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Wyoming Water Resources Center
University of Wyoming
Laramie, WY 82071

Steven P. Gloss, Director

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ABSTRACT

Three research projects were funded under the FY93 program, as well as information transfer activities. These three research projects relate to important water issues in the State of Wyoming and the region.

Comparison of Depth-to-Groundwater Suitability Curves for Important Riparian Plant Species in the Subalpine and Montane Zones. This study provides some of the basic information needed to make informed management decisions regarding the response of riparian vegetation to various surface- and ground-water level regimes. For the second year of the study we evaluated the response of aspen (*Populus tremuloides*) density, and shrubby cinquefoil (*Pentaphylloides floribunda*) density and canopy cover to streamflow augmentation and altered groundwater levels. Depth-to-groundwater suitability relationships were investigated for both species. Aspen density declined significantly as a result of streamflow augmentation on sites that became saturated or inundated for several consecutive growing seasons. Shrubby cinquefoil density also decreased significantly where the soil was saturated or inundated for several consecutive growing seasons. Conversely, shrubby cinquefoil canopy cover increased one site as a result of flow augmentation. Both aspen and shrubby cinquefoil showed a wide range of tolerance for groundwater levels, but neither showed a distinct relationship to depth to groundwater. Other environmental factors may play a significant role in determining the distribution of these species.

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.

Econometric Study of Water Right Market Prices: Determinant Identification and Quantification of Relationships and Price Trends. As the demand for existing water supplies continues to grow and drought conditions persist, increasing attention is being placed on transferring water rights through voluntary markets. Transfers of water rights are not new; they have occurred whenever irrigated agricultural properties are purchased. More recently water transfers are being proposed and used as a means of reallocating water to urban uses. Critical to this transfer process is knowledge about the current and future prices of water rights. Knowledge about water right prices is necessary to evaluate the economic benefits and costs of state and

interstate water transfers and to analyze management options and development alternatives. Information about current water right prices is only available for selected market transfers around the region and virtually no research has been conducted to identify factors that may explain current prices or establish relationships to assist in evaluating or forecasting water right prices.

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.

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WATER PROBLEMS AND ISSUES OF WYOMING

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

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

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

Water quality, availability, and allocation for future agricultural, mineral extraction, industrial, recreational, and municipal purposes continue to be the center of water related problems in Wyoming. The future management of Wyoming's water resources, in compliance with existing interstate water compacts and decrees and water quality regulations, is a challenge

in planning and implementation. After available surface and groundwater supplies are utilized, their equitable distribution, conservation, and maintenance of quality become important legal and complex social issues. The problems associated with the capture, diversion, dispersal, and re-use of these water resources are encompassing. In addition, being better able to forecast quantity and quality of water availability to downstream users is extremely important.

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

PROGRAM GOALS AND PRIORITIES

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

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

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

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

Beginning with the inception of the WWRC, the University received a line item in its biennial budget from the legislature which provided the principal support for the Center. The "base" budget for the WWRC is completed by the receipt of approximately $100k annually from the federal WRRI program. This base funding has provided an infrastructure for the WWRC enabling it to compete effectively for additional external research funding. Although the line item funds received by UW previously came from the state general fund, beginning in FY 89-90, and continuing to FY 94-95, those funds have been allocated from one of the state's water development accounts. The WWRC also receives an annual contract through the Wyoming Water Development Office to operate the Water Resources Data System.

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

Section 104 Objectives

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

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

The following outline of topics represents areas of research for which proposals were solicited in FY 93.

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. Our 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*). Our overall 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 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. Work for the second year of this two-year study focused primarily on the response of aspen and shrubby cinquefoil to streamflow augmentation and altered groundwater levels. A synopsis of results for sedge, tufted hairgrass and slimstem reedgrass were presented with the first-year progress report.

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:

Non-flow augmented sites exhibited a much greater range and consistently deeper groundwater levels than sites with flow augmentation. Monthly median groundwater levels (1986-93) for the aspen sites without flow augmentation varied from a low of -2.35 m in January to a high of -0.51 m in early June following peak snow melt, while the flow augmented aspen sites ranged from a low of -0.43 m in July to a high of -0.10 m in April during spring runoff. Median groundwater levels in the non augmented shrubby cinquefoil sites peaked at -0.24 to -0.29 m from mid April to early June and declined throughout the growing season to about -1.0 m by September and October, while the flow augmented shrubby cinquefoil sites ranged from a low of -0.80 m in January to a peak of -0.30 m in May.

Aspen and shrubby cinquefoil showed a varied response to 8 years of flow augmentation. Aspen in the upslope areas showed no change in density as a result of flow augmentation, but aspen density decreased due to increased mortality in the saturated and inundated areas near and in the augmented streamflow. Shrubby cinquefoil density showed a similar response to flow augmentation.

Depth-to-groundwater relationships for aspen and shrubby cinquefoil were not as well defined as those reported for sedge, tufted hairgrass and slimstem reedgrass in the first year's Synopsis. Three different duration values (D_{10}, D_{50}, D_{90}) were examined to evaluate the relationship between water levels and plant response. 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. No discernible relationships between water level and aspen or shrubby cinquefoil response were observed, however, so no suitability curves were developed for these two species. The range of observed groundwater levels for aspen were 0.07 to -2.61 m for D_{10}, -0.03 to -3.30 m for D_{50}, and -0.19 to -3.74 m for D_{90}; while the range of observed groundwater levels for shrubby cinquefoil were 0.06 to -1.13 m for D_{10}, -0.24 to -1.82 m for D_{50}, and -0.49 to -2.26 m for D_{90}. The lack of apparent suitability relationships for both aspen and shrubby cinquefoil suggests that, except for long duration flooded conditions, both aspen and shrubby cinquefoil have a broad ecological tolerance for groundwater levels. Other factors, such as soil moisture and texture, may play a more dominant role in the distribution of aspen and shrubby cinquefoil in the study area. The presence of extensive aspen stands on adjacent uplands indicates that an available water table may not be necessary for aspen growth. Conversely, shrubby cinquefoil stands in the study area invariably occur on sub-irrigated sites, suggesting that an available water table may play a significant role in the distribution of shrubby cinquefoil.

Although depth-to-groundwater suitability curves may not be appropriate for all species, they can be 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 ground water. The herbicides dicamba and picloram have been detected in surface and ground waters 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, field studies, computer modeling, and direct analysis of the herbicides dicamba and picloram were all components 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)

was selected because of the recorded use of dicamba on different agricultural crops under various tillage practices. The Crook County site was 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 application 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.

The computer model, LEACHP, which is one of the four models in LEACHM and simulates pesticide degradation, transportation and movement was utilized for this project. 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. Other models (GLEAMS and CMLS) were examined but LEACHP was found to be the best suited for this project. A transfer function model was also investigated and proved to be useful based on preliminary results.

Principal findings and significance:

Soil chemical and physical properties that influence pesticide fate and mobility were examined in soils and substrata within three areas of Wyoming. Deep core incremental sampling was employed for pesticide analysis and was used as material for sorption studies to determine the potential extent of pesticide movement. Soil/substrata chemical and physical properties were also used in conjunction with results from the sorption studies to predict pesticide transport.

Essentially no sorption of dicamba was detected in laboratory studies; however, picloram sorption was found to be greater in soils containing increasing organic carbon contents. In saturated column (5.90, 2.96, and 0.82 kg ha^{-1} dicamba and 1.85, 0.97 and 0.47 kg ha^{-1} picloram) and unsaturated column (2.76 and 1.00 kg ha^{-1} dicamba and picloram, respectively) experiments, both herbicides and a Br tracer were displaced through soils using distilled water applied daily (60 ml d^{-1}). Herbicide and tracer breakthrough curves were obtained from the column experiment. Degradation rate constants were calculated using both a simple recovery fraction technique and by matching LEACHP-generated breakthrough curves to experimental data. 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 dicamba dissipation 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. Both herbicides were found to be highly mobile, with the mobility of picloram increasing at the higher pore-water velocities.

Soil collected at the Torrington experiment station prior to herbicide application did not, for the most part, contain any dicamba. Concentrations below the detection limit (8 ug/kg) were found at the 3 conventional tillage sites at all depths. The highest dicamba content was found at the 60-90 cm depth for some no-till-injection and chisel-broadcast sites with different tillage and fertilizer treatments. All samples from no-till sites with fertilizer injection treatment contained trace amounts of dicamba at all depths. Results also suggest dicamba leached to depths of 60-90 cm (trace content) and deeper after 80 days. The highest persistence of dicamba was in the no-till sites with fertilizer injection treatment.

The results of picloram concentrations in soils from the Sundance area (Crook County) were variable with respect to its movement and degradation rate. An initial application rate of 0.25 lb. a.i./ac was equivalent to 250 ppb of picloram in the top 15-20 inches of soil. In some sites, picloram was present in the top 15 cm of soil at 8.5 mg/kg one to six months after application of 1 lb. a.i./ac. Fourteen months after an application of 1 lb. a.i./ac, picloram content was highest at the 40-100 cm depth. Results indicate that picloram residues were limited to the top 100 cm with the highest concentration in the upper 40 cm. At one site, 10% of the applied picloram remained after 34 months.

Field studies were performed at an irrigated pasture site equipped with 64 soil water extractors installed at four depths. Samplers extract solution from 15, 30, 60 and 90 cm depth, with four replicated per plot at each depth. Two different herbicide application rates were applied to a total four plots. The highest application rates for picloram and dicamba were 2.9 kg ha^{-1} and 9.4 kg ha^{-1}

respectively, and the lower application rate was 0.9 kg ha^{-1} for both picloram and dicamba each. Plots were irrigated weekly with 5 cm of water for a total of 20 weeks.

Mean herbicide concentrations as a function of time were determined because of the spatial variability in contaminant movement that was evident both between neighboring samplers and plots. For plots, with lower herbicide application rates, herbicide disappearance was relatively quick, especially for dicamba. Dicamba concentrations approached the detection limit (0.0015 ppm) in 96 days at the depth of 15 cm and in 57-89 days at the depth of 30 cm. Maximum concentration at the depth of 60 cm (0.01-0.02 ppm) was reached in 29 days and was below the detection limit in 43 days after application. Dicamba was not detected at the 90 cm depth during the entire experiment.

Picloram remained in the profile longer, but did not penetrate into the vadose zone as deeply as dicamba into the vadose zone. Picloram was not detected in any solution samples collected from 60 and 90 cm samplers. However, picloram was detected on 327th day at the depth of 60 cm. This is consistent with column study results in which picloram was adsorbed by all the soil materials.

For plots with higher herbicide application rates, dicamba content within the profile decreased more rapidly than picloram. Concentration peaks of picloram and dicamba diminished and spread with increasing depth. Picloram concentration peaks moved throughout the profile at a slower rate than dicamba peaks. The highest measured concentration of picloram and dicamba was reached 15 days after application at the depth of 15 cm; the peak reached a depth of 30 cm two weeks later and a depth of 60 cm six weeks later. Picloram content at the 90 cm depth was still increasing 327 days after herbicide application.

Modeling pesticide movement in a vadose zone proved to be a useful research tool. LEACHP provided modeling parameters of solute movement in repacked soil columns. However, comparing model-predicted and field contaminant movement was more difficult due to spatial variability. Hydraulic conductivity was found to be highly variable, and would have the greatest effect on contaminant movement.

Additional studies are being conducted on the field site used for this project. Ground water monitoring wells have been installed at 10 locations throughout the research site. Both dicamba (9.4 kg ha^{-1}) and Br- (225 kg ha^{-1}) have been applied to plots 1 and 2, and a Cl^- tracer (50,000 mg L^{-1}) added to one of the ground water monitoring wells. Results of this additional study will provide information on pesticide and tracer characteristics in both vadose zone and ground water environments.

SYNOPSIS

Project Number: 04

Start: 06/93
End: 05/94

Title: **Economic and Statistical Analysis of Water Right Transfer Prices, Determinants, and Trends**

Investigator: Michelsen, Ari M., Associate Professor,
Department of Agricultural Economics

Focus Categories: ECON,MOD,PRICES **Congressional District:** First

Descriptors: water right price, water markets, transfers, agricultural use, econometrics

Problem and research objectives:

As the demand for existing water supplies continues to grow and drought conditions persist, increasing attention is being placed on transferring water rights through voluntary markets. Transfers of water rights are not new; they have occurred whenever irrigated agricultural properties are purchased. More recently water transfers are being proposed and used as a means of reallocating water to urban uses. Critical to this transfer process is knowledge about the current and future prices of water rights. Knowledge about water right prices is necessary to evaluate the economic benefits and costs of state and interstate water transfers and to analyze management options and development alternatives. Information about current water right prices is only available for selected market transfers around the region and virtually no research has been conducted to identify factors that may explain current prices or establish relationships to assist in evaluating or forecasting water right prices.

Knowledge about water right prices, factors and relationships is essential to evaluate the benefits and costs of water marketing and transfers and interbasin-interstate transfers and economic options for improving water use efficiency. The main objectives of this project were to: 1) identify specific factors that determine water right prices; 2) quantify water right price-determinant relationships; and 3) develop and provide an understanding of historical and expected water right prices and price trends.

Methodology:

The research is divided into four tasks. In task 1, economic theory is applied as the framework to identify supply, demand and other factors that may influence water right prices. In task 2, an econometric model based on rational expectations was developed to investigate variations in water right prices. Task 3 involved the selection of a case study market and collection of detailed price, transaction and determinant data identified in Tasks 1 and 2. Using this information, econometric models and price-factor relationships were tested and analyzed in Task 4 for theoretical and applied significance in understanding water right price determinants and trends.

Principle findings and significance

A number of supply and demand factors were identified as potential price determinants including, regional population and growth, per capita income, housing construction starts, hydrologic (drought) conditions, irrigated crop prices, yield and net revenue, farm debt-to-asset ratio, farm foreclosures, ratio of agricultural to urban water right owners, addition or withdrawal of existing water supplies, inflation, real interest rate, market conditions and participant's expectations, relative acquisitions by municipal/industrial sectors, and transaction activity.

A two equation model based on rational expectations theory was developed to explain water right market price variation. This model incorporates historical information in the form of a linear distributed lag structure with future value expectations to account for speculative pressures. The price expectation equation is intended to capture the effects of long-term market and financial conditions from which market participants generate future price expectations. The current price equation integrates price expectations from the first equation, price history, and more immediate market variables to account for short-term fluctuations.

The study area selected for analysis is the market for Colorado-Big Thompson (CBT) water operated by the Northern Colorado Water Conservancy District. Advantages of studying this market include its similarities with many other western regions (e.g. crops produced and urban growth), and its legal characteristics which allow water right price variation to be isolated from the influence of many institutional factors. Potential price determinant data identified in task 1 was collected from several sources and joined with information on market structure and transactions developed by reviewing monthly reports of more than 2,700 individual water right transactions.

Descriptive and econometric methods were used to analyze factor determinants and trends in CBT water right prices. The two equation rational expectation model of prices was estimated using a three stage least square procedure. The R^2 for the price expectation equation was 0.94 and for the current price equation 0.93. The parameter values were consistent with theoretically expected relationships. Although irrigated agriculture is the dominant water user, the results of the econometric analysis suggest that the returns to water in irrigation do not adequately explain the CBT price level. Socioeconomic, market and speculative factors however, do appear to explain much of the variation in water right prices and to play an important role in water right price formation. Significant parameters in the expected value equation include economic growth, historical CBT prices, the prime interest rate and degree of agricultural water right ownership.

Based on the CBT market, the econometric model developed for this analysis can successfully explain variation in historical prices and trends. The future expectations component allows better modeling of the investment decision process and speculation regarding water rights. Analysis of ex-post forecasts suggest that the model should not be the sole instrument used to forecast future prices. However, these tests were very insightful about probable changes in price-determinant relationships.

The present study should be of interest to water managers, policy makers and market analysts for three main reasons. First, this study identifies a set of water right price determinants, including agricultural, socioeconomic, financial and market factors, which can successfully explain the

variation in water right prices. Second, the study findings confirm and stress the importance of expectations (and their variability over time) in market price formation. In other words, price determinant relationships are based, in part, on participants perceptions of the future and this element should be taken into account when considering water right prices. Third, water rights seem to be considered as investment assets in practice, and some relevant "market signs" may be captured in the markets for other investment commodities such as farmland, crude oil or precious metals.

This study needs to be expanded to other water right markets. Application of the same model to a market where prices have followed a different trend or where the economic situation is different would be most instructive. Moreover, in the future, price and market activity information will be available for longer periods, which will benefit future analyses in that it will allow consideration of more variables and/or gain in precision. Finally, further research would be desirable in estimating the specific real returns to water used for municipal development purposes.

INFORMATION TRANSFER ACTIVITIES

June 1, 1993 - May 31, 1994

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, 1993 through May 31, 1994 have included: conducting, co-sponsoring and coordinating seminars, workshops and conferences on water resource issues and technological and management issues; the dissemination of water resources research results in technical reports, professional journals and presentations at conferences; coordination and participation in University of Wyoming, federal, and state agency water quality education efforts; and publication of research and education programs, research results and information transfer activities in newsletters and bulletins.

A. WATER RESOURCES SEMINARS, WORKSHOPS AND CONFERENCES

1. **Water Institute for Teachers**: A two-week Water Institiute 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 6-16, 1993.

2. **WY-AWRA Conference**: The WWRC co-sponsored the 6th Annual Meeting of the Wyoming State Section-American Water Resources Association. The conference was held at the University of Wyoming in Laramie, November 3-4, 1993. The meeting included panel discussions on biodiversity and watershed planning, and paper presentations. Some of the organizations represented included: the U.S. Geological Survey, U.S. Forest Service, U.S. Fish and Wildlife Service, U.S. Environmental Protection Agency, the Wyoming State Engineer's Office, The Nature Conservancy, U.S. Bureau of Land Management, and the University of Wyoming.

3. **1993 Common Sense Riparian Area Management Workshops**: WWRC Associate Director served as a member of the planning and teaching group and gave presentations concerning stream dynamics, hydrology and watershed characteristics, and stream improvements. The workshops were the first such comprehensive management programs offered in Wyoming. They provided an opportunity to look at techniques that will improve riparian habitats while maintaining the economic viability of operations. Experts who gave presentations included university personnel, agency scientists, and ranchers.

4. **48th Annual Meeting of the Wyoming Association of Conservation Districts**: WWRC Information and Education Coordinator visited with District members about water resource issues in Wyoming and staffed an information booth focusing on WWRC programs. Topics covered ranged from funding to water quality and several panel discussions were held.

5. **5th Annual Wyoming Legislative Water Resources and Law Forum**: WWRC was a co-sponsor of this annual legislative review, along with the State Engineer's Office, Wyoming Water Development Office, Wyoming Department of Agriculture, Department of Environmental Quality, and the University of Wyoming. The goals of the forum are to improve the understanding of legislators regarding Wyoming's water resources and their management, discuss current water issues facing the state, and describe the particular responsibilities and programs of individual agencies with respect to water.

6. **Water for Wildlife Foundation Symposium**: The WWRC, the Water for Wildlife Foundation, and the USDI Bureau of Land Management sponsored a spring symposium on April 27-29, 1993, at the University of Wyoming. The topic of the symposium was "Wildlife Water Development: Integrated Approach to Wildlife Management and Conservation." The symposium provided a forum for discussion of techniques, materials and designs, and successes and failures in the area of water development for wildlife in the semi-arid west. The meeting was attended by many range and wildlife personnel who are involved in wildlife water development. Publications of workshop proceedings were made available to those who could not attend.

7. **National Forest Service Soil and Water Quality Seminar**: A WWRC Research Scientist attended the Routt and Medicine Bow National Forest Service's Soil and Water Quality Seminar on March 8-9, 1993 at the University of Wyoming. The Scientist gave a presentation entitled "Watershed Hydrologic Processes" which covered the topic of watersheds and how they are influenced by such factors as climate, geology, topography, land use, and vegetation.

8. **2nd International Conference on Groundwater Ecology**: A WWRC Research Scientist was chosen to give a presentation on "Depth-to-Groundwater Relationships for Three Riparian Species/Assemblages in Southeastern Wyoming" at the conference which was held in Atlanta, Georgia on March 27-30, 1994. The value of healthy riparian wetlands to wildlife, fisheries, agriculture, and for non-point pollution control was addressed.

9. **Water Resources Management Information Systems Conference**: WWRC Water Resources Data System Coordinator participated in roundtable discussions with state representatives at the conference in Albuquerque, New Mexico. The conference addressed such issues as global positioning systems, hydrologic modeling, water demand/supply modeling, environmental databases, and data clearing houses.

10. **Intermountain Conservation District Mine Reclamation Workshop**: A WWRC Senior Research Associate spoke at the Intermountain Conservation District Mine Reclamation Workshop which was held on March 8, 1994 in Gillette, WY. WWRC research concerning selenium and other groundwater contaminants was discussed.

11. **National Drinking Water Week Groundwater Video Teleconference**: The WWRC sponsored the National Drinking Water Week Groundwater Video Teleconference which was broadcasted live at the University of Wyoming on May 4, 1994. Co-sponsors included the League of Women voters, Wyoming Cooperative Extension Service, City of Laramie, and the Laramie Rivers Conservation District.

B. COOPERATIVE EDUCATION AND RESEARCH EFFORTS

1. **1993-1994 Willard C. and Elaine N. Rhoads Scholarship for Graduate Studies in Water Resources**: Two University of Wyoming students received the Rhoads Scholarship for the 1993-94 school year. The scholarship honors the late Willard C. Rhoads who was a long-time member of the Wyoming Water Development Commission and had served on the Research Review and Priorities Committee for the WWRC. Recipients are selected on the basis of demonstrated academic achievement, recommendations from graduate faculty advisors, enrollment for at least nine hours of credit for two semesters and a written statement of academic and career goals.

2. **Severe and Sustained Drought Research at WWRC**: WWRC explored the possible consequences of a severe and sustained drought (SSD) in the Colorado River Basin as part of a joint research project with Utah State University, Colorado State University, University of Colorado, University of Arizona, and University of California at Riverside. State and federal agency personnel, including the Wyoming State Engineer's office, supported the project in an advisory capacity. By demonstrating the potentials of alternative approaches to drought damage reduction, researchers identified opportunities for improved Colorado River Basin water management.

3. **WWRC Classroom Presentations**: A WWRC Research Associate gave presentations concerning water quality, hydrology, recycling, and environmental issues to elementary classes in Laramie. The WWRC Associate Director and Information and Education Coordinator gave field presentations regarding Wyoming's stream resources, stream ecology, and fish populations to Laramie elementary school classes. Additional presentations were given by the WWRC Director to elementary classes in Lander, Wyoming.

4. **Poster Display Featured**: As part of the WWRC's Information and Education (I&E) activities, a poster display was featured during the Fourteenth Annual American Geophysical Union Hydrology Days in Fort Collins, Colorado. The goal of the display is to offer outreach and information concerning the WWRC to professionals and students interested in water resources. Another goal of the display is to inform undergraduate students about the University of Wyoming's Master of Sciences Interdisciplinary Water Resources Option.

5. **Wyoming Department of Agriculture "Country to Classroom" Publication**: The WWRC assisted in the editing and distribution of a special non-point source pollution issue of "Country to Classroom" which was oriented towards Wyoming's eighth grade students.

C. INFORMATION TRANSFER PUBLICATIONS

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

UW and Chinese Water Institute Agree to Exchange Program
Research Proposals Due at Wyoming Water Resources Center
State Water Resources Meeting in Laramie
Wyoming Water Research Projects Funded for Fiscal 1994
Water Resources and Law Forum Held for Legislators
Scholarship Awards Given at Annual Water Resource Meeting
Outstanding Service Award Presented by Wyoming State Section AWRA
Water Institute for Teachers
WWRC Announces Water Education Poster Contest
WWRC Director Announces Rhoads Scholarship Winners
1993 Water Education Poster Contest Winners
Assessing Vulnerability of Aquifers in Wyoming to Contamination

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 1993-94: Environmental Effects of Saline Oil-field Discharges on Surface Waters, RB93-104, The Influence of Wind-blown Material on an Alpine Water Catchment, Snowy Range, Wyoming, RB93-105, Depth-to-Groundwater Relationships for Three Riparian Species/Assemblages in Southeastern Wyoming, RB94-01.

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

4. **Water Issues**: A series of information and education bulletins were published in a joint WWRC, Wyoming Department of Environmental Quality, and University of Wyoming Cooperative Extension Service program. An issue regarding groundwater contamination was published and disseminated to the public and offices statewide.

5. **WWRC Fact Sheet**: A Fact Sheet describing the research, education, information transfer, and state service project activities of the Wyoming Water Resources Center was developed for distribution to individuals desiring information about the WWRC Resources Center .

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

7. **WWRC Public Information and Education Exhibits:**

a. Invited 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 Visitor's Center.

b. Invited exhibit for display at the Wyoming State Capitol Building in Cheyenne during the 1993 Legislative session. Also coordinated sponsorship and set-up a historical photographic exhibit on water resources from the archives of the American Heritage Center in February-March, 1993.

c. UW Student Resource Fair, September, 1993.

d. UW Family Weekend, October, 1993.

e. Wyoming Section American Water Resources Association Annual Meeting. Graduate student in Range Management/Water Resources, received the best student presentation award. November 3-4, 1993.

f. Wyoming Water Development Association's 1993 Annual Meeting, November, 1993.

8. **1993-94 School-Year Powell Water Education Calendar**: The Powell Water Education calendar features full-color pictures of the 1992 posters and poster contest winners, water facts, and water experiments. Calendar sponsors include: WWRC, Amax Coal Company, Holly Sugar Corporation, Powder River Basin Resources Council, U.S. Department of Agriculture-Working Group on Water Quality, Bureau of Reclamation, U.S. Environmental Protection Agency, International Office for Water Education, National Water Information Clearinghouse, Wyoming Department of Education, Wyoming Game And Fish Department, Wyoming State Engineer's Office, Wyoming State Section-AWRA, and the Wyoming Water Development Commission.

9. **Wyoming HydroMaps**: Wyoming HydroMaps, a series of digital water resource educational maps, were developed by the WWRC Geographical Information Systems (GIS) lab which portray a wide range of water resources-related themes including surface water, groundwater, and climate and are published as black and white inserts into the Wyoming Hydrogram.

D. SERVICE ACTIVITIES

1. **WWRC/National Technical Information Processing System**: A cooperative agreement was signed that allows WWRC access to the National Technical Information Processing System (TIPS) in Denver, Colorado. The TIPS system provides a framework for hydrologic data exchange, access to data, data sharing, and scientific applications for Wyoming's surface and ground water as it relates to coal production statewide. Agencies included in this cooperative agreement are the Bureau of Land Management, Office of Surface Mining, State Engineer's Office, Department of Environmental Quality, and the University of Wyoming. The agreement will enable the involved parties to evaluate the hydrologic impact of coal mining and other activities in a timely manner, will reduce the duplication of computerization efforts by agencies with overlapping data needs, and will allow the parties access to hydrologic models which can be adapted to their own needs.

2. **WWRC Water Resources Data System**: Operated by WWRC, with funding from the Wyoming Water Development Office, the Water Resources Data System (WRDS) is a

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

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

COOPERATIVE ARRANGEMENTS

ADMINISTRATION

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

1. Service

Service to State and Federal Agencies

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

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

University Service

- Member, University of Wyoming Deans Council.
- Serve on University Committees (e.g., Women and Minority Faculty Hiring Committee).
- Serve on Steering Committee for Abandoned Mine Lands Research Program.
- Continued effort to apprise faculty members of research needs and opportunities in water-related research.
- Work with academic standards committee on interdisciplinary Master of Science/Water Resources curriculum.
- Serve on appropriate graduate student committees.
- Serve on appropriate national and international technical review panels and committees.
- Serve on School for Environment and Natural Resources Committee.

Other

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

TABLE 1: COOPERATING STATE AND FEDERAL AGENCIES IN WYOMING

STATE

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

FEDERAL

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

TABLE 2: SERVICE-TO-STATE - FY 93

Research Projects Performed in Response to Wyoming State Agency Requests

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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. Research

- **Federal Program FY 93**

Research accomplishments of the FY 93 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 94**

The Director solicited proposals under the FY 94 Federal Water Research Program from interested faculty on campus and the seven community colleges. Proposals were received and reviewed by state agencies and regional university personnel through the Water Institute Directors in the region--three were funded under the program.

3. Information Transfer

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

4. Education

The 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 is housed within the Wyoming Water Resources Center. This individual is expected to serve the public and the Wyoming Water Resources Center by directing

existing statewide climatological programs and services and by assisting academic researchers involved with meteorology-related work.

ENVIRONMENTAL PROTECTION AGENCY

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

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
April 28, 1993

Governor Mike Sullivan (*ex officio*)
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 (1990-1993)
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
Wyoming Water Resources Center
Box 3067, University Station
Laramie, Wyoming 82071 766-2143

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 (1993-1996)
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 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*, (in preparation).	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*, (in preparation).	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*, (in revision).	G-2056-02
Krzyszowska, A.J., R.D. Allen and G.F. Vance, 1993, Assessment of Herbicide Fate of Two Herbicides in a Wyoming Rangeland Soil: Column Study, *Journal of Environmental Quality*, (in press).	G-2056-03
Krzyszowska, A.J., and G.F. Vance, 1993, Solid Phase Extraction of Dicamba and Picloram in Water and Soil Samples for HPLC Analysis, *Journal of Agricultural and Food Chemistry*, (in press).	G-2056-03
2. Book Chapters	
3. Dissertations	
Michelsen, Ari, 1994, Determinants and Trends in Water Right Prices: An Econometric Analysis.	G2056-04
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, 120 pp.	G-2056-02

CITATION	Supporting Section 104 Project Number
McCoy, Thomas H., 1994, Aspen and Shrubby Cinquefoil Response to Streamflow Augmentation, and their Groundwater Relationships, "M.S. Dissertation", Department of Range Management, College of Agriculture, University of Wyoming, Laramie, Wyoming, 52 pp.	G-2056-02
4. Water Resource Research Institute Reports	
McCoy, T.H., R.J. Henszey, T.A. Wesche, and Q.D. Skinner, 1994, Aspen and Shrubby Cinquefoil Response to Streamflow Augmentation, and their Groundwater Relationships, Wyoming Water Resources Center, University of Wyoming, Laramie, Wyoming, 52 pp.	G-2056-02
Henszey, R.J., T.A. Wesche, and Q.D. Skinner, 1994, Riparian Zone Changes Caused by Streamflow Augmentation, Wyoming Water Resources Center, University of Wyoming, Laramie, Wyoming, 120 pp.	G2056-02
Person, P. , and Michelsen, Ari, 1994, Determinants and Trends in Water Right Prices: An Econometric Analysis, Wyoming Water Resources Center, University of Wyoming, Laramie, Wyoming, 172 pp.	G-2056-04
5. Conference Proceedings	
Michelson, Ari, Person, P., and Young, R.A., 1994, Determinants and Trends in Water Right Market Prices, "Conference on Water Policy and Management: Solving the Problems, American Society of Civil Engineers, Denver, Colorado.	G-2056-04
Henszey, R.J., Q.D. Skinner, and T.A. Wesche, 1994, Depth-to-Groundwater Relations for Three Riparian Species/Assemblages in Southeastern Wyoming, "Second International Conference on Ground Water Ecology", Atlanta, Georgia.	G-2056-02
6. Other Publications	
Krzyszowska, A.J., and G.F. Vance, 1992, Soil and Water Analysis of the Herbicides - Picloram and Dicamba, National Soil Science Society of America Meetings, *Agronomy Abstracts*, p. 46	G-2056-03

CITATION	Supporting Section 104 Project Number
Allen, R.D., A.J. Krzyszowska and G.F. Vance, 1993, Modeling Herbicide Fate in a Wyoming Rangeland Environment, National Soil Science Society of America Meetings, *Agronomy Abstracts*, p. 25.	G-2056-03
Zhang, R., A.J. Krzyszowska, R.D. Allen, and G.F. Vance, 1994, Modeling Pesticide Transport in the Vadose Zone: Field Validation, National Soil Science Society of America Meetings, *Agronomy Abstracts*, p.237.	G-2056-03
Allen, R.D., A.J. Krzyszowska, and G.F. Vance, 1994, Field Investigation and Model Validation of Herbicide Movement and Fate in an Irrigated Wyoming Pasture, National Science Society of America Meetings. *Agronomy Abstracts.*	G-2056-03
Kryzyszowska, A.J., G.F. Vance and R.D. Allen, 1994, Assessment of Herbicide Transport in an Irrigated Pasture Environment, USA, 3rd International Symposium on Environmental Geochemistry, *Abstracts.*	G-2056-03
Henszey, R.J., Hand-dug wells to monitor riparian groundwater levels, *Monitoring Rangeland: A Guide for Ranchers* by Douglas A. Reynolds, University of Wyoming Extension Service, 11 pp. (In preparation)	
Henszey, R.J., Q.D. Skinner, and T.A. Wesche, 1994, Depth-to-Groundwater Relationships for Three Riparian Species/Assemblages in Southeastern Wyoming, *Research Briefs*, Wyoming Water Resources Center RB94-01, 2 pp.	

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 1993 Program are indicated below.

Training Category	Academic Level				
Field of Study	Undergraduate	Master's Degree	Ph.D. Degree	Post-Doc	TOTAL
Chemistry					
Engineering:					
Agriculture					
Civil					
Environmental					
Soils	5		2		7
Systems					
*Other					
Geology					
Hydrology	5	1			6
Agronomy					
Biology					
Ecology/Range Management					
Fisheries, Wildlife & Forestry					
Computer Science					
Economics		1			1
Geography					
Law					
Resources Planning	1				1
Other*					
TOTAL	11	2	2		15

POSTGRADUATE EMPLOYMENT

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