Report No.
G2056-01

Fiscal Year 1992 Program Report
Grant No. 14-08-0001-G2056-01

for

U.S. Department of the Interior
Geological Survey

by

Wyoming Water Resources Center
University of Wyoming
Laramie, WY 82071

Steven P. Gloss, Director

July 1993

The activities on which this report is based were financed in part by the Department of the Interior, U.S. Geological Survey, through the Wyoming Water Resources Center. The contents of this publication do not necessarily reflect the views and policies of the Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement by the United States Government.

ABSTRACT

Four research projects were funded under the FY92 program, as well as information transfer activities. These four research projects relate to important water issues in the State of Wyoming and the region.

Depth-to-groundwater on a yearly basis is more important to subalpine plant community existence than is surface water except in late summer when the surface water is influent to the system. The peak median groundwater level occurred in May or early June, and the lowest median groundwater level occurred during or after August. Recharge occurred after August and varied between a gradual recharge over the winter (dry meadows) to a rapid recharge during snow melt in the spring (moist meadows). Depth-to-groundwater duration was shown to be important with respect to the existence of certain subalpine riparian plant communities. Depth-to-groundwater suitability curves are an effective technique for quantifying the relationship between the water-level regime and the plant species response.

Monitoring dicamba and picloram movement in the vadose zone for groundwater quality protection in Wyoming. This study is being conducted to evaluate the herbicides dicamba and picloram (2 of 3 most widely used pesticides in Wyoming) interactions in agricultural and rangeland settings. The content of dicamba in soil after 80 days from application in 1993 was very low. The highest content was found at 60-90 cm for sites in which no-till-injection and chisel-broadcast combinations of tillage and fertilizer practices were implemented. All samples from sites located at the no-till with fertilizer injection treatment contained a trace amount of dicamba at all depths. The results of the concentration of picloram in soil from the study area did not indicate any consistent rate of movement or trend in degradation. Results indicate that picloram residues were primarily limited to the top 100 cm of soil with the highest concentration in the upper 40 cm. For one site, 10% of the applied picloram remained after 34 months following treatment. Results of column studies were utilized in the LEACHP model. For this study, crops were not present and all plant related subroutines were excluded from the model. Differences in herbicide degradation rates apparently resulted from variations in application rates and the degree of saturation.

Severe drought and water shortages in the Upper Green River Basin: Modeling economic impacts and institutional alternatives for water management. A mathematical modeling technique known as discrete stochastic programming is used to simulate irrigators' water management decisions under uncertainty. This approach improves upon others used to estimate damages of drought by explicitly recognizing that cropping and management decisions must be made with only imperfect knowledge of water supply conditions and future weather conditions. The costs of water shortages in Wyoming's Green River Basin include indirect impacts in sectors supporting and supported by irrigated agriculture, and of lost consumer spending power. Estimates of total indirect

income and employment impacts of reduced surface water supplies are made building upon recently completed input-output modeling of the Wyoming county economies.

Assessment of the Potential Environmental Fate and Effects of Oil-Field Discharge Waters Containing Radium (^{226}Ra). Radium being discharged from produced groundwater into skimming ponds and then into class 3 and 4 surface water streams in Wyoming tends to decrease in the surface water of the stream with distance from the point of discharge, but the sediments in the stream are increasing in radium content away from the point of discharge. Guidelines regulating the management of radium-contaminated sediments in receiving waters or skim ponds have yet to be established, and the data necessary for formulating management decisions are currently unavailable. Results of analyses of water and sediment samples were consistent with the results anticipated based on the chemical behavior of radium in aqueous solution. The concentration of radium in water decreased with increasing distance from the point of discharge. Conversely, the concentration of radium in sediment tends to increase with increasing distance from the point of discharge. Factors that may influence the rate of ^{226}Ra deposition in the sediments include water cooling rate, pH changes caused by equilibration of dissolved gases with ambient concentrations, the retention time of water within the ponds, and the distances between ponds.

The Wyoming Water Resources Center uses several networks to inform the people of Wyoming, as well as neighboring states and regions, of what the WWRC is doing in education, research, and interagency cooperation to better manage and protect Wyoming's, and the nation's, water resources. **Information transfer activities** of the WWRC 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.

TABLE OF CONTENTS

WATER PROBLEMS AND ISSUES OF WYOMING

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

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

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

possible, as well as improving and creating new water delivery systems within the state. Wyoming also has recognized instream flow rights for fisheries purposes.

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

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

PROGRAM GOALS AND PRIORITIES

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

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

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

The WWRC structure includes a Director responsible for program development and implementation who reports to the Vice-President for Research. The Director also serves as Executive Secretary to the WWRC Research Review and Priorities Committee (RRPC) which is appointed by the University President and the Governor. The RRPC is comprised of state legislators, state agency representatives, university faculty and members from the public. The WWRC consists of faculty members jointly appointed between the Center and various academic departments as well as research specialists who, along with joint faculty, work in conjunction with cooperating faculty at UW and

other institutions. Although the primary mission of the WWRC is research and service, the Center also participates actively in extension and information transfer activities as well as joint graduate degree programs with several departments on campus.

Beginning with the inception of the WWRC, the University received a line item in its biennial budget from the legislature which provided the principal support for the Center. In addition, a small amount of the University's Instruction and Research budget was allocated to the Center. These funds were for equipment and partial salary support for the Director and one Associate Director. The "base" budget for the WWRC is completed by the receipt of approximately $105k annually from the federal WRRI program. This base funding has provided an infrastructure for the WWRC enabling it to compete effectively for additional external research funding. Although the line item funds received by UW previously came from the state general fund, beginning in FY 89-90, and continuing to FY 93-94, those funds have been allocated from one of the state's water development accounts. The WWRC also receives an annual contract through the Wyoming State Engineer's Office and the Wyoming Water Development Office to operate the Water Resources Data System.

In summary, the Wyoming Water Resources Center provides a focal point for the coordination and conduct of water resources research and education in the State. Direct linkages exist in the Center's structure between state agencies, the University, and citizen groups responsible for, or interested in, water resources. In addition, the Center is involved in numerous regional, national and international activities. The Wyoming Water Resources Center is part of both the Colorado and Missouri river basin regional organizations with other Water Resources Research Institutes. In compliance with the USGS guidelines, and in consultation with state water officials and the Wyoming Water Resources Center's Research Review and Priorities Committee, state and regional research priorities are addressed. Oversight by the Research Review and Priorities Committee and careful administration of the research program insure the best quality and most cost effective means of obtaining information relevant to Wyoming's water resource management.

Section 104 Objectives

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

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

The following outline of topics represents areas of research for which proposals were solicited in FY 92.

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

RESEARCH PROJECT SYNOPSES

SYNOPSIS

Project Number: 02 **Start: 06/92**
End: 05/94

Title: **Comparison of Depth-to-Groundwater Suitability Curves for Important Riparian Plant Species in the Subalpine and Montane Zones.**

Investigators: Wesche, Thomas A.; Skinner, Quentin D.; and Henszey, Robert J., University of Wyoming, Laramie

Focus Categories: WL **Congressional District:** First

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

Problem and research objectives:

Increasing development in the headwaters of the Missouri River basin for recreation, second home communities, transportation corridors, and water diversion has lead to the destruction of natural subalpine and montane wetlands. Such areas support diverse plant and animal communities, and exert a dominant influence on the magnitude, timing and duration of streamflows and their water quality. Basic information is needed regarding riparian vegetation/groundwater-surface water interactions upon which to base informed management decisions to address these impacts. This study provides some of this basic information by describing the relationships between important riparian plant species and the hydrology critical to their maintenance in the subalpine and montane zones of southeastern Wyoming. The species investigated were an assemblage of wetland sedges (*Carex* spp.), tufted hairgrass (*Deschampsia cespitosa*), slimstem reedgrass (*Calamagrostis neglecta*), shrubby cinquefoil (*Pentaphylloides floribunda*) and aspen (*Populus tremuloides*). Research objectives were to: 1) Continue to describe the seasonal dynamics of surface-water stage and groundwater elevation in subalpine and montane riparian wetlands, 2) Continue to relate the distribution of important wetland plant species to hydrologic dynamics along perennial and ephemeral streams in both the subalpine and montane zones, 3) Develop habitat suitability curves relating alluvial groundwater stage to a normalized measure of plant response for three important wetland plant species in the montane zone and refine such curves for the same species within the subalpine zone, and 4) Compare the habitat suitability curves for each species across elevational and hydrologic gradients to better define plant-water dynamics and evaluate curve utility.

Methodology:

Hydrologic and biologic data were collected from the Snowy Range Observatory (subalpine zone) and the South Fork of Middle Crow Creek Riparian Research Watershed (montane zone). Both watersheds were located within the Medicine Bow National Forest in southeastern Wyoming and were equipped with precipitation gages, streamflow gages, and alluvial-groundwater well networks. The South Fork of Middle Crow Creek Research Watershed (SFMCC) included sites with a natural groundwater regime, and sites that received augmented streamflow to mitigate part of the City of Cheyenne's Stage II water development project. Selected wells were equipped with continuous water-level recorders. These data were used to develop depth-to-groundwater duration curves that described the percent of time water was at a specific level or above. The plant response to the various hydrologic regimes was determined by measuring one or more of the following attributes: above-ground biomass, density, basal cover, or canopy cover. Depth-to-groundwater suitability curves were developed for each species by plotting the depth-to-groundwater for 10%, 50%, and 90% (D_{10}, D_{50}, D_{90}) of the growing season verses the plant response.

Principal findings and significance:

Groundwater hydrographs from the South Fork of Middle Crow Creek show that the peak median groundwater level occurred in May or early June, and the lowest median groundwater level occurred during or after August. Recharge occurred after August and varied between a gradual recharge over the winter (dry meadows) to a rapid recharge during snow melt in the spring (moist meadows). The mean depth-to-groundwater for five plant community types in the SFMCC study area are presented in Table 1. Although three years of data are presented in Table 1, data through 1993 (7 years) will be included in the final report.

Table 1. Mean depth-to-groundwater (m) for 10, 50, and 90% of the time (D_{10}, D_{50}, and D_{90}) by plant community type. Values shown are the mean depths that were equaled or above for each treatment (flow, or no flow augmentation) during June through September 1987-89. Means within a column followed by the same letter were not significantly different ($p > 0.05$) according to the Bonferroni t test.

Plant Community Type	D_{10}		D_{50}		D_{90}	
	Flow	No flow	Flow	No flow	Flow	No flow
Aspen (near watercourse)	-0.02^{ab}	-0.55^{b}	-0.20^{bc}	-1.53^{d}	-0.34^{bc}	-2.02^{d}
Dry meadow	-0.20^{b}	-0.98^{c}	-0.35^{c}	-1.22^{c}	-0.45^{c}	-1.28^{b}
Moist meadow	0.03^{a}	-0.37^{b}	-0.09^{ab}	-1.11^{bc}	-0.21^{ab}	-1.58^{c}
Moist-wet meadow	0.06^{a}	-0.37^{b}	-0.01^{a}	-0.95^{b}	-0.09^{a}	-1.21^{b}
Wet meadow	0.05^{a}	-0.05^{a}	-0.05^{ab}	-0.44^{a}	-0.18^{ab}	-0.65^{a}

Depth-to-groundwater suitability curves were developed for three different duration values (D_{10}, D_{50}, D_{90}). These three values show the percent of time (10, 50, 90%) that the water was at a specific level or higher, and represent the "typical" shallowest (D_{10}), median (D_{50}), and deepest (D_{90}) groundwater levels observed. Based on the available information from the SFMCC and the Snowy Range Observatory, the optimum depth-to-groundwater for the hydric sedges (beaked sedge, Nebraska sedge, water sedge, fieldclustered sedge) appears to be a nearly constant 0.06 to 0.09 m (D_{10} to D_{90}) above the surface. The optimum depth-to-groundwater for the mesic sedges (smallwing sedge, sedge spp.) appears to be 0.00 m (D_{10}), 0.30 m (D_{50}), and 0.46 m (D_{90}) below the surface. The optimum depth-to-groundwater for tufted hairgrass appears to be between -0.14 and -0.46 m for D_{10}, -0.90 m for D_{50}, and between -1.10 and -1.80 m for D_{90}. Slimstem reedgrass had the least well defined relationship with the water level, but response appeared to be optimized with 0.91 m for D_{10}, from 0.91 to 1.22 m for D_{50}, and from 1.37 to 1.68 m for D_{90}. Data for shrubby cinquefoil and aspen have been collected, and their suitability curves will be ready for the final report in 1994.

Depth-to-groundwater suitability curves are an effective technique for quantifying the relationship between the water-level regime and the plant species response. This technique has been used extensively by fish habitat managers to develop instream flow relationships for maintaining fish populations, and may also prove useful for developing instream flow criteria for maintaining riparian plant populations.

SYNOPSIS

Project Number: 03 **Start:** 07/91
End: 06/94

Title: **Monitoring Dicamba and Picloram Movement in the Vadose Zone for Groundwater Quality Protection in Wyoming**

Investigators: Vance, George F. and Krzyszowska, Anna J., University of Wyoming, Laramie, WY

Focus Categories: GW, IG, MET, NPP, WQL **Congressional District:** First

Descriptors: pesticides, groundwater quality, soil-water relationships, soil chemistry, adsorption and exchange, agriculture, model studies, herbicides

Problem and research objectives:

Wyoming has a diverse agricultural base with areas of intensive short season crop production. Coupled with the arid Wyoming climate, many of the agricultural areas rely heavily on irrigation as a source of water for crop growth. With the scope of pesticide usage in cultivated crop production, along with the volumes of irrigation water used, leaching of pesticides becomes a potential concern for contamination of the underlying groundwater. In Wyoming, water supplies for 61% of the residents comes from subsurface sources with 89% of the rural population depending on groundwaters.

Although there is no legislative mandate for groundwater monitoring in Wyoming, the Wyoming Department of Agriculture, the Wyoming Weed and Pest Control Districts, and the U.S. Geological Survey are cooperating in an effort to determine the extend of pesticides in groundwater supplies. The three herbicides they are monitoring include 2,4-D, dicamba and picloram which represent approximately 50% of all the pesticides applied in the state. The herbicides dicamba and picloram have been detected in surface and groundwaters of Wyoming. Of the 105 wells tested in Wyoming during an EPA survey, 42 contained detectable levels of pesticides. In 1983, picloram was detected in approximately 30% of Wyoming water samples with a maximum concentration of about 1 ppb. Recent sampling has found picloram concentrations as high as 30 ppb.

The objectives of this research project are to: 1) Analyze pesticide levels in soils/substrata from areas in Wyoming believed susceptible to groundwater contamination; 2) Characterize soil/substrata chemical and physical properties at each depth to determine which of these factors are important in controlling pesticide transport; 3) Examine pesticide sorption at different soil/substrata depths for correlation to chemical and physical characteristics; and 4) Evaluation

of pesticide transport models for the estimation of potential groundwater contamination in Wyoming based on soil/substrata properties and pesticide use.

Methodology:

Laboratory batch and column studies (for determining adsorption characteristics), field studies to verify predictions of computer models, and direct analysis of the herbicides dicamba and picloram to evaluate their movement and fate are being studied. The field study has been initiated and will be completed during the next year of this project. Soil samples were collected from three study areas which include sites in Albany, Goshen and Crook counties, Wyoming. The Albany county site is at the University of Wyoming (UW) experimental farm located west of Laramie. This site was selected to simulate an irrigated cropland, and has utilized lysimeters for collection of soil solutions. Soil from this site has already been used for several column studies. The site at UW's experimental farm located northwest of the city of Torrington (Goshen County), has been selected because of the recorded use of dicamba on different agricultural crops under various tillage practices. The Crook county site is located within the Leafy Spurge research study area operated by UW in cooperation with the Wyoming Department of Agriculture. This site has been selected for studying picloram use on rangeland systems.

The content of herbicides in soils was determined by sampling soil profiles as follows: Goshen County (Torrington), before and after applying of dicamba, April 1992 (1/4 lb a.i./ac); Crook County, near Sundance, from sites having different rates of picloram application since 1987. Samples from Torrington were collected at depths of 0-30 cm; 30-60 cm and 60-90 cm from 3 different sites of conventional, chisel plow and no-till type practices. A second collection in July 1993 represented sites amended with dicamba and different types of fertilizer application (full rate injection, broadcast and control). Samples from Crook County were collected from 9 profiles to depths of 120 cm (42 samples). Samples were taken from sites differentiated by rate and date of picloram application (0.25, 1 and 2 lb a.i./ac).

Several adsorption studies were performed on soils collected from the three research sites. All adsorption isotherms were done in triplicate using a soil to solution ratio of 1:2. Samples were shaken on a wrist action shaker for 20 hours and centrifuged at 2,000 RPM for 30 min at 8,000 RPM for 15 min. Solutions were stored in glass bottles and analyzed by using the solid phase extraction/HPLC technique developed for this project.

Column experiments were used to study pesticide displacement from soils collected at the Albany county site. Fine loamy soil was collected from depths of 0-20, 20-35, and 35-50 cm. Disturbed soil profiles were assembled in glass columns constructed by assembling 5 cm segments glued together with silicon. Herbicide concentrations corresponding to 5.90, 2.96 and 0.82 kg ha^{-1} for dicamba and 1.85, 0.97 and 0.47 kg ha^{-1} for picloram were applied to separate saturated columns, an unsaturated column with 2.76 kg ha^{-1} of dicamba and 1.00 kg ha^{-1} picloram, with all initial solutions containing a nonreactive tracer (KBr). Initially, 60 mls of varying herbicide concentrations were applied to the different columns. Every day 60 ml of water was applied to each column. Columns reached a steady flow after 3 days of initiating

water applications. Chemical migration was monitored by analyses of daily effluent solutions using a solid-phase extraction/HPLC technique.

Principal investigators are using the computer model, LEACHP, which is one of the four models in LEACHM, and simulates pesticide degradation, transportation and movement. Parameters required by the LEACHP model are pesticide sorption characteristics, soil hydraulic properties, soil bulk density, and the characteristics of pesticide application. Parameters characterizing sorption (Kd) were obtained from batch studies. Saturated conductivity was measured by the constant-head method. The moisture-retention data (volumetric water content) as a function of matrix potential was obtained by pressure plate apparatus. From these properties, the model estimates unsaturated conductivity and specific water capacity for any water content or matric potential.

Principal findings and significance:

In a recent literature survey, of pesticide studies conducted throughout the United States, Wyoming was listed as having suspected regional or localized contamination. This study is being conducted to evaluate the herbicides dicamba and picloram (2 of 3 most widely used pesticides in Wyoming) interactions in agricultural and rangeland settings. Analytical methods for the analysis of dicamba and picloram in soils and solutions have been developed.

Soil collected at the Torrington Experiment Station prior to 1993 herbicide application, did not, for the most part, contain any dicamba. However, trace concentrations of dicamba residual from 1992 applications were detected at conventional tillage sites at all depths. The content of dicamba in soil after 80 days from application in 1993 was also very low. The highest content was found at 60-90 cm for sites in which no-till-injection and chisel-broadcast combinations of tillage and fertilizer practices were implemented. All samples from sites located at the no-till with fertilizer injection treatment contained trace amount of dicamba at all depths. Dicamba, after 80 days, was leached to depths of 60-90 cm and deeper.

The results of the concentration of picloram in soil from the Sundance Leafy Spurge study area did not indicate any consistent rate of movement or trend in degradation. An initial application rate of 0.25 lb a.i./ac was equivalent to 250 ppb of picloram in the top 15-20 cm of soil. In some sites, the input of picloram remaining in soil after 1-6 months after application of 1 lb a.i./ac. After 14 months from application of 1 lb a.i../ac, the picloram content was highest at the 40-100 cm depth. Results indicate that picloram residues were primarily limited to the top 100 cm of soil with the highest concentration in the upper 40 cm. For one site, 10% of the applied picloram remained after 34 months following treatment.

There was no adsorption of dicamba to soil from Goshen and Albany Counties. Picloram adsorption isotherms were linear at concentrations higher than 0.2 mg picloram per kg soil. The adsorption of picloram to soil from Albany County was highest at the 20-35 cm depth,

presumably because of the higher content of organic carbon. The effect of pH (values between 6-8) on adsorption coefficients for picloram and dicamba was insignificant.

Breakthrough peaks in the column studies were 16 to 17 days for picloram and 13 to 14 days for dicamba. The effluent from the column with the highest application rates were devoid of any herbicide by day 27, and for other columns was about 13 days for picloram and 22 to 25 days for dicamba. The effluent contained dicamba by the 8th day after application, which was five days earlier than picloram. This was due to the effect of sorption, which for dicamba was negligible. About 50% of the cumulative mass of picloram and dicamba in high application columns, and 30% in the low application column was recovered in the effluent. The rest of herbicides was hypothesized as being biologically degraded or sorbed. Results indicated the breakthrough time was similar for dicamba and the Br. However, the simulated breakthrough peak for non-adsorbing dicamba occurs two days later than the experimental peak. This was possibly due to the bulk density being higher than anticipated in the column, which, in turn, caused a decrease in porosity and an increase in pore-water velocity.

Results of the column studies were utilized in the LEACHP model. For this study, crops were not present and all plant related subroutines were excluded from the model. LEACHP model was employed to obtain estimates of modeling parameters by a curve fitting technique. Specifically, values were assumed for dispersivity and degradation rate constants until the experimentally-measured breakthrough curves matched the simulated breakthrough curves generated by LEACHP. The relative width (spreading) of the breakthrough curves is proportional to the dispersivity of the soil. The area under the curve is a function of the degradation rate. Other significant parameters affecting solute movement such as: soil hydraulic properties, normalized distribution coefficients, percent organic carbon, and bulk density were determined by separate experiments or obtained from references.

Differences in herbicide degradation rates apparently resulted from variations in application rates and the degree of saturation. For the two columns receiving intermediate application rates, anaerobic picloram dissipation was more rapid ($t_{1/2}$ = 19 d) than for aerobic conditions ($t_{1/2}$ = 87 d). The rate of dissipation of dicamba was approximately the same under aerobic and anaerobic conditions ($t_{1/2}$ = 15 and 17 d in the saturated and unsaturated columns, respectively). Picloram and dicamba dissipation was more rapid at the lowest application rates, with $t_{1/2}$ of 13 and 10 days. At the highest application rates, $t_{1/2}$ of 23 and 17 days were measured for picloram and dicamba, respectively. Both herbicides were found to be highly mobile, with the mobility of picloram increasing at higher pore-water velocities. Experimental results thus far indicate the potential for high picloram persistence. Specific findings of our studies are summarized as follows:

- Herbicide disappearance was found to depend upon application rate. At low application rates, dicamba and picloram were degraded more quickly than at high rates.

- Picloram adsorption was reduced with higher pore-water velocity. No adsorption of dicamba was evident.

- Degradation of picloram varied with water content and picloram disappearance was much slower in the unsaturated column.

- Predicted degradation rates obtained from the simulation model, LEACHP, were similar for dicamba at the intermediate application rate regardless of whether anaerobic or aerobic conditions dominated.

A field study is currently being conducted which will allow evaluation of the mobility and fate of dicamba and picloram in a natural environment. The computer model, LEACHP, is being calibrated using field conditions, and will be utilized to predict the transport of the herbicides over time.

SYNOPSIS

Project Number: 04 **Start: 06/91**
End: 05/93

Title: **Severe Drought and Water Shortages in the Upper Green River Basin: Modeling Economic Impacts and Institutional Alternatives for Water Management**

Investigators: Michelsen, Ari M. and Booker, James F., University of Wyoming, Laramie

Focus Categories: DROU, ECON, IG, LIP, MOD **Congressional District:** First

Descriptors: economic impact, agriculture, water shortage, institutional constraints, optimization, wildlife habitat

Problem and research objectives:

Increased water shortages to agricultural producers induced by drought, climate change, or transbasin diversions are widely believed to have significant adverse impacts to both producers and area economies. The potential losses from water shortages call for strategies for reducing the impacts of shortages. Because structural approaches to improving water supply reliability are costly and face numerous environmental hurdles, alternative water management policies are being increasingly considered. In the Green River Basin there may be a role for innovations in both state and federal management of the water resource, particularly in times of shortage.

The objective of this project work was to identify and estimate the economic impacts of reduced surface water supplies on irrigated agriculture in the basin, and the externalities arising from agricultural user responses. Direct economic impacts, indirect (secondary) economic impacts and physical externalities (on wildlife and recreational resources) were of primary interest. The extent to which innovative water allocation policies at both the state and federal level could mitigate impacts of reduced supplies were investigated.

Methodology:

The research was divided into four tasks. In Task 1, a farm level water use decision model was developed and direct impacts on farm income from changes in water supply were estimated. Task 2 required the development of a network model of Upper Green River Basin water use for investigation of the economic and hydrologic impacts of alternative water allocation policies. This work is included in a full Colorado River Basin modeling effort for the Severe and Sustained Drought Project. This full Colorado River Basin model incorporates farm level

irrigation decisions and economic impacts determined in Task 1. In Task 3, the magnitude of indirect (secondary) economic impacts were estimated using the basin wide direct economic impacts generated in Task 2. Physical externalities (recreation and wildlife impacts) caused by changes in water supply and agricultural water use (determined in Task 2) were identified in Task 4.

Principal findings and significance:

Modeling Producer Response to Variable Water Supplies

A mathematical modeling technique known as discrete stochastic programming is used to simulate irrigators' water management decisions under uncertainty. This approach improves upon others used to estimate damages of drought by explicitly recognizing that cropping and management decisions must be made with only imperfect knowledge of water supply conditions and future weather conditions. In the example presented here, this technique is applied to the Eden-Farson region of Wyoming's Green River Basin. Irrigation water is derived from snowpack in the Wind River Mountains and is delivered by the Eden Valley Irrigation and Drainage District from storage in the Big Sandy and Eden Valley Reservoirs. Alfalfa hay and grass hay are the dominant crops. Fertilizer and irrigation decisions must be committed before the full annual water allotment is known with certainty.

It is assumed that irrigators seek to maximize profit over the range of possible irrigation supplies by their choice of fertilizer use and their water management decisions. Fertilizer applications are chosen based on snowpack estimates available in early March. The irrigation season is represented by a first and second irrigation. The level of irrigation and its allocation among hay stands during the first irrigation uses a forecast of the yearly water allotment provided May 15 by the irrigation district. Decisions in the second irrigation period make use of the final water allotment for the year; thus there is no uncertainty in this final period.

Indirect Impacts of Irrigation Water Shortages

The costs of water shortages in Wyoming's Green River Basin include indirect impacts in sectors supporting and supported by irrigated agriculture, and of lost consumer spending power. Estimates of total indirect income and employment impacts of reduced surface water supplies are made building upon recently completed input-output modeling of the Wyoming county economies. These county level models have 13 sector detail for agricultural industries and are used to develop estimates of the total (direct plus indirect) economic impacts of changes in agricultural water supplies.

The contribution of the estimated 82,000 cow units supported by Green River based hay irrigation shows total income of $19.7 million or $76/af, and total employment of 1,528 full time equivalent jobs.

Range sheep are excluded from this study of irrigation water as they are typically grazed through the winter months, particularly in Sweetwater and Uinta Counties. Locally produced hay is thus unlikely to be a critical input for Basin sheep production.

Non-Agricultural Impacts

Major water users in Wyoming's Green River basin include not only irrigators, but also industrial plants producing power and trona, and households in Rock Springs and Green River. Drought imposes varying economic losses on these users, while community impacts occur from employment changes in water using enterprises and the economic links between these users and local businesses. Instream flows support regionally significant fisheries, including two reaches for which instream flow filings have been made. Potentially endangered species in the basin include native cutthroat trout and the round-tailed chub. Cutthroat trout may be impacted by high elevation irrigation diversions in the Western Wyoming Range, while round-tailed chub habitat, formerly dominated by the Green River mainstem, may include the Blacks Fork River. Sustained drought in the Colorado River basin, of which Wyoming's Green River basin is but one component, would cause damages across these distinct users of basin water, in addition to costs of lost hydropower production and increased salinity.

SYNOPSIS

Project Number: 05

Start: 06/91
End: 05/94

Title: **Assessment of the Potential Environmental Fate and Effects of Oil-Field Discharge Waters Containing Radium (^{226}Ra)**

Investigators: Bergman, Harold and Hill, Sheryl, University of Wyoming, Laramie

Focus Categories: RAD, TS, WW, WQL, WL **Congressional District:** First

Descriptors: isotopes, industrial wastewater, contaminant transport, soil-water relationships, plant-water relationships, pollution control

Problem and Research Objectives:

The naturally occurring radionuclide, 226-radium (^{226}Ra or radium), has been detected in oil production waters in all oil-producing regions of the country, including Wyoming. The instream water quality standard for radium, originally set at 5 pCi/L for all surface waters of the state, was recently modified to allow instream concentrations of 5 pCi/L in class 1 and 2 surface waters and 60 pCi/L in class 3 and 4 surface waters. According to the Petroleum Association of Wyoming, 80% of the produced water discharged is released to dry or intermittent drainages (i.e., class 4 waters). These discharges are generally of good quality and provide a variety of beneficial uses, including stock and wildlife watering and agricultural irrigation. While the short-term benefits of many of these discharges are indisputable, the long-term hazards posed by the transport of radium from deep aquifers to surface waters are not well understood. Furthermore, the Wyoming Oil and Gas Commission recently approved the release of produced waters to skim ponds to allow the precipitation of radium before the water is discharged. This approach may limit the distribution of radium in surface waters and downstream sediments but only by concentrating it in the sediments of the skim ponds. Guidelines regulating the management of radium-contaminated sediments in receiving waters or skim ponds have yet to be established, and the data necessary for formulating management decisions are currently unavailable.

The objectives of this study are to (1) determine the environmental fate of radium discharged to skim ponds and class 3 and 4 surface waters in Wyoming, (2) assess the biological availability of radium in these surface-water environments, and (3) provide a preliminary assessment of the environmental hazards posed by radium in produced-water discharges.

Methodology:

During years one and two of this project, water and sediment samples were collected from seven oil production facilities in Wyoming. Preliminary analytical data provided by the Wyoming Department of Environmental Quality indicated that the waters produced by these facilities contained concentrations of radium ranging from 3 to 140 pci/L. Water discharged from these facilities passed through a series of one-to-four skim ponds before it was finally discharged to a surface stream or wetland. A sample of influent was collected from the point at which the produced water exited each pond. Four, 500-mL sediment cores were also collected from the bottom surface of each skim-pond.

The samples were returned to the laboratory where they were prepared for analysis of ^{226}Ra. The four sediment samples from each pond were composited, weighed, and dried at 176°C for 24 hours, then reweighed to determine water content. The dried sediment was reduced to ash by combustion at 550°C for 24 hours and the ash was weighed to determine the organic content of the original sample. All but one of the ashed sediments were crushed to pass through a 2-mm sieve opening. The remaining sample contained large amounts of gravel that could not be crushed to a diameter of less than 4 mm.

A one-liter volume of filtered water or ashed sediment was placed in a Marinelli beaker to provide a consistent counting geometry among samples. The Marinelli beakers were sealed with an acrylic latex silicone caulk and stored for 28 days to allow the decay product to reach equilibrium with its parent material.

Concentrations of ^{226}Ra in the water and sediment samples were determined by counting the high-energy gamma emissions of its daughter products, 214-lead and 214-bismuth. The total counts (i.e., total radioactive decay events) were measured at the 0.352-MeV peak channel for 214-lead and the 0.609-MeV and 1.764 MeV peak channels for 214-bismuth. Although other daughters of ^{226}Ra emit gamma radiation, their emissions are very weak or of low yield, and their contribution to the total count is insignificant. The 214-lead peak yields 36% of the counts and the 214-bismuth peaks yield 47% and 17% of the counts.

The samples were counted for 80,00 seconds to obtain a coefficient of variation of 10% or less. Gamma counts were determined using an Ortec coaxial detector system with a high-purity germanium crystal connected to an Ortec Model 3200 multichannel analyzer. A sealed Marinelli beaker containing deionized water was counted after every sixth water or sediment sample to measure background emissions. The coefficient of variation between background counts was only 0.0211, indicating that the counting efficiency of the spectrometer has been reliable. Total counts will be corrected for background and converted to pCi/L for water samples and pCi/g for sediment samples.

Portions of some samples analyzed in our laboratory were also submitted to a commercial laboratory (CORE Laboratories, Casper, WY) for analysis. Large discrepancies between our results and the results obtained by the commercial laboratory have been attributed to the standard

on which our conversion from counts to pCi was based. The standard was replaced with one traceable to the National Bureau of Standards and plan to prepare spiked samples of water and sediment to evaluate recovery and to correct for variations in counting geometries. Portions of spiked samples will again be submitted for analysis by a commercial laboratory.

During year two, technical problems necessitated the repair, and eventually the replacement, of our multi-channel analyzer. The time spent repairing the old analyzer and purchasing a new one delayed our analyses of samples several months. It has also necessitated recounts of many samples to ensure that data obtained using the new analyzer is consistent with that obtained using the new analyzer.

In addition to samples collected from skim ponds, samples of water, sediment, and plant material were collected from the Loch Katrine wetlands area in Park County, Wyoming. The Loch Katrine site is important to this study because it represents a closed system in which the only source of water other than precipitation is radium-containing oil-field production waters. Discharge from the skim-pond facility has created a saturated zone or wetland of approximately 140 acres on the southern edge of the lake that supports a dense emergent community of bulrush and cattail. During year one, sediment samples were scraped from various locations within the lake bed and water samples were collected from the wetland. During year two, samples of water, sediment and algae were collected near the northwest rim of the lake and samples of water, sediment and emergent vegetation were collected from the wetland. The water and sediment samples were analyzed as described above. The vegetation was separated according to species, washed in detergent, rinsed, dried at 70°C for 12 hours, weighed, crushed to a standard size, and counted.

Samples of animal tissue were also obtained during year two from Dr. Pedro Ramirez, U.S. Fish and Wildlife Service. The skeletons of fifteen fledgling ducks collected in July 1992 were isolated, dried at 100°C for 24 hours, weighed, crushed, and counted by gamma spectrometry. Additional samples of water, sediment, plants, and insects will be collected during year three, especially during waterfowl nesting periods.

Principal Findings and Significance:

Results of analyses of water and sediment samples were consistent with the results anticipated based on the chemical behavior of radium in aqueous solution. The concentration of radium in water decreased with increasing distance from the point of discharge. Conversely, the concentration of radium in sediment tends to increase with increasing distance from the point of discharge. Factors that may influence the rate of ^{226}Ra deposition in the sediments include water cooling rate, pH changes caused by equilibration of dissolved gases with ambient concentrations, the retention time of water within the ponds, and the distances between ponds.

INFORMATION TRANSFER ACTIVITIES

June 1, 1992 - May 31, 1993

The Wyoming Water Resources Center uses several networks to inform the people of Wyoming, as well as neighboring states and regions, of what the WWRC is doing in education, research, and interagency cooperation to better manage and protect Wyoming's, and the nation's, water resources. Information transfer activities of the WWRC during the period June 1, 1992 through May 31, 1993 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 Resources 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 1993 Water Resources Seminars were held in Riverton, Wyoming on January 6, 1993 and in Cheyenne, Wyoming on March 16, 1993. Issues addressed at the seminars included: fisheries development and management, lake rehabilitation,

Wyoming Conservation Districts involvement in the clean water programs, safe drinking water standards and regulations, impact of federal regulations on Wyoming water development projects, movement of herbicides and pesticides in irrigated soils, groundwater flow demonstration, on-farm irrigation efficiencies, community drinking water issues, irrigation scheduling methods, Wyoming water administrative activities and issues impacting Wyoming water users, and water development project potentials and projects underway in the state. Over 20 cooperating agencies participated in the seminar program, including the Wyoming State Engineer's Office, Wyoming Water Development Office, Wyoming Association of Conservation Districts, Governor's Non-Point Source Task Force, American Water Works Association, Wyoming Water Development Association, local water development groups, and Central Wyoming College and Laramie County Community College. Over 200 people attended the two seminars.

2. **Wyoming Legislative Water Resources and Law Forum:** Over 65 legislators (almost 3/4 of the entire Wyoming legislature) attended the Wyoming Legislative Water Resources and Law Forum held at the Capitol Building in Cheyenne, Wyoming, January 11, 1993. The one-day forum is an opportunity for all legislators to learn about water resources and particularly about water issues in Wyoming. The Forum is co-sponsored by the WWRC and the Wyoming Legislative Services Office and is held in cooperation with the Wyoming State Engineer's Office, State Attorney General's Office, Wyoming Water Development Office, Wyoming Department of Agriculture, Wyoming Department of Environmental Quality, Wyoming Game and Fish Department and the University of Wyoming. Legislators also received a reference book containing information on Wyoming water resources, issues, forum papers and cooperating agency contacts.

3. **WY-AWRA Conference:** The WWRC co-sponsored the 5th Annual Meeting of the Wyoming State Section, American Water Resources Association. The conference was held at the University of Wyoming in Laramie, October 28-30, 1992. Technical sessions included analytical methods in water quality, surface water and sediment transport, water resource economics, water resources management and policies and education in water resources. There were 80 attendees.

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, 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 a State Senator, State Engineer, Assistant State Attorney General, a member of the Wyoming Water Development Commission, coal industry representative and environmental group 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 Water Institute for Teachers was held in Laramie, July 6-17, 1992.

5. **Efficient Sprinkler Irrigation Operation:** Three information meetings were conducted around the state for irrigators using center pivot sprinkler irrigation. The meetings were co-sponsored by the Wyoming Water Resources Center, UW Civil Engineering Department, UW Cooperative Extension Service (respective counties), and Wyoming rural electric cooperatives. Field studies in Wyoming show that irrigators can save

substantial pumping costs if the sprinkler systems are properly maintained and operated. Topics of discussion for the one-day meetings included: factors that determine the energy required to operate a sprinkler system, irrigation pumping plant efficiencies, importance of having a pump curve, reading the watt-hour meter, uniform water application, irrigation water requirements, water to be pumped to meet requirements and economics of an inefficient system versus and efficient system. Approximately 250 sprinkler irrigators attended these meetings.

COOPERATIVE EDUCATION AND RESEARCH EFFORTS

The Wyoming Water Resources 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. **Water Conservation Committee - American Water Works Association, Rocky Mountain Section:** WWRC Associate Director served as the Wyoming representative and Vice-Chair. The group is developing education information and a database of water conservation materials.
3. **Water Resources Committee, Great Plains Agricultural Council:** WWRC Associate Director served as the UW representative leading a study of the impacts of water transfers in agriculture.
4. **Water Education Poster Contest:** The Wyoming Water Resources Center was a co-sponsor in the 1992-93 Powell (Colorado River Basin) Water Education Poster Contest for K-6 students. The contest theme was "Water Makes Earth Our Home." Governor Mike Sullivan presented awards to six students who were regional and state winners. Posters drawn by regional

winners will be featured on the 1993-94 school year calendar that also contains challenging questions about water, environmental sciences and educational activities. Supporting contributions were raised to provide a Water Education Calendar to every Wyoming elementary classroom. This was a very successful program co-sponsored by the WWRC and International Office of Water Education, Utah State University, supported by a grant from the USGS.

5. **Water Management and Conservation in Western Irrigated Agriculture, Western Regional Research Project W-178 and WWRC-90.** Participated in meetings and coordination of interdisciplinary water management research on a regional level. Developed proposal (accepted) to continue and expand the scope of this regional research to water management in the northwest and Colorado River Basin.

6. **WWRC Groundwater Demonstration Model:** This was used for the WWRC Water Institute for Teachers and loaned to UW Cooperative Extension Service for programs to develop a better understanding of land use, surface and groundwater interactions and impacts on water quality.

7. **Water Education Curriculum Training:** Six Water, Youth and Optimism water education curriculum training courses were held around the state in 1992-93. Training courses were conducted by the Wyoming Institute for the Development of Teaching sponsored by a grant from the Wyoming Game and Fish Department. Curriculum materials used in the course were developed through a WWRC grant sponsored, in part, by USGS Section 104 monies.

INFORMATION TRANSFER PUBLICATIONS

Information transfer publications for the report period included a bimonthly newsletter, educational slide programs and brochures, research briefs, bulletins, news releases, and public information and education exhibits.

1. **Wyoming Hydrogram:** The Wyoming Hydrogram is a newsletter produced and distributed bi-monthly by the WWRC. The newsletter is sent to over 1,600 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 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. Three briefs were published in 1992-93: Modeling Groundwater Flow and Contaminant Transport, Technical RB 92-03, Evaluation of Irrigation Diversions and Return Flows, RB 92-103, and Irrigation Decisions When Water Supplies From Storage are Uncertain: Drought Impacts on Farm Profit in the Green River Basin, Technical RB 93-04.

3. **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. Two more issues on the hydrologic cycle and Wyoming and groundwater resources were published and disseminated to the public and offices statewide.

4. **Irrigation Efficiency:** WWRC, in cooperation with Civil Engineering faculty, published the following two-page fact sheets addressing efficient operation of sprinkler irrigation in Wyoming:
   - Optimizing Energy Requirements for Sprinkler Irrigation
   - Application Uniformity of Sprinkler Irrigation Systems

- Irrigation Pumping Plant Efficiencies
- Testing Irrigation Pumping Plants
- Pump Curves and Efficiency
- Horsepower Determination from Watt-hour Meters
- Irrigation Water Quantity and Application Time

In addition, a computer program, "SPIREC" for calculating sprinkler irrigation pumping plant efficiencies, energy costs and water application uniformities was developed for Wyoming sprinkler irrigators.

5. **"Wyoming's Water Resources":** In cooperation with the UW Department of Agricultural Economics, this bulletin which outlines Wyoming's water basins, water quantities, water use in the state, reservoir storage, water rights, interstate water rights, potential uses of water, and water planning and development is made available for use by the public.

6. **WWRC Information Brochure:** An information brochure describing the research and activities of the Wyoming Water Resources Center was developed and disseminated to the public, water resources agencies and organizations, UW, and other universities and research/education organizations.

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

8. **Federal Acts, Agencies and Programs Related to Water Resources.** Two information/education slide programs were developed and included in the information provided to Wyoming state legislators during the Wyoming Legislative Water Resources and Law Forum, January 1993.

9. **Water Savings Guide and Water Fact Guide:** Information/education publications were distributed to the public and schools through WWRC Water Resource Seminar programs, UW Cooperative Extension Service Offices, teachers' workshops and public meetings.

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

- Water Resources and Law Forum Held for Legislators
- Papers Sought for Dissertation/Thesis Award (UCOWR)
- Wyoming Water Resources Center Request for Research Proposals
- Scholarship Awards Given at Annual Water Resource Meeting
- Outstanding Service Award Presented by Wyoming State Section AWRA
- Appreciation Award Given by University of Wyoming AWRA Student Section
- State Meeting on Water Resources Scheduled in Laramie
- UW Professor Recognized for Colorado River Study
- UW-WWRC Rhoads Scholarship Winners Named
- Winners Announced for Water Poster Contest/Governor Sullivan Presents Awards
- Meeteetse Student Receives Regional Poster Contest Award
- Water Research Projects Funded
- UW Scientists Apply Water Resource Practices Throughout the World
- Water Institute for Teachers
- WWRC Announces Water Education Poster Contest
- UW Professor Writes Hydrosystem Textbook
- All-Day Seminar Concerned With Water Resources

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

- Developed an information and education exhibit on UW-Wyoming Water Resources Center research, education and service programs, and Colorado-Green River Basin water use, compacts and treaties for display at the University of Wyoming Visitors Center, January-present.

- Developed a water resources information and education exhibit on UW-WWRC research, education and service programs and information/education publications on display at the Capitol Building in Cheyenne during the 1992 Legislative session. Also coordinated sponsorship and set-up a historical photographic exhibit on water resources from the archives of the American Heritage Center. February-March 1992.

- Prepared and participated in the UW Student Resource Fair with an exhibit about Wyoming's water resources and hand-out information and education materials on UW-WWRC research, education and service programs. September 17, 1992.

- Prepared and participated in the UW Family Weekend with an exhibit about Wyoming's water resources and hand-out information and education materials on UW-WWRC research, education and service programs. October 16-17, 1992.

- Prepared and participated in the Wyoming Section American Water Resources Association Annual Meeting with an exhibit on Wyoming's water resources and information and education materials on UW-WWRC research, education and service programs, October 28-30, 1992.

- Prepared and participated in the Wyoming Water Development Association's 1992 Annual Meeting with an exhibit on Wyoming's water resources with information and education materials on UW-WWRC research, education and service programs. November 4-6, 1992.

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 Office provides funds in the amount of $85,000 annually through a service contract with the Wyoming Water Resources 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 over 13,000 citations.

Geographic Information Systems

The Wyoming Water Resources Center has taken the lead in the state by developing a state-of-the-art GIS computer lab. The initial WWRC project has involved mapping ground water vulnerability, first for Goshen County, and then for the rest of the state. Other on-going and future projects at the WWRC include: underground injection well mapping, surface water rights mapping, compilation of digital map sources for Wyoming Water Division II, mapping of archeology sites at South Pass City, agricultural nonpoint source surface water quality modeling, development of a geographical decision support tool for the Forest Service's common water unit parameters, and cumulative hydrologic impact modeling in the Powder River Basin.

COOPERATIVE ARRANGEMENTS

ADMINISTRATION

As specified in its charter, the Wyoming Water Resources Center has responsibility for: 1) Service, 2) Research, 3)Information Transfer, and 4) Instruction. The Director and Associate Director, in keeping with the Center's charter, and in cooperation with the State of Wyoming, continue to participate in the following.

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 research for Wyoming Department of Environmental Quality Nonpoint Source Pollution Program.

University Service

- Member, University of Wyoming Deans Council.
- Serve on University committees (Director currently working with Women and Minority Faculty Hiring Committee).

- Serve on Steering Committee for Abandoned Mine Lands Research Program.

- Continued effort to apprise faculty members of research needs and opportunities in water-related research.

- Work with academic standards committee on interdisciplinary Master of Science/Water Resources curriculum.

- Serve on appropriate graduate student committees.

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

- Serve on School for Environment and Natural Resources Committee.

Other

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

- Director elected Vice-President of Powell Consortium

- Director served as President-Elect of National Institutes for Water Resources.

- Serve as delegates to Universities Council on Water Resources.

- Transfer of research results to appropriate users.

TABLE 1: COOPERATING STATE AND FEDERAL AGENCIES IN WYOMING

STATE

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

FEDERAL

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

TABLE 2: SERVICE-TO-STATE - FY 92

Research Projects Performed in Response to Wyoming State Agency Requests

---

Conveyance Losses in Wyoming Streams and Rivers, WWRC (V.R. Hasfurther, Civil Engineering, July 1, 1989 through June 30, 1994).

Modeling Surface Water for the Green River Basin of Wyoming--Future Severe Drought Considerations, WWRC (V.R. Hasfurther, WWRC, July 1, 1991 through August 31, 1993).

Development and Enhancement of a Comprehensive Statewide Water Quality Database for Wyoming, WWRC (V. Hasfurther and B. Lawrence, WWRC, July 1, 1992 through June 30, 1994).

DEQ/WQD Cooperative Agreement to Develop a Wyoming Statewide Groundwater Sensitivity Mapping System Based on a Geographic Information System, Department of Environmental Quality, Water Quality Division (S. P. Gloss, V.R. Hasfurther, W. Gribb, P. Huntoon, R. Marrs, L. Munn, S. Needham, J. Case, July 1, 1991 through September 26, 1993).

Underground Injection Control/Geographic Information System Mapping, Department of Environmental Quality, Water Quality Division (V. Hasfurther and S. Needham, WWRC, August 1, 1992 through June 30, 1993).

DEQ/WQD Cooperative Agreement: Assessing Vulnerability of Aquifers in Wyoming to Contamination/Phase One: Vulnerability Mapping of Goshen County, Wyoming Using Geographic Information Systems, Department of Environmental Quality, Water Quality Division (S.P. Gloss, V.R. Hasfurther, W. Gribb, L. Munn, R. Marrs, P. Huntoon, January 13, 1992 through March 15, 1993).

Water Resources Data System (WRDS), Wyoming Water Development Commission (S.P. Gloss, July 1, 1990 through June 30, 1994).

Role of Natural Organic Solutes on the Mobility of Selenium in Abandoned Coal Mine Spoil-Ground Water Systems, Abandoned Coal Mine Lands Research Program (UW) (R.B. See, USGS; K.J. Reddy, WWRC; G. Vance, Plant, Soil and Insect Sciences; D. Naftz, USGS, May 1, 1991 through December 31, 1993).

Modeling Surface Water for the Green River Basin of Wyoming: Future Severe Drought Considerations, Wyoming Water Development Commission (V. Hasfurther, August 1, 1991 through August 31, 1993).

Methodology for the Geomorphic Classification and Design of Drainage Basins and Stream Channels in the Powder River Coal Field of Wyoming, Abandoned Coal Mine Lands Research Program (UW) (T. Wesche, WWRC, H. Lowham, R. Daddow and M. Smith, USGS, May 1, 1992-June 30, 1994).

Flushing Flow Requirements of Large Rivers to Maintain Fishery, Channel and Riparian Values, Wyoming Water Resources Center (T.A. Wesche, WWRC; W.A. Hubert, Wyoming Cooperative Research Unit, July 1, 1991 through June 30, 1993).

---

2. Information Transfer

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

3. Research

- **Federal Program FY 92**

Research accomplishments of the FY 92 Federal Water Research Program were reviewed by the Director. The results of these projects have been provided to the Center's advisory committees and presented at professional meetings.

- **Federal Program FY 93**

The Director solicited proposals under the FY 93 Federal Water Research Program from interested faculty on campus and the seven community colleges. Proposals were received and reviewed by state agencies and regional university personnel through the Water Institute Directors in the region--three were funded under the program.

4. Instruction

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

ENVIRONMENTAL PROTECTION AGENCY

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

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 input of the Executive Office, the legislative branch of government, the academic community, the State Climatologist, citizens representing each of the state's four administrative water divisions, and the University administration (Table 3). The Committee meets at least twice annually to discuss WWRC activities and research priorities and to approve projects presented.

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

WYOMING WATER RESOURCES CENTER
RESEARCH REVIEW AND PRIORITIES COMMITTEE
July, 1993

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

Steve F. Adams (1992-1993)
Member at Large
Box 177
Baggs, Wyoming 82321 324-7876

Harold Bergman (1992-1995)
Zoology and Physiology Department
Box 3166, University Station
Laramie, Wyoming 82071 766-4330

Wendy H. Bilek (1992-1995)
Water Division 1
Kerr-McGee
P.O. Box 1669
Casper, Wyoming 82602 237-2514

Beryl Churchill (1992-1995)
Water Division 3
Rural Route 3, 848 Road 10
Powell, Wyoming 82435 754-4865

Doyl M. Fritz (1992-1995)
Water Division 2
Western Water Consultants, Inc.
1949 Sugarland Drive, Suite 134
Sheridan, Wyoming 82801 672-0761

Jim Geringer (1990-1997)
Wyoming Senate
190 Preuit Road
Wheatland, Wyoming 82201 322-9709

Steven P. Gloss (Executive Secretary)
Wyoming Water Resources Center
Box 3067, University Station
Laramie, Wyoming 82071 766-2143

Victor Hasfurther
State Climatologist
Civil Engineering Department
Box 3295, University Station
Laramie, Wyoming 82071 766-2963

President Terry P. Roark (*ex officio*)
Office of the President
Box 3434, University Station
Laramie, Wyoming 82071 766-4121

Derek Hodgson, Vice-President
Research Office
Box 3355, University Station
Laramie, Wyoming 82071 766-5353

Rich Lindsey, State Planning Coordinator
Governor's Office
Capitol Building
Cheyenne, Wyoming 82002 777-7435

Larry Munn (1992-1993)
Plant, Soil and Insect Sciences Department
Box 3354, University Station
Laramie, Wyoming 82071 766-2127

Jim Noble (1992-1993)
Water Division 4
Box 80
Cora, Wyoming 82925 367-4553

Cynthia Nunley (1992-1993)
Member at Large
864 North 4th Street
Lander, Wyoming 82520 332-2442

Rodney "Pete" Anderson (1993-1997)
Wyoming House of Representatives
1070 Albin Road
Pine Bluffs, Wyoming 82082 245-3201

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

Paul Schwieger (Chairman)(1983-1993)
6609 Braehill
Cheyenne, Wyoming 82009 638-8220

PUBLICATIONS

Publications completed during FY 92 as a result of work funded under Section 104

CITATION	Supporting Section 104 Project Number
1. Article in Refereed Scientific Journals	
Henszey, Robert, Quentin Skinner and Thomas Wesche, 1994, Response of riparian vegetation to four years of streamflow augmentation in southeastern Wyoming, *Wetlands*, (Submitted).	G-2056-02
Henszey, Robert, Thomas Wesche and Quentin Skinner, 1994, Time-of-travel in an ephemeral watercourse responding to streamflow augmentation, *Water Resources Bulletin*, (Submitted).	G-2056-02
Henszey, Robert, Quentin Skinner and Thomas Wesche, 1994, Depth-to-groundwater relationships for three riparian species/assemblages in southeastern Wyoming, *Journal of Applied Ecology*, (Submitted).	G-2056-02
Krzyszowska, A.J., R.D. Allen and G.F. Vance, 1993, Assessment of herbicide fate in a Wyoming rangeland environment: Soil column study, *Journal of Environmental Quality* (in review).	G-2056-03
Krzyszowska, A.J., and G.F. Vance, 1993, Solid phase extraction and HPLC analysis of dicamba and picloram in soil and water samples, *Journal of Agricultural and Food Chemistry*, (in review).	G-2056-03
2. Book Chapters	
3. Dissertations	
Henszey, Robert, 1993, Riparian zone changes caused by streamflow augmentation, Ph.D. Dissertation, Department of Range Management, College of Agriculture, University of Wyoming, Laramie, Wyoming, 110 pp.	G-2056-02
4. Water Resources Research Institute Reports	

CITATION	Supporting Section 104 Project Number
5. Conference Proceedings	
G. Briand, J.F. Booker, and A.M. Michelsen, 1991, Water Supply Uncertainty and its Impacts on Profits: Eden-Farson Hay Producers, Fifth Annual Meeting, Wyoming State Section of the American Water Resources Association, Laramie, WY, October 28-30.	G-2056-04
J.F. Booker, A. Michelsen, B. Colby, and R.A. Young, 1993, Economic Impacts on Instream Users, 29th Annual Conference, American Water Resources Association, Tucson, AZ.	G-2056-04
H. Vaux, Jr., J.F. Booker, B. Colby, and P. Watters, 1993, Economic Impacts on Off-Stream Users, 29th Annual Conference, American Water Resources Association, Tucson, AZ.	G-2056-04
A. Michelsen and J.F. Booker, 1993, Water Supply Expectations and Forecast Accuracy: The Effects of Uncertainty on Farm Profit, 29th Annual Conference, American Water Resources Association, Tucson, AZ.	G-2056-04
6. Other Publications	
Krzyszowska, A. and G.F. Vance, 1992, Soil and Water Analysis of the Herbicides - Picloram and Dicamba, *Agronomy Abstracts*, p. 46	G-2056-03
Allen, R.D., A.J. Krzyszowska and G.F. Vance, 1993, Modeling Herbicide Fate in a Wyoming Rangeland Environment, *Agronomy Abstracts*, p. 25.	G-2056-03

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 1992 Program are indicated below.

Training Category	Academic Level				
Field of Study	**Undergraduate**	**Master's Degree**	**Ph.D. Degree**	**Post-Doc**	**TOTAL**
Chemistry					
Engineering:					
Agricultural					
Civil		1			1
Environmental				1	1
Soils	3				3
Systems					
*Other					
Geology					
Hydrology	5	1			6
Agronomy					
Biology	1	1			2
Ecology	3		1		4
Fisheries, Wildlife & Forestry					
Computer Science					
Economics		1		1	2
Geography					
Law					
Resources Planning	1				1
Other*					
TOTAL	13	4	1	2	20

*Less than 5 students in any one field of study

POSTGRADUATE EMPLOYMENT

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