and understanding of previous studies on this topic sponsored by the Gas Research Institute, the Coalbed Methane Information Center at the Colorado School of Mines, and the Wyoming Geological Survey.

WWRC-RFP-90-2. Methods for Assessment of Groundwater-Surface Water Interactions

Development and utilization of either groundwater or surface water supplies has the potential for interactive effects on the other source. Project proposals should seek to develop new or synthesize existing methodologies/ techniques for predicting these kinds of interactions on the major aquifer types occurring in Wyoming. Naturally occurring groundwater sources (springs) should be included. Application of methods to representative case studies or proposed development scenarios may be considered.

WWRC-RFP-90-3. Human Health Impacts of Drinking Water Quality Standard Exceedance

Several domestic water supplies in Wyoming and adjacent states are known to be in violation of various Drinking Water Quality Standards according to the U.S. EPA. However, there is little known about the human health effects of exceeding these standards. Proposals should use epidemiological techniques to ascertain what human health impacts may have resulted from chronic exceedance of various drinking water quality standards.

WWRC-RFP-90-4. Consumptive Use of Surface and Ground Water in Wyoming.

The most recent estimate at selected weather stations of statewide consumptive use requirements for crops under irrigation in Wyoming is 20 years old. The WWRC would like to fund a project which would refine and expand this analysis in several ways. Using the most appropriate available techniques, provide contemporary estimates of 1) statewide consumptive water use by various types of irrigated agriculture with particular emphasis on new information available at higher elevations, 2) long-term averages of precipitation, temperature, and streamflow yield, and 3) consumptive water use by municipalities and industry. This project should not involve collection of new data related to these areas, but rather utilize the best currently available techniques and data. This effort should include a search for existing lysimeter studies from across the State for use in calibration of the appropriate techniques for estimating consumptive use.

WWRC-RFP-90-5. Analysis of Weather Modification

Weather modification projects have been carried out by the Bureau of Reclamation and other entities in several of the states surrounding Wyoming, as well as in the State of Wyoming. Proposals are requested which will analyze existing data gathering efforts, models and reports that address 1) downwind effects from cloud seeding, and 2) effectiveness of cloud seeding. Downwind effects from cloud seeding are of special interest with respect to surrounding states and their cloud seeding efforts in promoting less/more precipitation and changes in weather patterns which would affect conditions in Wyoming. Effectiveness of cloud seeding is of special interest with respect to cloud seeding efforts which occurred near Eden/Farson for many years, as well as general probabilities of increased cost/benefit on such things as crop yields and the skiing industry.

WWRC-RFP-90-6. Conveyance Losses in Natural Stream Channels

The prior appropriation doctrine in Wyoming allows for the transfer of a water right as long as the administrative authority (Board of Control) is satisfied that other prior rights within the stream system in which the transfer is being proposed will not be injured in any way. One facet of this "no injury" rule is conveyance or transmission losses in the natural stream system. Proposals should address methods and models for more accurately quantifying conveyance losses of increased water flows in natural stream channels that satisfy the prior appropriation doctrine in Wyoming.

WWRC-RFP-90-07. Additional State Research Priorities

The following outline of topics represents additional priority research areas established by the RRPC for the FY91 funding cycle. Major or subtopics identified by an asterisk (*) were given higher priority for funding assuming proposals received favorable peer reviews. However, innovative proposals in areas of lower priority, or in areas not listed below, were also given consideration.

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 stepwise 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 1990

FEDERAL RESEARCH PRIORITIES

	Project 02* Development of a Chemical & Biological Method to Reclaim Alkaline Solid Wastes K.J. Reddy & S.E. Williams	**Project 03** Transport, Detection and Degradation of Aldicarb in Droughty Irrigated Soils of the Big Horn Basin of Wyoming D.N. Barkan D.A. Nelson & R.C. Palmquist	**Project 04*** Transformation & Stimulated Plant Uptake of Selenium by Soil Microorganisms S. Williams	**Project 05** Theoretical studies of Pollutant Transport in Water Bodies S.D. Shih & Y.K. Tung	**Project 06** Consumptive Use and Irrigation Water Requirements for Wyoming L. Pochop, G. Kerr and V. Hasfurther R. Delaney	**Project 07** A Comprehensive Water Education Program for Wyoming's Elementary Schools R. Beiswenger, P. Ellsworth, V. Sindt & E. Sturges
WATER QUANTITY						
Water Distribution						
Dynamics of Groundwater/ Surface Water Interaction				X		
WATER QUALITY	X	X		X		
INSTITUTIONAL RELATIONS						
UTILIZATION & CONSERVATION OF WATER						
Enhancement of Water Use Efficiency					X	
Improved Water Management					X	
ECOLOGICAL/ENVIRONMENTAL RELATIONSHIPS						
Instream Flow Needs						
Wetland Hydrology			X			
Impact of Pollutants	X	X	X			

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

Fiscal Year 1990

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** Transport, Detection and Degradation of Aldicarb in Droughty Irrigated Soils of the Big Horn Basin of Wyoming D.N. Barkan D.A. Nelson & R.C. Palmquist	**Project 04*** Transformation & Stimulated Plant Uptake of Selenium by Soil Microorganisms S. Williams	**Project 05** Theoretical studies of Pollutant Transport in Water Bodies S.D. Shih & Y.K. Tung	**Project 06** Consumptive Use and Irrigation Water Requirements for Wyoming L. Pochop, G. Kerr and V. Hasfurther R. Delaney	**Project 07** A Comprehensive Water Education Program for Wyoming's Elementary Schools R. Beiswenger, P. Ellsworth, V. Sindt & E. Sturges
GROUNDWATER & SURFACE WATER RESOURCES						
Water Quantity & Management				X	X	
Water Quality	X	X	X	X		
Legal & Institutional Issues						
WATERSHED & RIPARIAN ZONE MANAGEMENT						
Groundwater Storage						
Surface Water Storage						
Non-Point Sources of Pollution	X	X				
Riparian Ecosystems			X			
WATER DEVELOPMENT & CONSERVATION						
Improving Water Management					X	
Legal & Institutional Issues						X
Environmental Relationships						
Agricultural/ Municipal/Industrial/ Recreational Uses					X	

Figure 2. State of Wyoming 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, Laramie

COWRR: 05G

Congressional District: First

Descriptors: groundwater quality, pollution control, powerplants, toxic substances, waste disposal, alkaline scale

Problem and research objectives:

The use of fossil fuels (e. g., coal and oil shale) for the production of energy in the nation has increased considerably over the last few decades and it is expected to continue growing. Wyoming is the nation's leading producer of coal. Some of the coal extracted is used within the state to produce electricity. Wyoming has an abundance of oil shale deposits.

In recent years, the quality of groundwater in the state has changed due to various activities including solid waste generation and disposal. Combustion of coal and oil shale often produce alkaline solid wastes commonly referred to as fly ash and spent shale, respectively. Several studies have shown pollution consequences (i.e., contamination of surface water and groundwater) associated with disposal of alkaline solid wastes.

Successful reclamation (e.g., revegetation) of alkaline solid wastes is hampered by the toxicity of plant nutrients and low activity of microorganisms. Thus, there is a need for developing effective methods that minimize pollution of natural resources associated with alkaline solid wastes. Objectives of this research were to:

A. Develop a method to lower the alkalinity of alkaline solid wastes by exposing these materials to CO_2 gas under pressure and in the presence of moisture.

B. Determine the effect of lowering alkalinity on solubility and availability of As, B, F, Mo, and Se in alkaline solid wastes.

C. Determine the biological activity of waste materials before and after treatment. These studies will include microbial activity and capacity of the waste material to support growth of introduced plants and microorganisms.

Methodology:

For alkaline solid wastes, we collected fly ash and spent shale samples from Wyoming. Two fly ash samples (fly ash 1 and fly ash 2) and two spent shale samples (PPP6 and Lurgi) were used in this study. Fly ash samples were collected from power plants, whereas spent shale samples were collected from the Western Research Institute, Laramie, WY. For initial characterization, samples were subjected to the following studies: precipitation/dissolution reactions, X-ray diffraction analysis, AB-DTPA extractable trace elements, total elemental analysis, and calcium carbonate analysis.

Standard guidelines were followed for collection and analysis of samples. Laboratory quality control procedures were: use of blanks, standard reference samples, duplicate or triplicate analysis, and spike recovery analysis. Biological activity of the samples were tested by plating the materials on various media and using plate counts to determine microbial populations existing within the samples. The capacity of the samples to support growth of introduced plants and microorganisms was determined by setting up a bio-assay using samples mixed with soil and sand at specific dilutions.

Objective A:

To lower alkalinity of samples, a 30 cm dia. by 55 cm long reaction chamber was designed. The reaction chamber was connected to an instrument grade CO_2 (99.9% pure) gas tank. 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 was vented into a fume hood.

Objective A consisted of preliminary experiments and optimization of treatment variables to develop CO_2 pressure process for chemical stabilization of alkaline solid wastes. Results from preliminary studies were very encouraging and the process appeared to be worthy of further investigation. However, the treatment variables (moisture, reaction time, and pressure) needed to be optimized. Subsequent experiments were designed to constitute a two-level, three-variable factorial design for optimization of treatment variables.

Overall, results from the above studies suggested that high moisture and longer reaction time played significant roles in success of CO_2 treatment. Higher pressure was not found to be necessary to lower the pH and the trace element concentrations. After optimization studies, approximately 1 kg samples of each of the waste materials (fly ash and spent shale) was prepared at 20% moisture and then reacted in the chamber for 5 days at 40 psi pressure. Samples were mixed well to ensure complete recarbonation of samples. After treatment, samples were transferred into plastic bottles and used for subsequent experiments.

Objective B:

Treated samples from the previous experiments were subjected to precipitation/ dissolution, X-ray diffraction, AB-DTPA extractable, and calcium carbonate studies to determine the effects of the CO_2 pressure process on the chemistry of alkaline solid wastes.

Objective C:

Biological experiments were designed to determine the existing microbial communities and the effects of innoculation of introduced biological constituents on the samples. Plating onto media was done to examine specific microbial communities and a bio-assay was done to assess the effect of the samples on plant growth.

Principal findings and significance:

Significant findings of this research include the following:

Fly ash and spent shale samples examined in this study were alkaline (pH ranged between 12.0-13.0) and consisted of significant concentrations of environmentally deleterious elements (e.g., Pb, Cd, Cu, Mn, Ni, Mo, As, B, F, and Se). Observed high pH of the untreated samples was due to the rapid reaction of oxide and silicate phases with water. Reacting samples at 40 psi pressure with 20% moisture for 5 days lowered pH to around 9.0 through the precipitation of calcite.

The AB-DTPA extractable studies suggested that CO_2 treatment was effective in reducing the concentrations of toxic elements. For example, Mn concentrations were decreased from 4.5 to 1.6 mg/L for fly ash 1 and from 31.0 to 5.4 mg/L for fly ash 2. Whereas for spent shale samples, treatment decreased Mn concentrations from 24.0 to 2.6 mg/L for PPP6 and 40.0 to 4.4 mg/L for Lurgi. Furthermore, results suggested that fly ash and spent shale samples were effective absorbents for CO_2. Biological studies suggested a general increase of native population of microbes in treated samples. However, the trend was subtle and would require further testing to prove results obtained from the biological experiments.

Findings of this study demonstrate that CO_2 pressure treatment is an effective means of reducing the alkalinity and the concentrations of toxic elements in alkaline solid wastes. The significance of this process is the fact that CO_2 is a by-product of the combustion process used to produce the solid waste and this can be collected for use in this process at little additional cost. Another potential benefit of the process is that it may help to reduce emissions of CO_2 into the atmosphere.

SYNOPSIS

Project Number: 03

Start: 06/90
End: 05/91

Title: **Transport, Detection, and Degradation of Aldicarb in Droughty Irrigated Soils of the Big Horn Basin of Wyoming.**

Investigators:

Nelson, David A., University of Wyoming, Laramie; Barkan, David N. and Palmquist, Robert C., Northwest College, Powell, WY.

COWRR: 05A

Congressional District: First

Descriptors: water quality monitoring, surface-groundwater relationships, pesticides, groundwater quality, groundwater hydrology, contaminant transport, agriculture

Problem and research objectives:

Droughty conditions and intense irrigation practices of agriculture in the Big Horn Basin, Wyoming, along with the widespread use of aldicarb within the basin (Taylor, 1983) make the study of its movement within the unsaturated zone of the soil and into the aquifer important. A large part of the basin is somewhat dependent upon the Powell Alluvial Aquifer for drinking water. This aquifer is continually recharged by irrigation water which is aldicarb contaminated during the growing season.

This project should yield the following results: (1) geo-hydrologic data for the test plots in the Powell Aquifer including ground water velocities and hydraulic gradients, (2) information relating to the ground water/surface water interaction in the transport of aldicarb and its degradative products to the Powell Aquifer, and (3) evaluation and potential development of a more sensitive method for the detection of aldicarb by use of a fluorescent analog which should give a better determination of minimum use levels.

Methodology:

Hydrology Studies:

Given the low gradient and the range of inferred values for the hydraulic conductivity (K), between 10^{-1} to 10^{-2} cm/sec for the gravels of the aquifer (Cherry and Freeze, 1979; Palmquist and Sendlein, 1975), most flow is expected to be nearly horizontal. The location, spacing, and depth of three test wells (piezometers) was determined. The direction of flow for the aquifer was found to be in a northeasterly direction from well A to well C. Because of this flow, any water flowing onsite is either from distant ditches to the southwest, irrigation, or a combination of both. In addition to the three piezometric wells used for water sampling on the University of Wyoming Research and Extension Center (UWREC), there are three developed wells that were monitored for aldicarb.

Field Studies:

Horizontal movement of aldicarb is being monitored by the sampling of the six test wells. Water was drawn from the three piezometric wells by a portable battery-powered pump, allowing the pump to run for a minimum of five minutes to completely replenish the standing water in the wells. The three developed wells were also allowed to run for a minimum of five minutes before being sampled. The temperature and pH of each sample were recorded. Samples were taken prior to and after application of aldicarb on the land. The pH of each sample was lowered to below 3 by the addition of 6 M HCl, and the samples were stored below 0°C in the dark. Water samples were taken in August, October, and December of 1990, and each month (January-May) in 1991.

Vertical movement of aldicarb is being monitored by analysis of core soil samples collected by a Giddings Probe to depths extending to the coarse gravels. Each core was divided into six-inch segments. Samples were taken from field plots 16 and 17 prior to and after application of aldicarb. Plot 16 had no aldicarb applied in 1991. The last application was in May, 1990. Plot 17 had aldicarb applied to the seed furrows at a rate of 8 oz. of Temik 15 (15% by weight of aldicarb) per 90,000 ft^2 on April 26, 1991. Temik 15 was also applied at the same rate to plot 15 on April 30, 1991. Field 16 was irrigated over a two day period, 13-14 May, and Field 17 was irrigated on 15-16 May. The soil samples were taken on March 13 and May 31.

Laboratory Analysis:

Soil Extraction: Each 6 inch core soil sample was dried in air at room temperature on aluminum foil and passed through a 1 mm sieve. A 25-g sample of the sieved soil was extracted with 25 mL of acetone:water 40:60 v/v in a capped centrifuge tube, shaken for 30 min. and centrifuged for 5 min. at 3000 rpm (2960g). The extract was decanted into a 60 mL sample bottle. A second extraction was performed with 20 mL of methanol:water 50:50 v/v, and the two extracts were combined. The combined extracts were stored below 0°C until analyzed.

Aldicarb Residue Analysis: A HPLC carbamate analysis system meeting the requirements of EPA Method 531 was used for analysis of aldicarb (AL), aldicarb sulfoxide (ASO), and aldicarb sulfone (ASO_2). The limit of sensitivity of the method was 0.5 $^{+}$/- 0.1 ppb for each of the three analytes, although estimates could be made down to 0.1 ppb. The water samples were injected directly after filtering through a 0.45 micron filter. A sample size of 500 microliters was used.

The soil extracts were first treated under reduced pressure at 40-50°C to remove the organic solvents before filtration and injection.

Synthesis of Fluorescent Analog of Aldicarb:

A fluorescent analog of aldicarb was synthesized as part of this project. A 3-cyano-5-methyl-2-pyridone fluorophore was chosen to tag the aldicarb because this structure had shown greater stability in sunlight and aqueous solution than other 3-substituted 2-pyridones. The behavior and fluorescent properties of this analog have not yet been determined.

Principal findings and significance:

This project is being continued with funding from the Wyoming Water Research Center. Only preliminary data were obtained during the project period.

Low levels (< 2 ppb) of aldicarb sulfoxide and sulfone, but no aldicarb, were detected in samples taken from the developed wells during the period August 1990 - April 1991. These locations are all on the southern edge of the test area, and would receive water flowing in the aquifer from the southwest. Likewise, similar results were obtained from the test (piezometric) wells A, B, and C. A is on the southern edge of the test area, B is on the northern edge, and C is on the eastern center edge. A and B showed no detectable aldicarb residues when sampled in January 1991. Levels of ASO and ASO_2 rose to 2 ppb in one of the developed wells in March along with the spring thaw and rising water levels in the wells, but then fell again in April to less than 0.5 ppb. No residues could be detected in wells B and C in April. A high level of around 10 ppb was found for aldicarb and aldicarb sulfoxide in Bitter Creek, a small drainage in the area, on May 7. This probably reflects run-off from other users in the area, since field 17 had not yet been irrigated. The only other water sample that was found to contain aldicarb was taken from an irrigation pipe on May 21. This is after active use of aldicarb has begun in the Basin. The level was low, about 1 ppb, but again this indicated that aldicarb is being dispersed in some general way. The irrigation water comes from a main canal located south of the UWREC.

Soil samples taken from Field 16 on May 31 showed aldicarb at levels of about 5 ppm of dried soil in the upper 6" - 12". Below that, only traces of ASO and ASO_2 were detected. This was the field that had aldicarb applied in 1990. This finding needs additional data for interpretation. It could indicate residues persisting from the previous year, or aldicarb that came in with the irrigation water. No additional soil samples have yet been analyzed.

These initial results seem to indicate that aldicarb is not persistent in the test area, but that the sulfoxide and sulfone metabolites are quite persistent. Since no data exist previous to this study, it cannot be determined whether these residues persist for more than one year. The very limited soil analysis data would seem to indicate that aldicarb does not extend much below the root zone. Similar results have been found in other studies. It would appear that only low levels of aldicarb or its metabolites will be found in the aquifer waters entering the test area, and therefore increases due to transport from local application should be definitely measurable. However, water samples taken during the height of the irrigation period have yet to be analyzed. There is definite evidence for aldicarb residue transport from areas "upflow" from the test area.

References:

Taylor, D.T., M.A. Ferrell, A.F. Gale, and T.D. Whitson. 1983. Pesticide use in Wyoming; Agricultural Extension Services, University of Wyoming.

Cherry, J.A. and R.A. Freeze. 1979. Ground Water. Chapter 2, Prentice-Hall, New York, NY. p. 29.

Palmquist, R.C., and L.V.A. Sendlein. 1975. The configuration of sontamination enclaves from refuse disposal sites on flood plains. Ground Water V. 13, p. 267-181.

SYNOPSIS

Project number: 04*

Start: 6/88
End: 5/91

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

Investigators:

Williams, Stephen E.
University of Wyoming, Laramie

COWRR: 05B

Congressional District: First

Descriptors: Vesicular-arbuscular mycorrhizal fungi, free living microorganisms, Astragalus bisulcatus, Astragalus pectinatus, selenium, selenate, selenite, aerobic, anaerobic, biological treatment, plant growth, soil chemistry, soil microbiology, toxic substances

Problems and research objectives:

Very little is known about how or why selenium is taken up from soil sources by seleniferous plants, such as Astragalus bisulcatus and Astragalus pectinatus. This research addressed the role which free living microorganisms and symbiolic micro-organisms have in mobility and uptake of selenium by these plants.

Methodology:

Three studies have been completed which address the role of soil microorganisms in selenium uptake by plants.

Astragalus pectinatus (two-grooved milkvetch), Medicago sativa (alfalfa), and melilotus officinalis (yellow blossom sweet clover), were planted in seleniferous soils which had been further supplemented with elemental and selenate selenium. The soil included top soil material which was abundantly populated by vesicular arbuscular (V.A.) mycorrhizal spores as well as subsoil which was lacking in V.A. mycorrhizal spores. At the end of the growth period, over 100 days, selenium levels of plants were determined and the infection rates of root systems by V.A. fungi.

In a field study, A. pectinatus (fine-leaved milkvetch) and A. bisulcatus were examined for the presence of V.A. mycorrhizal fungi and for nodulation. A native range site on the Harris Ranch 30 km north of Laramie was sampled weekly for about six months. Each week three A. bisulcatus and one A. pectinatus were excavated and roots examined for V.A. fungi and for the presence of nodules.

In another field location on the Harris Ranch, 9 pits were excavated across a transect which extended from a ridge of seleniferous materials to an intermittent lake, across a linear distance of about 1 km. Soils from all horizons in these pits were plated on a minimal media containing various levels of either selenate, selenite or no selenium. Plates were incubated aerobically and anaerobically.

Principal findings and significance:

A. pectinatus, M. sativa and M. officinalis were all shown to be heavily infected with V.A. mycorrhizal fungi in the soil having high populations of these organisms. Conversely, in soils lacking these organisms infection was low. Relatively high uptake of selenium by these target plant species was correlated with high V.A. mycorrhizal infection. Low selenium uptake was concluded with low infection. Although this information is somewhat circumstantial, it does suggest a role for V.A. fungi in stimulating the uptake of selenium by plants.

In the field study, A. bisulcatus and A. pectinatus were found to be heavily infected with V.A. mycorrhizae during all parts of the growing season examined. Further, these leguminous plants were found to commonly bear nodules. The clear results of this study is that V.A. fungi are common on the root systems of these plants under field conditions. The presence of nodulation on these plants is an indication that A. bisulcatus and A. pectinatus are somewhat independent of exogenous nitrogen.

In the transect study, it was noted that free living microorganisms capable of transforming selenium from highly soluble oxidized forms, such as selenite, to highly immobile reduced forms such as selenium metal, existed commonly in soils. Generally, these organisms were the most common in surface soils, but did also exist deeply in soils, sometimes to nearly three meters below the surface. Micro-organisms used selenite as a terminal electron acceptor even in the presence of free oxygen.

SYNOPSIS

Project Number: 05

Start: 06/90
End: 05/91

Title: Theoretical Studies of Pollutant Transport in Water Bodies

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

COWRR: 05C **Congressional District:** One

Descriptors: Water quality modeling, contaminate transport, groundwater quality, fluid flow, pollutants, saturated flow, unsaturated flow

Problem and research objectives:

Understanding pollutant transport mechanisms in water bodies, including surface and subsurface flows, is essential for risk assessment, pollutant cleanup, monitoring network design, and various other related activities. In this research, we consider a solute transport process in water bodies which can be described mathematically by a nonclassical convection-dispersion model (CDM) with arbitrary, time-dependent coefficients. In one spatial dimension this prototypical CDM is based on the linear parabolic partial differential equation

$$\frac{\partial c}{\partial t} - D\frac{\partial^2 c}{\partial x^2} + V(t)\frac{\partial c}{\partial x} = 0, \tag{1.1}$$

for $0 < x < \infty$, $0 < t < \infty$, where $c(x,t)$ is a resident solute concentration at the position x and time t; D is the positive-valued dispersion coefficient; and $V(t)$ is the mean solute velocity, which may be a function of time. In most practical applications, the values of D are very close to zero. The equation (1.1) is subject to the initial condition

$$c(x,0) = f(x), \tag{1.2}$$

for $0 < x < \infty$ and the Dirichlet boundary condition at $x = 0$

$$c(0,t) = g(t), \tag{1.3}$$

or the Robin boundary condition at $x = 0$

$$V(t)c(0,t) - D\frac{\partial c}{\partial x}(0,t) = g(t), \tag{1.4}$$

and the boundary condition at infinity

$$\lim_{x\to\infty} c(x,t) = 0; \tag{1.5}$$

for $0 < t < \infty$, where $f(x)$ and $g(t)$ are functions to be determined by the physical conditions of specific cases. For subsurface flows, description of the flow physics must often be augmented by chemical and/or biological considerations. This generally leads to convective-diffusive-reactive transport equations. When multiple species are present in the aqueous phase, the governing equations form a set of partial differential equations that are coupled through reaction terms. These equations generally need to be solved numerically. In this consideration, the most important factor is still convection domination.

Furthermore, uncertainties exist in model parameters (dispersion coefficient in particular), initial and boundary conditions. The presence of these uncertainties affects the calculated concentration of pollutant which, in turn, may have impacts on various decision making relating to water quality management, control, monitoring, and regulation.

The main objectives of the proposed research are as follows: (1) to determine a systematic way of finding a reasonable approximate solution to the concentration of a solute transport process based on singular perturbation procedures; (2) to compare the accuracy and behavior of concentration level based on the proposed procedures and the other solution techniques; and (3) to investigate the effect of uncertainties in model parameters, initial and boundary conditions on the pollutant concentration level computed by the model.

Methodology:

The proposed research was carried out in two phases. The first phase concentrated on the theoretical study of solute transport mechanisms in water bodies. The solution technique of singular perturbation was applied. More precisely, one constructs the *outer solution*, which is determined by a first-order hyperbolic partial differential equation and hence it is a good approximation to the concentration of solute transport for the entire domain except along a neighborhood of a curve called the characteristics of the first-order hyperbolic differential operator. Therefore the outer solution has a shock layer along the curve and is not *uniformly* valid for all intended values of the independent variables. Another type of solution which must be found for this domain by introducing a stretched variable along the curve of nonuniform approximation is called the *inner solution.* It satisfies a parabolic partial differential equation without a small parameter after scaling the original independent variables. The initial and boundary conditions are imposed in such a way that a matching principle between outer and inner solutions is valid and this inner function is important only near the curve. The inner solution is used to supplement the outer solution along the characteristic curve and their sum provides an approximation to the solute concentration for the entire domain. Results from the phase 1 study laid the foundation for the phase 2 study which examined the effect of uncertainties on model outputs.

Principal findings and significance:

For a constant dispersion $0 < D \ll 1$, the resident solute solution $c(x,t)$ defined by (1.1), (1.2), (1.3), and (1.5) can be approximated by the function $u(x,t)$ which is defined by the equation

$$\frac{\partial u}{\partial t} + V(t)\frac{\partial u}{\partial x} = 0, \tag{2.1}$$

for $0 < x < \infty$, $0 < t < \infty$ subject to the initial condition (1.2) and the boundary condition (1.3). The equation (2.1) has the characteristic curve

$$x = \int_0^t V(\eta)d\eta := P(t), \tag{2.2}$$

emanating from the origin. The function u is found to be

$$u(x,t) = \begin{cases} f(x - P(t)), & x > P(t); \\ g(t - P^{-1}(x)), & x < P(t); \end{cases}$$

where P^{-1} is the inverse function of P. It is clear to see that the function $u(x,t)$ does not provide a good approximation to $c(x,t)$ along the curve $x = P(t)$ unless $f(0) = g(0)$. With the general assumption $f(0) \neq g(0)$, one is required to supplement u along $x = P(t)$ by constructing the *shock layer function* $v(\xi,t)$ with the stretched variable ξ defined by $\xi = [x - P(t)]/D$.

The function $v(\xi, t)$ is defined by the heat equation

$$\frac{\partial v}{\partial t} - \frac{\partial^2 v}{\partial \xi^2} = 0,$$

for $-\infty < \xi < \infty$, $0 < t < \infty$ subject to the initial condition

$$v(\xi, 0) = 0,$$

and the boundary conditions

$$v(0,t) = \frac{g(0) - f(0)}{2}, \qquad \lim_{\xi \to \infty} v(\xi, t) = 0;$$

when $0 < \xi < \infty$ and

$$v(0,t) = -\frac{g(0) - f(0)}{2}, \qquad \lim_{\xi \to -\infty} v(\xi, t) = 0;$$

when $-\infty < \xi < 0$. Consequently, the shock layer function $v(\xi, t)$ is written as

$$v(\xi,t) = \begin{cases} \dfrac{g(0) - f(0)}{2} \text{erfc}\left(\dfrac{\xi}{2\sqrt{t}}\right), & \xi > 0; \\[2ex] -\dfrac{g(0) - f(0)}{2} \text{erfc}\left(-\dfrac{\xi}{2\sqrt{t}}\right), & \xi < 0; \end{cases}$$

where erfc is the complementary error function defined by

$$\text{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty \exp(-s^2) ds.$$

Based on the techniques of singular perturbation, one has obtained an asymptotic expansion $C := u + v$ given by

$$C(x,t) = \begin{cases} f(x - P(t)) + \dfrac{g(0) - f(0)}{2} \text{erfc}\left(\dfrac{x - P(t)}{2D\sqrt{t}}\right), & x > P(t); \\[2ex] g(t - P^{-1}(x)) + f(0) - g(0) + \dfrac{g(0) - f(0)}{2} \text{erfc}\left(\dfrac{x - P(t)}{2D\sqrt{t}}\right), & x < P(t); \end{cases} \tag{2.3}$$

and this approximation to $c(x,t)$ is uniformly valid for $0 < x < \infty$, $0 < t < \infty$. In the case of $f(0) = g(0)$, one constructs a *corner layer function* instead of the shock layer function. This corner layer function can be described by a complementary error function and its first derivative (an exponential function). Similar results can be carried out for the other case with the Robin boundary condition (1.4).

The significance of obtaining the above results by using perturbation methods is the following: First of all, the equation (2.3) provides an excellent approximation to the solute concentration $c(x,t)$ for a small dispersion D. It gives a good way to measure the accuracy of other solution techniques including numerical methods. Secondly, the above results yield functional relationships for the time-distribution of pollutant concentration in water bodies. These functional relations provide the basis for examining the sensitivity of model output with respect to model parameter values and initial/boundary conditions. Information obtained from sensitivity analysis can further be incorporated into uncertainty analysis. Finally, the identification of the shock (or corner) layer function as a complementary error function (and its first derivative) gives a foundation to design a highly *accurate*, *stable* numerical method for the general problem. This study is presently under investigation.

SYNOPSIS

Project Number: 06

Start: 6/90
End: 5/91

Title: **Consumptive Use and Irrigation Water Requirements for Wyoming.**

Investigators:

Pochop, Larry; Kerr, Greg; Hasfurther, Victor; and Delaney, Ronald;
University of Wyoming, Laramie

COWRR: 02D

Congressional District: First

Descriptors: evapotranspiration, consumptive use, irrigation, climate, vegetation, crop water use

Problem and research objectives:

A two-year project, "Consumptive Use and Irrigation Water Requirements for Wyoming", was initiated July 1, 1990 with the overall objective of preparing estimates of the consumptive use and irrigation water requirements for Wyoming. The project will result in a report which will be a revision and update of Wyoming Water Planning Report No. 5, "Consumptive Use of Irrigation Water in Wyoming" which was published in 1970 by Trelease, et al.

Specific objectives of the project are:

A. To select a model or models for estimating ET for vegetation commonly irrigated in Wyoming.

B. To prepare estimates of consumptive use, irrigation water requirements, and the statistical variations of each for selected locations in Wyoming.

C. To prepare a master copy of a consumptive use and irrigation water requirement report for Wyoming.

Objective #1 was to be completed during this first year of the project. Selection of the appropriate ET model, from numerous possible models, requires comparison of estimates from various models using available climatic data from throughout Wyoming. The remaining two objectives are to be completed during the second year of the project.

Methodology:

Hill et al. state that there are over 50 methods available for estimating evapotranspiration (ET). In general, these methods use climatic data as input. However, information on the crops such as the growing season and the developmental stages of the crops and effective precipitation is also required. Since the methods require different climatic input and are calibrated for different climatic regimes, some may be more applicable to a particular region than others. Also, the availability of data is critical to the use of any particular method. Wyoming's predominately high elevation and semi-arid climate are of special concern in performing ET estimates. Methods which seem to best account for the dry, windy conditions that exist in Wyoming are the ones considered herein. These are generally the methods which have been calibrated and applied to Western U.S. conditions, although some methods calibrated on a World-wide basis have also been considered. It has been shown that some methods of estimating ET need to be adjusted for high elevation conditions.

The following equations were analyzed for estimating reference ET: (a) ASCE Penman, (b) Wright modification of the Penman, (c) the Kincaid-Heermann calibration of the Penman, (d) the Kohler-Nordensen-Fox, (e) FAO Blaney Criddle, Radiation, Penman, and Pan methods, (f) Christiansen-Hargreaves Pan, (g) original and modified Jensen-Haise methods, (h) Makkink, and (i) Linacre. In addition, the SCS version of the Blaney-Criddle and the Penman-Monteith, which provide direct estimates of crop ET, were analyzed. However, if the latter two are used to estimate alfalfa or grass ET then they may also be considered as methods of estimating reference ET. The above equations include all but one of the eight methods covered by the recently released REF-ET computer software program developed at Utah State University. These eight methods are listed as the methods most recommended by the editors of ASCE Manual 70 "Evapotranspiration and Irrigation Water Requirements", and by the Irrigation Water Requirements Committee of ASCE.

Measured ET and climatic data used for analyzing the various methods of estimating reference ET were obtained from two previously completed projects by Pochop et al. (1979 and 1987). These projects provide measured ET data for grass, alfalfa, and mountain meadows as well as climatic and evaporation pan data. Additional water use data for analysis of crop coefficients and for checking irrigation water requirements and various climatic data were obtained from Archer, Chugwater, and Torrington in Wyoming.

Principal findings and significance:

Results indicate a wide variation in the ability of the various equations to estimate reference ET. In general, the equations which provide the best estimates of seasonal reference ET are the ASCE Penman, Penman-Monteith, and FAO Blaney Criddle for grass reference, the Kincaid-Heermann and Wright calibrations of the

Penman for alfalfa reference, and the Kohler-Nordensen-Fox method for pan reference.

The most consistent estimates of monthly reference ET were obtained using the Kohler-Nordensen-Fox equation for pan reference, while the least consistent were the methods giving estimates using an alfalfa reference. The results for alfalfa reference estimates might be expected since alfalfa is not always at full canopy and a crop coefficient is required to account for early season, late season, and after-harvest periods. Existing coefficients for this purpose may not be fully applicable to Wyoming growing conditions. Since crop coefficients for pan reference ET are not readily available, the Kohler-Nordensen-Fox equation will not be used for this study. However, the results do indicate how closely monthly pan evaporation may be estimated. The results also tend to somewhat validate the water use data collected in the Green River Basin.

It appears that the most suitable equation for estimating ET in Wyoming should be selected from those providing estimates of grass reference, namely the ASCE Penman, Penman-Monteith, or the FAO Blaney Criddle. Of the three, the Penman-Monteith gave the most consistent estimates of measured grass reference ET from the Green River Basin followed closely by the ASCE Penman calibration. However, any of the three equations may be suitable when considering all factors, such as availability of climatic data, recommendations by others, legal acceptance, etc. For example, Allen and Brockway (1983) selected the FAO-BC method for estimating consumptive use on a statewide basis in Idaho. They calibrated the method for Idaho by using simple reference coefficients and elevation multipliers. The FAO-BC method has the advantage that it was developed for estimating consumptive use when temperature data are available at a specific site and the other climatic data are estimated. Further comparison with grass ET measurements from eastern Wyoming will be conducted before a final decision is made.

Other work, in various stages of completion, includes determination of growing seasons and locations for crops throughout Wyoming, selection of appropriate crop coefficients to permit estimating crop ET from estimates of reference ET, estimation of effective precipitation for determination of irrigation water requirements, and development of a format or formats for presenting the statistical variations of ET and irrigation water requirements. Most of the work for determining growing seasons has been completed. Development of crop coefficients for Wyoming growing conditions is well under way. Coefficients will be developed for winter wheat, spring wheat, sugar beets, corn, potatoes, dry beans, mountain meadows, and lawn grass.

<u>**References:**</u>

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SYNOPSIS

Project Number: 07

Start: 6/90
End: 5/91

Title: A Comprehensive Water Education Program for Wyoming's Elementary Schools

Investigators:

Beiswenger, Ronald.; Sindt, Vince G.; Ellsworth, Peter C.; and Sturges, Elaine L., University of Wyoming, Laramie

COWRR: 09A

Congressional District: First

Descriptors: education, water quality, conservation, water resources, information dissemination, institutional relationships

Problem and research objectives:

The wise use, development, and management of water is essential to the State of Wyoming. Because of Wyoming's semi-arid climate, water is considered by many people to be Wyoming's most valued natural resource. There are many demands placed upon Wyoming's water--including irrigation, livestock, domestic uses, industry, hydroelectric power, recreation and fish and wildlife. As Wyoming's youth mature, they will make important economic, legislative and conservation decisions regarding Wyoming's water. It is imperative that Wyoming children be knowledgeable and literate about water topics and issues affecting Wyoming in order to make wise decisions about future management.

This three-year project involves the development of a water education program for Wyoming's elementary schools. The objectives of this project are to:

A. determine the extent and nature of current water education programs in Wyoming and assess water education needs;

B. develop a comprehensive plan, including a conceptual framework for water education in Wyoming for kindergarten through sixth grade;

C. synthesize available water education resources and create new curriculum materials appropriate for Wyoming;

D. test, revise and print the new circular materials;

E. disseminate the new curriculum program through leadership training and teacher workshops; and

F. evaluate the total program.

Methodology:

An overview of the completed and proposed methods and procedures is outlined below by objective.

Objective 1: Needs Assessment

Five hundred elementary teachers throughout Wyoming were surveyed using a Water Education questionnaire which was developed in cooperation with the Wyoming Water Research Center. The survey generated data on the extent and nature of current water education topics taught at the elementary level in Wyoming and the knowledge base of elementary educators on 22 selected water topics.

Objective 2: Comprehensive Plan

A state water advisory committee consisting of 19 different federal, state, county, city, university and community colleges, educators and water consultants was created to develop a comprehensive plan for water education in Wyoming's elementary schools. The initial plan would be further developed with elementary educators and staff from the Wyoming Institute for the Development of Teaching by outlining water topics for specific grade levels and writing evaluation goals for the program.

Objective 3: Curriculum Development

Water curriculum workshops were designed for elementary educators to analyze existing water education curricula to adapt appropriate activities for use in Wyoming elementary curriculum and develop new water activities to meet the special needs of Wyoming's water resources.

Objective 4: Testing, Revising and Printing of Curriculum Material

A series of workshops structured to bring in 20 to 30 pilot elementary school teachers will be developed to test the curriculum developed in Objective 3. The teachers will perform the hands-on activities developed and will write questions for pre- and post-evaluation of the activities. The pilot teachers will take these activities to their respective schools and utilize them for feedback in formalizing the final form of each activity.

Objective 5: Dissemination

A leadership training workshop will be conducted for selected teachers throughout the state who will train other teachers in their areas on utilization of the water education activities developed under Objectives 3 and 4.

Objective 6: Evaluation

A four-phase evaluation is designed to evaluate the project during different phases of the project. The final phase of evaluation will involve the use of a questionnaire, phone interviews and on-site visits by a selected project team.

Principal findings and significance:

Objectives 1 and 2 have been completed and a research report was submitted to the "Journal of Environmental Education" which summarized the questionnaire and work of the comprehensive plan. Findings indicated that most elementary teachers did not have adequate or extensive knowledge on 13 of the 22 water topics surveyed. A need for development of an elementary water curriculum for Wyoming was indicated, but would require intensive workshops and personnel with water knowledge to help integrate the use of the water curriculum into the classroom.

A conceptual framework, water topics for specific grade levels, goals for evaluation, and an elementary water education guide (WYO - Water, Youth and Optimism) has been developed for specific grade levels K-6 to meet the needs of Wyoming's water resources. The K-6 water curriculum guide is presently being revised based on feedback received from 27 teachers that piloted the program during the 1990-91 school year. Information is also currently being collected on students' knowledge and attitudes toward water as they participate in the water activities.

INFORMATION TRANSFER ACTIVITIES

June 1, 1990 - May 31, 1991

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 period June 1, 1990 through May 31, 1991 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.

WATER RESOURCES 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 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 1991 Water Resources Seminars were held in Torrington, Wyoming on January 29 and in Casper, Wyoming on February 19. 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, the state's proposed pesticide/

groundwater management program, non-point source water pollution, U.S. Bureau of Reclamation river management, wetland issues and management, and water and economic development. Cooperating agencies in the seminar program included: Wyoming State Engineer's Office, USGS Cheyenne Office, Wyoming Water Development Commission, University of Nebraska, USDA Soil Conservation Service, Wyoming Department of Environmental Quality, U.S. Department of the Interior, Bureau of Reclamation, Wyoming Department of Agriculture, and Casper and Eastern Wyoming Community Colleges. There were approximately 100 attendees at each seminar.

2. **Wyoming Water Resources and Law Forum**: This annual information forum for state legislators was held in Cheyenne, WY, January 7, 1991 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/voluntary programs for underground storage tanks, non-point source water pollution, proposed wetlands legislation (Wyoming Wetlands Act passed during the Winter 1991 session), and Cooperative Extension Service and other USDA water quality programs. Attendance totaled 45-48 (50 percent of Wyoming's legislature).

3. **Water Measures Slide Show**: An educational slide show program was developed to increase awareness and understanding of five different types of water measures; volume, flow, uses, value and quality. The slide show has been presented to a number of groups, including the 1991 Legislative Forum on Water Resources, Cooperative Extension Service training meetings, and the Water Institute for Teachers.

4. **WY-AWRA Conference**: The WWRC co-sponsored the 3rd Annual Meeting of the Wyoming State Section, American Water Resources Association. The conference was held at the University of Wyoming in Laramie, October 3-4, 1990. Technical sessions were held on a variety of topics including: channel

morphology, water management and groundwater, water quality, and analysis and collection of hydrologic data. There were 80 attendees.

5. **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, co-sponsored by the WWRC and the UW Wyoming Institute for the Development of Teaching, is a combination of classroom sessions, hands-on activities and field trips. A water law and policy panel discussion was held as one of the afternoon sessions. Teachers were able to visit in person or via teleconference with Wyoming's U.S. Senator, a State Senator, State Engineer, Assistant State Attorney General, a member of the Wyoming Water Development Commission and the Director of the Wyoming Wildlife Federation to discuss federal versus state water laws and policies, the importance of local involvement in developing water policy, wildlife and instream flow issues, and conflicts in water right administration. Participants earned two hours of credit and scholarships were made available to encourage attendance. The WIT was held July 9-20, 1990.

6. **Water Engineering and Management Conference**: The Wyoming Water Research Center was a co-sponsor of the Water Engineering and Management Conference, organized by the Colorado Water Resources Research Institute and Office of the State Engineer, held February 27 and 28, 1991 in Denver, Colorado. A wide variety of regional water issues and research results were discussed at the conference including: water resources decision making, water transfers, barriers to water supply acquisition, Colorado River salinity control programs, irrigation management, groundwater pollution assessment, artificial recharge, data management and mapping, computer-aided decision support, aquifer management, and progress on non-point source control. The conference was attended by over 200 water resource specialists.

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 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.

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 (MOU) with the agencies that have primary responsibility for nonpoint source water quality education programs. The proposed cooperating agencies are: 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. The MOU being drafted by the WWRC specifies each organization's responsibilities and encourages interagency coordination of water quality education programs. Slow responses from two agencies delayed this effort but progress is anticipated in the upcoming year.

3. **Great Plains Agricultural Council (GPAC) 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. An inventory of Great Plains water quality research,

extension, technical assistance and interagency cooperation was undertaken. Draft revisions and a final report are anticipated in late Fall, 1991.

INFORMATION TRANSFER PUBLICATIONS

Information transfer publications for the report period included 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 1,400 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.

2. **"WWRC News"**: One page of the "Wyoming Water Flow Newsletter", published bi-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 (CES), in cooperation with the Wyoming State Engineer's Office, jointly reprinted and distributed an updated bulletin on Wyoming water law. Approximately 2,000 bulletins have been distributed at public Water Resource Seminars and through CES offices and other state agencies.

4. **WWRC Research Briefs**: Information briefs on WWRC research are being produced and distributed in Wyoming and nationwide through newsletter mailings and at water resource organization meetings. Two briefs were published in 1990-91; "Biological Response of Fish Populations to Increased Minimum Flow" and "Open Conduit Flow through the Madison Limestone As Determined From Seasonal Fluctuations in the Discharge Chemistry and Temperature of Periodic Spring, Salt River Range, Wyoming".

5. Water Issues: A series of information and education bulletins was initiated in a joint WWRC, Wyoming Department of Environmental Quality, and University of Wyoming Cooperative Extension Service program. The first two bulletins addressed Pesticides and Ground Water Quality and Wellhead Protection.

6. Water Quality and Hazardous Waste Wheels (information/education publications): These highly informative and popular education tools were acquired through the cooperation and cost sharing of the WWRC, UW Cooperative Extension Service, Wyoming Department of Environmental Quality, and USEPA non-point source water quality education grant. Over 1,300 Water Sense Wheels and 500 Hazardous Waste Wheels have been distributed at public meetings and through CES and other state offices.

7. Water Resources Display: A traveling display of WWRC programs and materials was developed and shown at the Water Resource Seminars, Wyoming State Capitol Building, and WWRC advisory group meetings. The display included information about WWRC research, information and service programs and sample publications.

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 water 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 and students, 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 Water Development Commission provides funds in the amount of $80,000 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 provide search and retrieval on the Wyoming Water Bibliography (WWB) for requestors, in addition to updating the database with federal and 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: l) Service, 2) Extension, 3) Research, and 4) Instruction. The Director and Associate Directors, 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).
- Participate in Governor's Selenium Work Group.
- Attend Governor's Water Forum.
- Attend meetings regarding specific research projects.
- Administer UW basic research for Wyoming Department of Environmental Quality Nonpoint Source Pollution Program

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 interdisciplinary Master of Science/Water Resources curriculum.

- Serve on appropriate graduate student committees.

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

Other

- Continued effort to be cognizant of regional and national water issues and research opportunities.

- Director served as Missouri River Basin representative to National Association of Water Institute Directors (NAWID) Council.

- Director selected as "Chair Elect" of NAWID Council.

- Serve as delegates to Universities Council on Water Resources

- Transfer of research results to appropriate users.

TABLE 1: COOPERATING STATE AND FEDERAL AGENCIES IN WYOMING

STATE:

Attorney General's Office
State Conservation Commission
Department of Agriculture
Department of Commerce-Division of Economic & Community Development
Department of Environmental Quality
Air, Land & Water Quality Divisions
Department of Transportation
Disaster and Civil Defense
Game & Fish Department
Governor's Office
Industrial Siting Administration
Legislative Services Office
Oil & Gas Commission
Recreation Commission
State Climatologist
State Engineer's Office
State Library
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 2. SERVICE-TO-STATE - FY1990

Research Projects Performed in Response to Wyoming State Agency Requests

- 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
- 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)
- Evaluation of Surface Water/Groundwater Interactions in a Cold Desert Stream System (Department of Agriculture, Ranchers, Water Quality Division of Department of Environmental Quality, U.S. Department of Agriculture, Bureau of Land Management, Soil Conservation Service)
- Consumptive Use and Irrigation Water Requirements for Wyoming (State Engineer's Office)
- Development of Channel Maintenance Requirements for the North Platte River System in Wyoming (Wyoming Game and Fish Department, Bureau of Reclamation, U.S. Fish and Wildlife Service)

2. Extension

One of the four major missions of the WWRC involves extension activities. The WWRC believes in a strong water resources extension effort. In cooperation with the UW Agricultural Extension Service, expanded education programs are developed among researchers conducting water-related research. It is intended 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 FY90

Research accomplishments of the FY90 Federal Water Research Program were reviewed by the Director. The results of the projects sponsored with the FY90 monies have been provided to the Center's advisory committees and presented at professional meetings.

- Federal Program FY91

The Director solicited proposals under the FY91 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--four were funded under the program.

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 multidisciplinary 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 is acknowledged on the graduate transcript and thereby certifies to potential employers that the candidate has completed an attractive, in-depth, multidisciplinary-course program in the broad area of water resources. A scholarship is awarded annually to a student enrolled in the Master of Science/Water Resources program.

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.

ENVIRONMENTAL PROTECTION AGENCY

The WWRC has an agreement with the Environmental Protection Agency permitting access to the agency's national computer center mainframe computer. Specific applications which have been validated for WWRC use include STORET, the water quality storage and retrieval system of the EPA, and FRDS, the Federal Reporting Data System which houses information on public water supply systems.

Both databases are accessed on a routine basis and serve to augment data already housed at the WWRC.

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.

U.S. GEOLOGICAL SURVEY

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

WWRC ADVISORY STRUCTURE

The organizational structure and operational procedures of the WWRC for a high degree of accountability and relevance to state and regional water research include a Research Review and Priorities Committee (RRPC) appointed by the Governor of the State of Wyoming and the President of the University of Wyoming. The membership was designed to reflect the interests and inputs of the Executive Office, the legislative branch of government, the academic community, the State Climatologist, 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.

A Citizens Water Issues Advisory Council (CWIAC) consists of members selected by the Governor and the University of Wyoming President (Table 4). 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) the 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 3

RESEARCH REVIEW & PRIORITIES COMMITTEE

July, 1991

Governor Mike Sullivan (ex officio) State Capitol Building Cheyenne, WY 82002 777-7434	President Terry P. Roark (ex officio) Office of the President University of Wyoming 766-4121
Governor's Appointees:	UW President's Appointees:
Paul Schwieger (Chairman) (1983-1993) Department of Commerce Div. of Economic and Community Devel. Herschler Building Cheyenne, WY 82002 777-7284	Steven P. Gloss (Exec. Sec.) Director Wyoming Water Research Center Room 152, Vocational Annex University of Wyoming 766-2143
Dan Perdue State Planning Coordinator[1] Herschler Building Cheyenne, WY 82002 777-7574	Derek Hodgson Vice President for Research[1] Old Main University of Wyoming 766-5353
Myron Goodson (1988-1991) Wyo. Water Development Commission Box 429 Sundance, WY 82729 283-2407	Bill Gern (1988-1991) Zoology & Physiology Dept. Biological Sciences Building University of Wyoming 766-4207
Patrick O'Toole Wyoming House of Representatives[1] Box 26 Savery, WY 82332 383-2418	Quentin Skinner (1985-1988) Range Management Department Agriculture Bldg., Rm. 2028 University of Wyoming 766-4139
Jim Geringer Wyoming Senate[1] 190 Preuit Road Wheatland, WY 82201 322-9709	Victor Hasfurther State Climatologist[1] Wyoming Water Research Center 13th and Lewis Streets Laramie, WY 82071 766-2143

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

TABLE 4

CITIZENS WATER ISSUES ADVISORY COUNCIL

July, 1991

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

Russell Michael
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Torrington, WY 82240
788-1139

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332-2442

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772-2728

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234-5333

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634-7561

Beryl Churchill, Chairperson
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754-4865

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Doyl M. Fritz
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1949 Sugarland Drive, Suite 134
Sheridan, WY 82801
672-0761

Dick Brown, Vice President
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Casper, WY 82602
577-6901

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

PUBLICATIONS

1. Dissertations

Citation	Field of Study	Supporting Project No.
None		

2. Conference Presentations

Citation	Supporting Project No.
Barkan, D.N. 1991. Transport, Detection, and Degradation of Aldicarb in Droughty Irrigated Soils of the Bighorn Basin of Wyoming, an Update. American Petroleum Institute Regional Meeting, Cody, WY, April 24, 1991.	03
Clark, R.A., K.J. Reddy and L. Wang. 1991. Utilization of CO_2 to Minimize the Solubilities of Toxic Elements in Alkaline Solid Waste. American Society of Agronomy Annual National Meetings, Environmental Quality Division, Denver, CO, October 27-November 1, 1991.	02
Reddy, K.J. Potential Solid Phases Controlling the Solubilities of Major and Trace Elements Before and After Lowering the pH of Spent Oil Shales. International Conference on Metals in Soils, Waters, Plants, and Animals, Orlando, FL, April 30-May 3, 1990.	02
Shih, Shagi-Di. 1991. On Internal Layers of Some Singularly Perturbedy Problems. Miniconference on Differential Equations, Utah State University, Logan, UT, May 31-June 1, 1991.	05

3. Articles in Refereed Scientific Journals

Citation	Supporting Project No.
Beiswenger, R., E.L. Sturges and R. Jones. Assessment of Educators' Knowledge of Water Topics and Their Current Use in the Elementary Curriculum. Journal of Environmental Education (in press).	07

Reddy, K.J. and L. Wang. Potential Solid Phases Controlling Solubility of Major and Trace Elements in Alkaline Solid Wastes. Environmental Science and Technology (in preparation).	02
Reddy, K.J. and S. Sarmah. The Factors Affecting the CO_2 Pressure Process for Chemical Stabilization of Alkaline Solid Wastes. Environmental Science and Technology (in preparation).	02
Reddy, K.J. and S.E. Williams. The Effects of CO_2 Pressure Process on Chemical and Biological Properties of Alkaline Solid Wastes. Environmental Science and Technology (in preparation).	02
Reddy, K.J. and L. Wang. Immobilization of Toxic Elements From Alkaline Solid Wastes. Water Research (in preparation).	02

4. Other publications

<u>Citation</u>	**Supporting <u>Project No.</u>**
Water, Youth and Optimism - A Water Curriculum for Kindergarten Through Sixth Grade. 1990. Institute for the Development of Teaching, University of Wyoming, Laramie, WY. 180 p. (rough draft).	07

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 1990 Program are indicated below.

TRAINING CATEGORY	ACADEMIC LEVEL				
		GRADUATE			
FIELD OF STUDY	UNDER-GRADUATE	MASTER'S DEGREE	PH.D. DEGREE	POST-PH.D.	TOTAL
Chemistry	4	1			5
Agricultural Engineering	1	1			2
Civil Engineering					
Environmental Engineering					
Geology					
Hydrology					
Agronomy					
Biology					
Ecology					
Fisheries, Wild-life & Forestry					
Computer Science					
Economics					
Geography					
Law					
Resource Planning					
Range Management					
OTHER: (specify)					
Science Education		2			2
Environmental Science	1				1
Plant, Soil & Insect Sciences	1	2			3
Statistics		1			1
Mathematics		1			1
TOTAL	7	8			15

POSTGRADUATE EMPLOYMENT

Please complete this form by placing an "X" under the applicable columns for positions taken by postgraduate students.

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