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## ABSTRACT

Four research projects were directly funded under the FY91 program, as well as information transfer activities. These four research projects relate to important water issues in the region and the State of Wyoming.

Groundwater movement 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. Depth-to-groundwater duration was shown to be important with respect to the existence of certain subalpine riparian plant communities.

Using Surface Enhanced Raman Spectroscopy with specific coatings on fiber optics, it was shown that it is possible to detect aromatic organic compounds in-situ in groundwater and/or the vadose zone. Detection limits should be less than 10 ppb for these compounds using this technique.

Discrete stochastic programming was used to simulate sequential irrigation decisions at Farson, Wyoming for irrigated hay production based on a stochastic allotment of a water short (drought) supply. Marginal reductions in net income resulted but are consistent with estimated water values in irrigated hay production derived from standard linear programming methods.

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.

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

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# WATER PROBLEMS AND ISSUES OF WYOMING

Wyoming's heritage stems from an abundance of natural resources. Vast areas of range and pastureland interspersed with fertile, irrigable stream valleys have enabled the agricultural and livestock industry to become a major driving force of the State's economy. The recreation and tourism industry thrives in Wyoming as visitors come to share the wealth of scenic beauty. Beneath the land surface lie such mineral resources as coal, oil and gas, uranium, oil shale, trona, gypsum, and iron ore. Their abundance has enabled Wyoming to become a national leader in mineral production.

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

Water availability and allocation for future agriculture, mineral extraction, industrial, recreation, and municipal purposes continue to be the center of water related problems in Wyoming. The future management of Wyoming's water resources, in compliance with existing interstate water compacts and decrees, is a challenge in planning and implementation. Once available surface and groundwater supplies are utilized, their equitable distribution, conservation, and maintenance of quality become important legal and complex social issues.

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

better able to forecast quantity and quality of water availability to downstream users is extremely important.

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

## PROGRAM GOALS AND PRIORITIES

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

The Wyoming Water 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 were addressed.

## USGS PRIORITY RESEARCH AREAS (REGIONAL)

### I. WATER QUANTITY

Water Distribution

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

Dynamics of Ground Water/Surface Water Interaction

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

### II. WATER QUALITY

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

### III. INSTITUTIONAL RELATIONS

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

### IV. UTILIZATION AND CONSERVATION OF WATER

Enhancement of Water Use Efficiency

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

Improved Water Management

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

## V. ECOLOGICAL/ENVIRONMENTAL RELATIONSHIPS

Instream Flow Needs

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

Wetland Hydrology

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

Impact of Pollutants

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

## WYOMING STATE RESEARCH PRIORITY AREAS

Proposals were solicited in the following six areas in addition to a general list of research priorities contained in WWRC RFP-91-7.

### WWRC RFP-91-1. Hydrologic and Water Quality Impacts of Coalbed Methane Production in Wyoming

Project proposals in this area should examine the potential water related problems associated with coalbed methane production in the state. Research on this subject should describe the geologic setting, magnitude of groundwater depletion with associated impacts and/or damages to existing aquifers and users of the water, potential water quality problems and/or benefits associated with disposal of the water produced from dewatering, and techniques to help evaluate these problems and impacts. Geohydrologic modeling to indicate long-term impacts may be required to address problems associated with the groundwater system. Investigators should demonstrate awareness and understanding of previous studies on this topic sponsored by such agencies as the Gas Research Institute, the Coalbed Methane Information Center at the Colorado School of Mines, and the Wyoming Geological Survey.

### WWRC-RFP-91-2. Stream and River Impacts Associated with Man-made Structures

Man-made structures in streams and rivers have had a significant impact on riparian areas and wetlands, flushing flows, channel morphology and water quality. Large impoundments and other instream structures have modified the natural flow regime of rivers. Research is needed on the effects these large impoundments and instream structures have or do not have on channel morphology such as encroachment and riparian/wetlands areas, flushing flows necessary for improved fish habitat and non-point source pollution resulting from channel degradation through man-made structures. A broad approach to this question in terms of developing best management practices for large river systems (in Wyoming), from an ecosystem approach, to better utilize the waters of the system is of interest.

### WWRC-RFP-91-3. Utilization and Conservation of Agricultural Water

The management and wise use (efficient use) of agricultural water to allow for use of this water for alternate purposes and promote water quality is of interest within the State of Wyoming. Research is needed into new and innovative methods that could enhance water irrigation efficiency for agricultural use to improve both water quantity and quality (e.g., Low Energy Precision Application (LEPA) systems). Research into the development of methods, fundamental principles, and practices to help mitigate and/or develop wetlands in Wyoming is of interest. Proper mitigation of wetlands which are destroyed or changed so as to provide equivalent or better ecological values and functions as the original or natural wetlands within the same environmental setting is needed. Studies into effective best management practices

being developed or implemented on irrigated croplands and rangelands to control erosion, natural contamination and agricultural chemicals associated with non-point source pollution to surface and groundwaters. Some natural contaminants that have been shown to be of concern are selenium, salts, radium and radon. To help with management of Wyoming's water resources, a need exists for new and more accurate methods to measure flows in natural streams and large canal systems.

**WWRC-RFP-91-4. Institutional and Economic Considerations of Wyoming Water**

The future wise use of Wyoming's water resources requires that institutional and economic constraints on our present system of use and administration be considered in order to develop strategies and methods to improve our effective use of this resource. Recent litigation, court decisions and agreements along with national trends being proposed with respect to western water have suggested that new and innovative institutional, administrative and economic considerations to preserve Wyoming's water are needed. Federal reserve water rights, selling of surplus water to downstream entities beyond Wyoming's border, and large trans-basin diversions with their associated institutional, administrative and economic considerations need to be explored. Development of future options for improving the wise use of water in basins where surface water is fully appropriated is also encouraged.

**WWRC-RFP-91-5. Analysis of Weather Modification/Changes**

Weather modification projects have been carried out by the Bureau of Reclamation and other entities in several of the states surrounding Wyoming, as well as in the State of Wyoming. Proposals are requested which will develop technically sound information which addresses: 1) downwind effects resulting from cloud seeding, 2) effectiveness of cloud seeding, and 3) long term climate change or severe drought effects on streamflow, groundwater aquifers and economics. Downwind effects from cloud seeding are of special interest with respect to surrounding states and their cloud seeding efforts in promoting less/more precipitation and changes in weather patterns which would affect conditions in Wyoming. Effectiveness of cloud seeding is of interest with respect to effects on e.g., crop yields and the skiing industry. Interest in weather changes with respect to severe drought conditions and/or changing climate conditions which affects streamflow and economics of a region is of concern with respect to Wyoming's water resources.

**WWRC-RFP-91-6. Conveyance Losses in Natural Stream Channels**

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

**WWRC-RFP-91-07 Additional State Research Priorities**

The following outline of topics represents additional priority research areas established by the RRPC for the FY92 funding cycle.

GROUND AND SURFACE WATER RESOURCES

a. Water Quantity and Management

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

b. Water Quality

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

c. Legal and Institutional Issues

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

WATERSHED AND RIPARIAN ZONE MANAGEMENT

a. Groundwater Storage

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

b. Surface Water Storage

- Headwater reservoirs
- Multiple reservoir management

c. Non-Point Sources of Pollution

- Sedimentation
- Salinity
- Nutrients

d. Riparian Ecosystems

- Economic valuation

WATER DEVELOPMENT AND CONSERVATION

a. Improving Water Management

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

b. Legal and Institutional Issues

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

c. Environmental Relationships

- Instream flow
- Species of high state interest

d. Agricultural/Municipal/Industrial/Recreational Uses

- Current consumptive use/loss estimates for Wyoming

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

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## FEDERAL RESEARCH PRIORITIES

| | Project 02<br><br>Surface and Groundwater Dynamics Critical to Maintenance of Subalpine Riparian Wetlands<br><br>T.A. Wesche | Project 03<br><br>Remote Detection of Organic Contaminants in Groundwater<br><br>K. Carron | Project 04<br><br>Severe Drought and Water Shortages in the Upper Green River Basin: Modeling Economic Impacts and Institutional Alternatives for Water Management<br><br>A.M. Michelsen and J.F. Booker | Project 05<br><br>Assessment of the Potential Environmental Fate and Effects of Oil-Field Discharge Waters Containing Radium ($^{226}$Ra)<br><br>H. Bergman and S. Hill |
|---|---|---|---|---|
| **WATER QUANTITY** | | | | |
| Water Distribution | | | | |
| Dynamics of Groundwater/Surface Water Interaction | X | | | |
| **WATER QUALITY** | | X | | X |
| **INSTITUTIONAL RELATIONS** | | | X | |
| **UTILIZATION & CONSERVATION OF WATER** | | | | |
| Enhancement of Water Use Efficiency | | | | |
| Improved Water Management | | | | |
| **ECOLOGICAL/ENVIRONMENTAL RELATIONSHIPS** | | | | |
| Instream Flow Needs | | | | |
| Wetland Hydrology | X | | | |
| Impact of Pollutants | | | | X |

**Figure 1.** Federal Research Priorities and Projects Funded by USGS through the Wyoming Water Resources Center.

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## STATE OF WYOMING RESEARCH PRIORITIES

| | Project 02<br><br>Surface and Groundwater Dynamics Critical to Maintenance of Subalpine Riparian Wetlands<br><br>T.A. Wesche | Project 03<br><br>Remote Detection of Organic Contaminants in Groundwater<br><br>K. Carron | Project 04<br><br>Severe Drought and Water Shortages in the Upper Green River Basin: Modeling Economic Impacts and Institutional Alternatives for Water Management<br><br>A.M. Michelsen and J.F. Booker | Project 05<br><br>Assessment of the Potential Environmental Fate and Effects of Oil-Field Discharge Waters Containing Radium ($^{226}Ra$)<br><br>H. Bergman and S. Hill |
|---|---|---|---|---|
| **GROUNDWATER & SURFACE WATER RESOURCES** | | | | |
| Water Quantity & Management | | | | |
| Water Quality | | X | | X |
| Legal & Institutional Issues | | | X | |
| **WATERSHED & RIPARIAN ZONE MANAGEMENT** | | | | |
| Groundwater Storage | X | | | |
| Surface Water Storage | | | | |
| Non-Point Sources of Pollution | | | | |
| Riparian Ecosystems | X | | | |
| **WATER DEVELOPMENT & CONSERVATION** | | | | |
| Improving Water Management | | | | |
| Legal & Institutional Issues | | | X | |
| Environmental Relationships | | | | X |
| Agricultural/Municipal/ Industrial/Recreational Uses | | | | |

**Figure 2.** State of Wyoming Research Priorities and Projects Funded by USGS through the Wyoming Water Resources Center.

# RESEARCH PROJECT SYNOPSES

## SYNOPSIS

**Project Number:** 02 **Start:** 6/91
**End:** 5/92

**Title:** **Surface and Groundwater Dynamics Critical to Maintenance of Subalpine Riparian Wetlands**

**Investigators:** Wesche, Thomas A., University of Wyoming, Laramie.

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

**Descriptors:** Wetlands, riparian vegetation, mountain lakes/streams, groundwater hydrology, surface-groundwater relations, soil-water-plant relationships, reclamation, alpine regions, instream flow

**Problem and research objectives:**

Quantification of plant-water relations is basic to the successful restoration of subalpine riparian wetlands. Research objectives were to 1) describe and compare the groundwater regimes of subalpine intermittent and perennial stream reaches; 2) describe and compare the groundwater regimes associated with different subalpine plant communities; and, 3) determine depth-to-groundwater relations for 3 important riparian plant species and express these relations in a habitat suitability format.

**Methodology:**

Groundwater well grids were established in 4 subalpine stream reaches. For each, plant community and piezometric head data were overlain on a base map of topography. Statistical evaluation of signature depth-to-groundwater durations was done for various subalpine plant communities. Habitat suitability curves using depth-to-groundwater as the independent variable and plant frequency as the dependent variable were developed for three riparian plant species.

**Principal findings and significance:**

Subalpine wetlands in the Snowy Range of the Central Rocky Mountains are complex. Surface water, groundwater, springs and seeps, precipitation and snowmelt all contribute inflows to the systems. Snowmelt dominates the surface water hydrograph and provides a large early season inflow source to the unconfined riparian aquifers.

Groundwater gradients are steepest in the early summer, gradually flattening after snowmelt. As the groundwater gradient resulting from downslope recharge lessened, overall gradients flattened. Surface water flow regimes changed from effluent to influent systems later in the season.

Groundwater seeps were present in all of the study reaches, but decreased greatly in flow after snowmelt ceased. We speculate these groundwater sources are indicative of hydraulic connections with upslope basins, rather than of significant confined aquifers. Nevertheless, these seeps and springs were locally important where they persisted throughout the summer and provided diffused surface flow.

Surface water flows appear to be secondary in importance in these subalpine meadows. As the season progresses, their importance may increase as portions of the streams become influent systems. Overbank flows in the subalpine appear to be even less significant, since they occur only marginally often. When such events do occur, they encounter saturated conditions, and most probably runoff. With regard to the health of the riparian area, they are at best neutral.

Data layering allowed the development of specific plant-water relationships. Groundwater $D_{90}$ depths were not significantly different between intermittent and perennial study reaches, but $D_{90}$ depths were positively correlated to riparian plant communities. In addition, suitability curves for Salix planifolia, Carex aquatilus, and Deschampsia cespitosa show strong trends associated with depth-to-groundwater. Statistical separation between species supports the hypothesis that a hydrologic gradient similar to that below does exist between the species:

Carex----------->Salix----------->Deschampsia

Hydric----------->Mesic

Within species separation by depth-to-groundwater duration was apparent primarily in Salix planifolia and Carex aquatilus. Deschampsia cespitosa clearly favored a specific depth duration, but data scatter and insufficient number of samples made statistical separation impossible.

Further research using biomass as the measure of vegetative response is in order. Biomass may reduce the amount of scatter associated with the vegetative data. The frequency technique used measures presence or absence of a species, failing to completely answer quantitative questions of species abundance.

## SYNOPSIS

**Project Number:** 03 **Start:** 6/91
**End:** 5/92

**Title:** **Remote Detection of Organic Contaminants in Groundwater**

**Investigators:** Keith Carron

**Focus Categories:** GW, TS, WQL **Congressional District:** First

**Descriptors:** Remote sensing, benzenes, agrochemicals, chemical analysis, groundwater, detection limits

**Problem and research objectives:**

This research project focused on testing the feasibility of using optical spectroscopy and fiber optics to perform remote analysis of organics in groundwater.

**Methodology:**

The spectroscopic technique which was tested is Surface Enhanced Raman Spectroscopy (SERS). SERS is very sensitive to molecules adsorbed to roughened silver surfaces. The problem was creating a locally high concentration of organic material at a silver surface. Alkylthiolates were examined as possible coatings on the silver. The alkylthiolates form compact monolayers which are capable of partitioning material out of solution and creating locally large concentrations of materials at the surface. They also form protective coatings on the surface.

**Principal findings and significance:**

It was found that one could use alkylthiols to partition organics out of aqueous solution. Octadecylthiol was used as the test case. It is an 18 chain hydrocarbon and is known to form perfect monolayers on silver. The spectra of octadecylthiol in the absence of an organic compound indicates that all carbon chains are trans and that it is "self-assembled". For quantification of the organic material in water a Raman band was used which is specific to the coating as a reference. This is very important since loss in fiber optics or changes in laser powers can have large effects on absolute intensities.

It was desired to demonstrate two aspects of the prototype sensor; selectivity and sensitivity. Selectivity will be discussed first and illustrated through the resolution

of the three isomers of xylene. Sensitivity was tested for benzene and naphthalene. These were chosen for their different solubility properties in water and the octadecylthiol coating. Correlation of our results with octanol/water partition coefficients indicates that some materials can be detected at sub-ppb levels.

*SELECTIVITY:*

We obtained SERS spectra of ortho, meta, and para-xylene intercalated into an octadecylthiolate film on a silver substrate. The saturated concentration of o-xylene was measured to be 199 ppm. Ortho-xylene contains a characteristic peak at 1055 $cm^{-1}$. This band is due to an $a_1$ ring mode which is characteristic of ortho-disubstituted benzenes. The saturated concentration of para-xylene was measured to be 142 ppm. A peak which is characteristic of para-xylene occurs at 830 $cm^{-1}$. This corresponds to an $a_g$ ring mode which is characteristic of para substituted benzenes. Meta-xylene was intercalated from a saturated aqueous solution at 178 ppm. Meta-xylene contains a characteristic peak at 1000 $cm^{-1}$. This band is an $a_1$ mode that is equivalent to the strong ring breathing mode of benzene. We obtained a spectrum of a 1:1:1 mixture of the isomers intercalated into the surface monolayer. We were able to completely resolve the mixture using the peaks described above. Ortho and meta-xylene also contain characteristic peaks in this spectral region at 740 $cm^{-1}$ and 730 $cm^{-1}$, respectively. However, it can be seen in the mixture spectrum that significant overlap exists and it would be difficult to quantify each species.

Absorption spectra for ortho, meta, para-xylenes and for a 1:1:1 mixture clearly show the advantage of SERS. It is impossible to resolve a mixture of xylenes with absorption spectroscopy. It can be seen that the similarity of the absorption spectra would make it impossible to specifically analyze for a single isomer of xylene. Furthermore, virtually all aromatic compounds have absorptions in this region. In Raman spectroscopy, distinction between these compounds arises from two sources. First is the symmetry of the molecule. Ortho and meta-xylene have $C_{2v}$ symmetry while para-xylene has $D_{2h}$ symmetry. Vibrational spectroscopies are very sensitive to symmetry and this leads to the large difference between the para and the two $C_{2v}$ isomers. The second factor which leads to selectivity is the neighbor effect. The center of mass must be conserved during the vibrations. In ortho substitutions this leads to very strong dissymmetry in the potential energy distributions of the C-C and C-H components of the ring modes. Meta substitution is more symmetrical across the rings and leads to spectra which more closely resemble benzene.

The large differences observed are not unique to methyl substituted benzenes. Halogenated benzenes and phenols will have similar characteristic frequencies. In the case of halogenated compounds the shifts are related to the mass of halogen. The bands used to characterize these substituted benzenes are called x-sensitive vibrations because of their characteristic changes with substitution.

*SENSITIVITY:*

To test the sensitivity of our technique, benzene and naphthalene were chosen as analytes. The solubility of benzene in water at 25 ℃ was found to be 661 ppm. A saturated solution of benzene was prepared in water and standard dilutions were made from this solution. The strong peak for analyte is the ring breathing mode of benzene at 991 $cm^{-1}$. Also present is the reference peak at 1101 $cm^{-1}$. It was found that the best fit was obtained for a Langmuir type isotherm. The $R^2$ value for the linear low concentration portion of this plot is 0.99994. The 991 $cm^{-1}$ peak is approximately 15 pixels wide. A 15 point Savitsky-Golay smooth was used to improve the signal to noise ratio. It was found that larger smoothing produced significant decreases in the signals. If the detection limit is calculated based on the smoothed data, a detection limit is found that is three times the standard deviation of the background to be 7.5 ppm. At this point the error in the reference peak is insignificant. At higher concentrations where the intensity of the benzene peak is larger than the reference the precision of the calculation will be determined by the reference. The detection for benzene has been recently improved and a detection limit of 2 ppm has been found.

Naphthalene is known to have a higher octanol/water partition coefficient than benzene. With the assumption that our coating mimics octanol, better detection limits for naphthalene are anticipated. The concentration of naphthalene in the saturated aqueous solution was found to be 25 ppm. The peak for the analyte is at 1385 $cm^{-1}$ and is the strong $a_g$ mode of naphthalene. The reference peak used was the 1101 $cm^{-1}$ octadecylthiol peak. Due to the low solubility of naphthalene in water it appears that all points fit a Langmuir type isotherm. An $R^2$ value of 0.9995 was found for this plot. The detection limit was found to be 2.3 ppm.

**CONCLUSION:**

The project has demonstrated that it is possible to detect aromatic organic compounds with SERS. The technique showed very good selectivity in detecting the isomers of xylene. Sensitivity was tested with benzene and naphthalene. The detection limits for benzene and naphthalene were 7.5 and 2.3 ppm, respectively. These values are below concentrations reported for leachates at contaminated sites. The octanol/water partition coefficient for naphthalene is 17 times higher than that for benzene. Our detection limit did not scale this due to the lower Raman cross section for naphthalene. However, the octanol/water partition coefficients for polychloronated biphenyls and polycyclic aromatic hydrocarbons are over 3 orders of magnitude larger than that for naphthalene. On this basis, the detection limits are predicted to be less than 10 ppb for these compounds.

When coupled with optical fibers this technique should provide a method of analysis for real-time in-situ monitoring of contaminated sites. The ability of the surface used in this research to partition organics out of the vapor phase will make them excellent tools for vadose zone monitoring. Future work will be directed at improving detection limits. These will include increasing the chain

length of the alkyl coatings and chemically altering the coating to make it better match the analyte. Finally, it is expected that high power diode lasers will become commercially available and could be used to improve our detection limit by as much as a factor of 50.

## SYNOPSIS

**Project Number:** 04 **Start:** 6/91 **End:** 5/93

**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 habitats

**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 investigation of 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 research project is 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) are of interest. The extent to which innovative water allocation policies at both the state and federal level could mitigate impacts of reduced supplies are being investigated.

**Methodology:**

The research is divided into four tasks. In Task 1, a farm level water use decision model is being developed and direct impacts on farm income from changes in water supply are estimated. Task 2 requires 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 basin wide model

incorporates farm level irrigation decisions and economic impacts determined in Task 1. In Task 3, the magnitude of indirect (secondary) economic impacts will be 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) will be identified in Task 4.

**Principal findings and significance:**

A discrete stochastic programming model was used to simulate sequential irrigation decisions when water supply is a stochastic allotment. The expected value of producer net income was relatively insensitive to expectations. Estimated consumptive use values were consistent with water values in irrigated hay production derived from standard linear programming methods.

The program models fertilization and irrigation decisions on land of variable productivity based on successive expectations of total annual irrigation supply and precipitation. The modeled decision stages are fertilization, and first and last irrigation periods. States of nature at each stage are three levels of irrigator expectations for water availability. The first state is based on snowpack estimates available approximately March 1, and the second on initial allotment estimates provided by the irrigation district. The final state can be considered the realization of actual water supply for the full year. Table 1 summarizes the model stages, irrigator expectations, irrigator responses, and formal decision variables.

**Table 1. Model states, expectations, actions, decision variables, and notation.**

| | State Description | Expectations Notation | Actions Description | Decision Variables Notation |
|---|---|---|---|---|
| 1 | Snowpack: *hi, moderate, lo* | *j1* | Fertilize: *full, zero* | $k1$, $x1_{j1,k1}$ |
| 2 | Initial allotment: *hi, moderate, lo* | *j2* | 1st Irrigation: *full, partial, zero* | $k2$, $x2_{j1,k1,j2,k2}$ |
| 3 | Realized allotment: *hi, moderate, lo* | *j3* | 2nd Irrigation: *full, partial, zero* | $k3$, $x3_{j1,k1,j2,k2,j3,k3}$ |

Irrigator expectations through the year give sets of mutually exclusive events. There are 3x3x3=27 sets of water supply states (*j1,j2,j3*). Within any given state (e.g. (*moderate,hi,moderate*)) many combinations of irrigator actions or activities are included in the model formulation. In principle, up to 2x3x3=18 distinct sets of management activities could be pursued under each set of water supply states.

Costs are incurred at each decision stage as the activity is chosen. In the final stage yields are determined as a function of fertilization and irrigation levels. Total irrigation applications are constrained below potential evapotranspiration levels in all but "hi" realized water supply conditions. Thus "moderate" and "lo" supplies reflect water short conditions in the irrigation district and require some zero or deficit irrigation.

*Results and Discussion*

The base case model solution for Eden-Farson estimated irrigator net income of $22.44 per acre. Net income in particular state sets (*j1,j2,j3*) ranged from $29 per acre for (*hi,hi,hi*) to -$2 per acre for (*mod,hi,lo*). Land was fertilized to the constrained limit in all state sets and activities. Irrigation in stage 3 was significantly curtailed when allotment expectations were not realized, sometimes with significant impacts on income. When greater than expected allotments were realized, the yield loss from holding back irrigation water in stage 2 had a relatively small impact on irrigator net income. Irrigators should thus err on the side of caution in estimates of realized supplies.

Value of Information and Consumptive Use The value of forecasts of realized allotments was examined by considering two alternative sets of expectations. In the first, perfect knowledge of realized allotments was assumed in state 1 and state 2 (perfect expectations). Expected net income increased only 1% from the base case. In the second, no knowledge beyond an estimate of the long term probability of realized allotments was assumed (average expectations). Expected net income declined by 6% from the base case. The expected value of net incomes was thus relatively insensitive to the quality of irrigator expectations. This occurred because the probability of state sets (*j1,j2,j3*) resulting in poor performance was small in all cases. If expectations of final allotments in stage 2 (first irrigation) were much too high or too low, and occurred frequently, then improved information would be of significant value. Particularly poor performance occurred with large changes in state 2 expected and state 3 realized allotments, caused by poor stage 2 irrigation allocations. The choice of net income for the objective function here requires producers to be risk-neutral. Because producers are generally believed risk-averse, impacts on utility of changes in the quality of expectations would be more significant than impacts on net income.

The value of consumptive use for hay production was estimated by reducing water allotments by a constant amount across the 3 realized allotment levels. In particular, reductions of 10% and 20% (2.18 and 4.36 inches consumptive use) from full allotment levels were considered. Marginal reductions in net income were $20.40 and $23.12 per acre-foot of consumptive use, respectively. These results are consistent with estimated water values in irrigated hay production derived from standard linear programming methods.

## SYNOPSIS

**Project Number:** 05 **Start:** 6/91 **End:** 5/94

**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, radium radioisotopes, oil industry, adsorption, pollution load, aquatic life, bioaccumulation

**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 (1990), 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 year one of this three-year study, a sampling survey of a variety of discharge sites was initiated. The primary objectives of this portion of the study were to determine (1) the proportion of introduced radium that remained in solution or was sequestered in sediments, and (2) the spatial distribution of radium contamination in water and sediment relative to the point of discharge.

Eight skim-pond facilities, most of which consisted of a series of ponds, were sampled during year one. Samples of produced water were collected from the points at which the water entered and exited each pond. The pond was divided into quadrants, and a sample of surface sediment was collected from each quadrant. The four pond-sediment samples were mixed in the laboratory to produce a single composite sample of sediment for radionuclide analysis.

The samples collected during year one (i.e., 30 water and 72 sediment samples) are currently being analyzed by gamma spectroscopy at the University of Wyoming. The samples are sealed in gas-tight Marinelli beakers for approximately 20 days to allow radium to equilibrate with its progeny (i.e., $^{222}$radon and its daughters). Water samples are filtered before analysis to remove solids; sediment samples are ashed to produce a homogeneous sample matrix. Gamma counts are determined using an Ortec Coaxial Detector system with a high-purity germanium crystal connected to an Ortec Model 3200 Multichannel Analyzer. A National Bureau of Standards source of $^{226}$Ra has been used to calibrate the equipment. Split samples have also been submitted to a commercial analytical laboratory to provide a basis for evaluating our analytical procedures.

In addition to the analyses of samples collected from skim ponds, analysis of samples of water and sediment collected from the Loch Katrine wetlands area in Park County, Wyoming is currently being done. 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. The results of the analyses of the samples collected during year one will enable us to develop a sampling plan for studying the Loch Katrine system during the final year of the study.

During the third year of this study, the project team will develop a detailed radium budget for the Loch Katrine site, including concentrations of radium in plants and aquatic animals. The information resulting from this portion of the study will be useful in evaluating the effectiveness of current discharge limits for protecting the quality of surface waters receiving radium-containing discharges. It will also provide a basis for evaluating possible options for the management of sediments contaminated with radium.

**Principal findings and significance:**

The preliminary results of analyses of water and sediment samples collected during year one are consistent with the results anticipated based on the chemical behavior of radium in aqueous solution. As shown by the data in Table 1, the concentration of radium in water tends to decrease 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.

**Table 1.** Concentrations of radium in water and sediment samples collected from two skim-pond facilities

| Site Number | Sample | Concentration of Radium |
|---|---|---|
| 5 | Pond 1 influent | 37 pCi/L |
| 5 | Pond 2 influent | 27 pCi/L |
| 5 | Pond 3 influent | 28 pCi/L |
| 5 | Pond 3 effluent | 28 pCi/L |
| 5 | Pond 1 sediment | 29 pCi/g |
| 5 | Pond 2 sediment | 31 pCi/g |
| 5 | Pond 3 sediment | 38 pCi/g |
| 7 | Pond 1 influent | 43 pCi/L |
| 7 | Pond 1 effluent | 42 pCi/L |
| 7 | Pond 2 influent | 36 pCi/L |
| 7 | Pond 2 effluent | 31 pCi/L |
| 7 | Pond 3 influent | 34 pCi/L |
| 7 | Pond 3 effluent | 41 pCi/L |
| 7 | Pond 4 influent | 14 pCi/L |
| 7 | Pond 4 effluent | 17 pCi/L |
| 7 | Pond 1 sediment | 15 pCi/g |
| 7 | Pond 2 sediment | 19 pCi/g |
| 7 | Pond 3 sediment | 25 pCi/g |
| 7 | Pond 4 sediment | 27 pCi/ |

## INFORMATION TRANSFER ACTIVITIES

June 1, 1991 - May 31, 1992

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, 1991 through May 31, 1992 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 1992 Water Resources Seminars were held in Powell, Wyoming on January 28 and in Sheridan, Wyoming on January 30. Issues addressed at the seminars included: developing Wyoming regulations for best management practices, 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, communicating concerns and interests with elected officials by the public who should pay for added recreational uses on existing projects and for wetlands retention and development, Wyoming water administrative activities and issues impacting Wyoming water users, and water development projects underway in the state. Cooperating agencies in the seminar program included: Wyoming State Engineer's Office, Wyoming Water Development Commission, 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 Northwest and Sheridan Community Colleges. At the Sheridan seminar, Wyoming legislators in the area served as moderators of the seminar sessions. Over 200 people attended the two seminars.

2. **WY-AWRA Conference**: The WWRC co-sponsored the 4th Annual Meeting of the Wyoming State Section, American Water Resources Association. The conference was held at the University of Wyoming in Laramie, November 6-7, 1991. Technical sessions included: groundwater quality, surface water data collection, irrigation canal efficiency, biological and water quality investigations following the Yellowstone National Park fires, water resources management and policies and computer applications in water resources and a tour of the University of Wyoming environmental laboratory. There were 80 attendees.

3. **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. For the first time, two Water Institutes for Teachers were held, one in Laramie July 8-19, 1991 and one in Riverton July 22-August 2, 1991. Twenty-two teachers attended both WITs.

4. **Water Engineering and Management Conference**: The Wyoming Water Resources Center was a co-sponsor of the Water Engineering and Management Conference, organized by the Colorado Water Resources Research Institute and Office of the State Engineer, held March 2-3, 1992 in Denver, Colorado. Region-specific water issues and research results were discussed at the conference including: surface water issues and water rights climate change, water resources decision making, water transfers, barriers, drought and watersheds, computing innovations in water resources, hydraulics and river system management, contaminant evaluation and treatment and agricultural impacts on water quality. The conference was attended by over 150 water resource specialists.

5. **Efficient Sprinkler Irrigation Operation:** Five 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 water requirements and economics of an inefficient system versus an efficient system. Approximately 150 sprinkler irrigators attended the meetings which were held in Worland, Lusk, Wheatland, Casper and Farson. In addition, four radio broadcasts were prepared through the UW Insight Program and broadcast throughout the state. Subjects addressed the cost savings resulting from properly maintained and operated sprinkler systems.

## 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. **Great Plains Agricultural Council (GPAC) Water Quality Task Force:** GPAC publication was completed, titled "Agricultural and Water Quality in the Great Plains: States and Recommendations (March 1992, MP-1738, #140 Texas Experiment Station). The report reviews and makes recommendations on water quality research, extension and technical assistance programs and evaluation of the impact of current and proposed state and federal regulatory options to reduce nonpoint source pollution. The task force was composed of representatives from universities in Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming, and USDA Soil Conservation Service, Economic Research Service, Animal & Plant Health Inspection Service, and Agricultural Research Service officials.

3. **Water Education Poster Contest:** The Wyoming Water Resources Center was a co-sponsor in the 1991-92 Powell (Colorado River Basin) Water Education Poster Contest for K-6 students. The contest theme was "Water, Essential to Life." Governor Mike Sullivan presented awards to six students who were regional and state winners. Posters drawn by regional winners will be featured on a 1992-93 school year calendar that also contains challenging questions about water, environmental sciences and educational activities. This was a very successful pilot program co-sponsored by the WWRC and International Office of Water Education, Utah State University, supported by a grant from the USGS.

## INFORMATION TRANSFER PUBLICATIONS

Information transfer publications for the report period included newsletters, bulletins, journals and technical reports.

1. **Wyoming Hydrogram:** The **Wyoming Hydrogram** is a newsletter produced and distributed bi-monthly by the WWRC. The newsletter is sent to over 1,600 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. **Wyoming Water Law: A Summary**: The Wyoming Water Resources Center reprinted and in cooperation with the Wyoming State Engineer's Office, distributed an updated bulletin on Wyoming water law. Over 2,000 bulletins have been distributed at public Water Resource Seminars and through CES offices and other state agencies.

3. **WWRC Research Briefs**: Information briefs on WWRC research are being produced and distributed in Wyoming and nationwide through newsletter mailings and at water resource organization meetings. Two briefs were published in 1991-92: "Development of a Chemical and Biological Method to Acclaim Alkaline Solid Wastes" and "Development of In-Situ Sensors for the Detection of Groundwater Contamination."

4. **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 developed and are in review for publication.

5. **Water Quality and Hazardous Waste Wheels** (information/education publications): These highly informative and popular education tools were acquired through the cooperation and cost sharing of the WWRC, UW Cooperative Extension Service, Wyoming Department of Environmental Quality, and USEPA non-point source water quality education grant. The Wyoming Water

Resources Center is continuing to distribute these Water Sense Wheels and Hazardous Waste Wheels at public meetings and through CES and other state offices.

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

7. **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.

8. **Water Management and Conservation in Western Irrigated Agriculture, Western Regional Research Project W-178:** 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.

9. **Visitors Information Center Display:** The Wyoming Water Resources Center developed an exhibit for the University of Wyoming Visitors Information Center. The exhibit provides information about WWRC activities and services, and includes an educational display on interstate compacts and historical use of water in the Green-Colorado River system.

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

11. **Exhibit at State Fair:** The Wyoming Water Resources Center display and information publications were exhibited and distributed at a staffed booth for one week at the Wyoming State Fair in Douglas.

12. **Water Education Curriculum Training Course:** This was held for school science coordinators and teachers. The K-6 education materials and activities were developed through a Wyoming Water Resources Center grant sponsored in part by USGS, Section 104 monies.

## SERVICE ACTIVITIES

### Water Resources Data System

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

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

The Wyoming Water Development Commission provides funds in the amount of $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.

## COOPERATIVE ARRANGEMENTS

### ADMINISTRATION

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

**1. Service**

Service to State and Federal Agencies

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

University Service

- Member, University of Wyoming Deans Council.
- Serve on University committees.

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

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

- Serve on appropriate graduate student committees.

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

Other

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

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

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

- Serve as delegates to Universities Council on Water Resources

- Transfer of research results to appropriate users.

**TABLE 1: COOPERATING STATE AND FEDERAL AGENCIES IN WYOMING**

**STATE:**

Attorney General's Office
State Conservation Commission
Department of Agriculture
Department of Commerce
    Division of Economic 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 & Fish Department
Governor's Office
Industrial Siting Administration
Legislative Services Office
Oil & Gas Commission
State Climatologist
State Engineer's Office
State Library
State Planning Coordinator's Office
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 - FY1991**

Research Projects Performed in Response to Wyoming State Agency Requests

- Development of Methodology to Determine Flushing Flow Requirements for Channel Maintenance Purposes (USGS, Wyoming Water Development Commission, Wyoming Game and Fish, and U.S. Forest Service)
- Snowy Range Watershed Laboratory
- Enhancement of Aquatic/Riparian Ecosystems (Pole Mountain) (Wyoming Water Development Commission, Wyoming Game and Fish, and U.S. Forest Service)
- Climatic Data Collection in Wyoming for Regional Climate Center in Lincoln, Nebraska (Farmers, Ranchers, Numerous State Agencies)
- Conveyance Losses in Natural Stream Channels (Wyoming Water Development Commission, State Engineer's Office, Board of Control)
- Evaluation of Surface Water/Groundwater Interactions in a Cold Desert Stream System (Department of Agriculture, Ranchers, Water Quality Division of Department of Environmental Quality, U.S. Department of Agriculture, Bureau of Land Management, Soil Conservation Service)
- Consumptive Use and Irrigation Water Requirements for Wyoming (State Engineer's Office)
- Development of Channel Maintenance Requirements for the North Platte River System in Wyoming (Wyoming Game and Fish Department, Bureau of Reclamation, U.S. Fish and Wildlife Service)

## 2. Extension

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

that both state and federal research results be packaged and presented in a useful and satisfactory manner to maximize the utilization of research effort and results.

3. **Research**

- Federal Program FY91

Research accomplishments of the FY91 Federal Water Research Program were reviewed by the Director. The results of the projects sponsored with the FY91 monies have been provided to the Center's advisory committees and presented at professional meetings.

- Federal Program FY92

The Director solicited proposals under the FY92 Federal Water Research Program from interested faculty on campus and the seven community colleges. Proposals were received and reviewed by state agencies and regional university personnel through the Water Institute Directors in the region--four were funded under the program.

4. **Instruction**

The Wyoming Water 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. The 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 inputs of the Executive Office, the legislative branch of government, the academic community, the State Climatologist, and the University administration (Table 3). The Committee meets at least twice annually to discuss WWRC activities and research priorities and to approve projects presented.

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

The Research Review and Priorities Committee (RRPC) of the Wyoming Water Resources Center and the University Board of Trustees approved two significant changes in the WWRC in last fall. The first change was in the name, from "Research" to "Resources" to better reflect the broader activities and programs the Center is involved with. The RRPC felt that a name which implied more than research was in order.

The second change approved was an integration of the former Citizen Water Issues Advisory Council (CWIAC) into the WWRC Research Review and Priorities Committee. The "new" RRPC now has six members of the former CWIAC appointed by the Governor. Two members serve at large while four represent each of the state's four administrative water divisions. Formerly, members of the CWIAC were advisory to the RRPC and had no voting privileges. The new members of the RRPC have full voting privileges.

## TABLE 3

## WYOMING WATER RESOURCES CENTER
## RESEARCH REVIEW AND PRIORITIES COMMITTEE
## July 1992

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

Steve F. Adams (1992-1993)
Member at Large
Box 177
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Harold Bergman (1992-1995)
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Derek Hodgson, Vice-President
Research Office
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Rich Lindsey, State Planning Coordinator
Governor's Office
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Jim Noble (1992-1993)
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Cynthia Nunley (1992-1993)
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Lander, Wyoming 82520 332-2442

Representative
Wyoming House of Representatives

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

### 1. Articles in Refereed Scientific Journals

| Citation | Supporting Project No. |
|---|---|
| Carron, Keith, Laura Pietersen and Mary Lewis, 1992, Octadecylthiol Modified SERS Substrates: A New Method for the Detection of Aromatic Organic Compounds, Environmental Science and Technology, October 1992, (in press). | G2056-03 |

### 2. Book Chapters

| Citation | Supporting Project No. |
|---|---|
| None | |

### 3. Dissertations

| Citation | Supporting Project No. |
|---|---|
| Peacock, Kenneth T., 1992, Subalpine and Groundwater Dynamics Critical to the Maintenance of Subalpine Riparian Wetlands, "M.S. Thesis", Department of Range Management and Wyoming Water Resources Center, College of Agriculture, University of Wyoming, Laramie, Wyoming, 147 pp. | G2056-02 |

### 4. Water Resources Research Institute Reports

| Citation | Supporting Project No. |
|---|---|
| Wesche, T.A. and K.T. Peacock, 1992, Surface and Groundwater Dynamics Critical to Maintenance of Subalpine Riparian Wetlands: Project Completion Report, Wyoming Water Resources Center, University of Wyoming, Laramie, Wyoming, 147 pp. | G2056-02 |

## 5. Conference Proceedings

| Citation | Supporting Project No. |
|---|---|
| Booker, J., G. Briand and A. Michelsen, 1992, Sequential Irrigation Decisions with Stochastic Water Supply, "in" Western Agricultural Economics Association Annual Meeting, Colorado Springs, Colorado. | G2056-04 |

## 6. Other Publications

| Citation | Supporting Project No. |
|---|---|
| None | |

## TRAINING ACCOMPLISHMENTS

Shown by fields of study and training levels indicated, the number of students participating in projects financed in part through the Fiscal Year 1990 Program are indicated below.

| TRAINING CATEGORY | ACADEMIC LEVEL | | | | |
|---|---|---|---|---|---|
| FIELD OF STUDY | UNDER-GRADUATE | GRADUATE | | | |
| | | MASTER'S DEGREE | Ph.D DEGREE | POST-Ph.D | TOTAL |
| Chemistry | | | 1 | | 1 |
| Agricultural Engineering | | | | | |
| Civil Engineering | | | | | |
| Environmental Engineering | | | | | |
| Geology | | | | | |
| Hydrology | | 1 | | | 1 |
| Agronomy | | | | | |
| Biology | 1 | 1 | | | 2 |
| Ecology | | | | | |
| Fisheries, Wildlife & Forestry | 8 | 4 | 1 | | 13 |
| Computer Science | | | | | |
| Economics | | 1 | | | 1 |
| Geography | | | | | |
| Law | | | | | |
| Resource Planning | | | | | |
| Range Management | | | | | |
| OTHER: (specify) | | | | | |
| Science Education | | | | | |
| Environmental Science | | | | | |
| Plant, Soil & Insect Sciences | | | | | |
| Statistics | | | | | |
| Mathematics | | | | | |
| TOTAL | 9 | 7 | 2 | | 18 |

# POSTGRADUATE EMPLOYMENT

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