Wyoming Water Resources Center
Annual Technical Report
FY 2003

Introduction

The NIWR/State of Wyoming Water Research Program (WRP), placed at the University of Wyoming, oversees the coordination of Wyomings participation in the NIWR program. The primary purposes of the program are to support and coordinate research relative to important water resources problems of the State and Region, support the training of scientists in relevant water resource fields, and promote the dissemination and application of the results of water-related research.

State support for the research program includes direct funding through the Wyoming Water Development Commission and active State participation in identifying research needs and project selection and oversight. Primary participants in the WRP are the USGS, the Wyoming Water Development Commission (WWDC), and the University of Wyoming. A Priority and Selection Committee (P&S Committee)--consisting of representatives from agencies involved in water related activities in the State--solicits and identifies research needs, selects projects, and reviews and monitors progress. The Director serves as a point of coordination for all activities and serves to encourage research by the University of Wyoming addressing the needs identified by the P&S Committee. The State also provides direct funding (from the WWDC accounts) for the administration of the WRP through the Office of Water Programs, which was approved by the 2002 Wyoming Legislature.

The WRP supports faculty and students in University of Wyoming academic departments. Faculty acquire their funding through competitive, peer reviewed grants, submitted to the WRP. Since its inception in the year 2000, the WRP has funded researchers in six academic departments and has supported a total of twelve research projects. Each project represents the education of one or more students. Benefits of the Water Research Program (WRP) to the State of Wyoming include: (1) support of water related research, both short term and long term, addressing water issues important to the State and Region, (2) support of water related training and education, (3) availability of personnel with water expertise to assist in addressing technical questions, and (4) coordination of agency and UW personnel.

Research Program

The primary purpose of the Wyoming Institute beginning with FY00 has been to identify and support water-related research and education under what has been entitled the Wyoming Water Research Program (WRP). The WRP supports research and education by existing academic departments rather than performing research in-house. Faculty acquire funding through competitive, peer reviewed proposals. A goal of the WRP is to minimize administrative overhead while maximizing the funding allocated toward research and education. Another goal of the program is to promote coordination between the University and State and Federal agency personnel. The WRP provides interaction from all the groups involved rather than being solely a University of Wyoming research program.

In conjunction with the WRP, an Office of Water Programs was established by Legislative action beginning July 2002. The duties of the Office, which provides for the administration of the Wyoming Institute, are specified by the legislation as: (1) to work directly with the director of the Wyoming water development office to identify research needs of state and federal agencies regarding Wyomings water resources, including funding under the National Institutes of Water Resources (NIWR), (2) to serve as a point of coordination for and to encourage research activities by the University of Wyoming to address research needs, and (3) to submit a report annually prior to each legislative session to the Select Water Committee and the Wyoming Water Development Commission on the activities of the office.

The Wyoming Water Research Program (WRP) is a cooperative Federal, State, and University effort. All activities reported herein are in response to the NIWR program, with matching funds provided by the Wyoming Water Development Commission and the University of Wyoming. The WRP Director, Larry Pochop (Professor of Civil Engineering), was appointed in October 1999. While the WRP is physically housed in the Civil and Architectural Engineering Department, the Director reports to the Vice President of Research. A State Advisory Committee (entitled the Priority and Selection Committee) serves to identify research priorities and select projects for funding. The Director coordinates all activities and has chosen to use students (graduate and/or undergraduate depending upon availability) to assist with the administration of the WRP. Thus, four students have been supported directly from Office of Water Programs funding for administration of the Wyoming Institutes activities. This approach supports student training and keeps administrative costs at a minimum.

The Wyoming Climate Atlas

Basic Information

Title:	The Wyoming Climate Atlas
Project Number:	2002WY5B
Start Date:	3/1/2002
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Management and Planning, None, None
Descriptors:	Climatology, Climate Change, Meteorology, Atlas, Wyoming
Principal Investigators:	Jan Curtis

Publication

1. Curtis, Jan and Kate Grimes, 2004. Wyoming Climate Atlas, Office of the Wyoming State Climatologist, 1000 E. University Ave., Laramie, WY 82071, 328 pp. plus data CD, Ph: 307-766-6659, e-mail: stateclim@wrds.uwyo.edu. Available on-line at: http://www.wrds.uwyo.edu/wrds/wsc/climateatlas/title_page.html

Problem and research objectives:
As with all data that is continuously being accumulated, statistics, changing user requirements, and changing technology to display and interpret these data create an ever present challenge. With the attention focused on issues of global warming and the impacts of climate change, the importance for accurate and timely climate data becomes all the more critical. The research objectives of this grant has been to provide an objective assessment of climate trends for Wyoming and to assemble the most comprehensive and complete dataset of Wyoming climate.

Methodology:
Weather and its associated historical record (climate data) is comprised of several elements including; surface temperature, precipitation, snowfall, wind, pressure, humidity, evaporation, drought, severe weather, clouds, solar radiation, air quality, and upper air climatology. While some weather stations collect only temperature and precipitation, other data is acquired remotely by radar and satellite, and still some data is derived or interpolated. Through the use of model data, such as **PRISM** (**P**arameter-elevation **R**egressions on **I**ndependent **S**lopes **M**odel) (http://www.ocs.orst.edu/prism/docs/), data is represented at a 1 mi^2 resolution (figure 1).

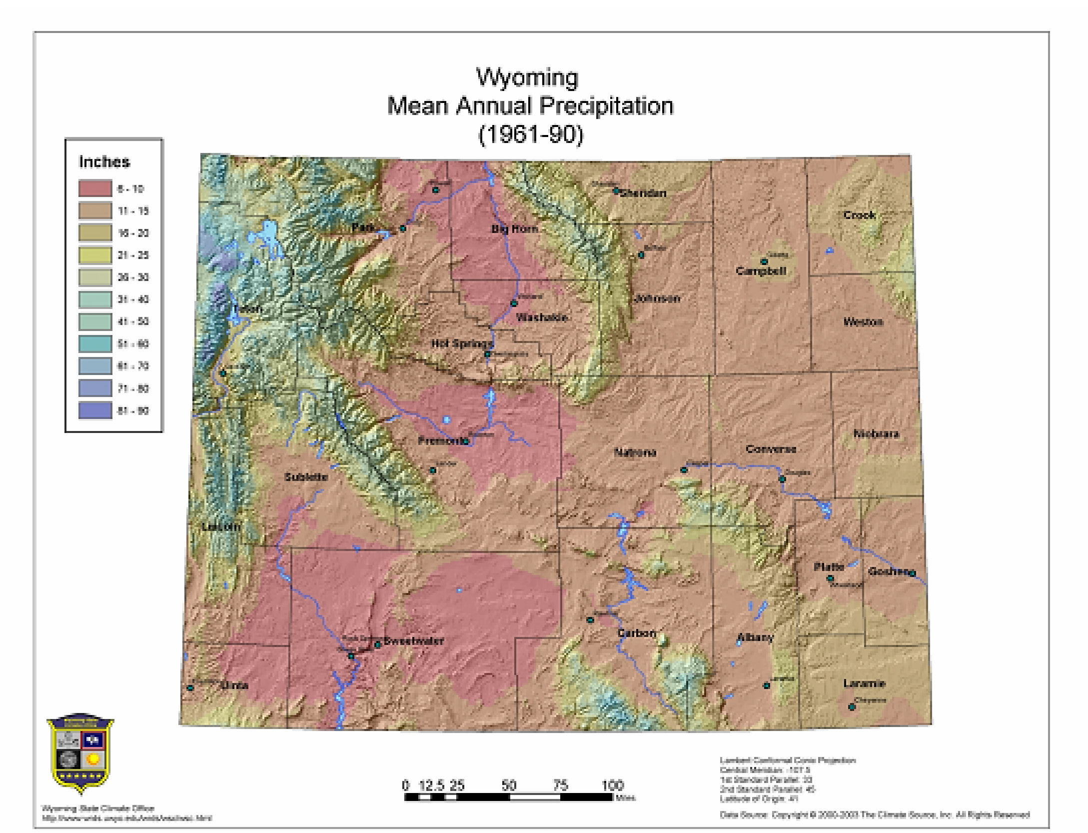

Figure 1 - PRISM(1961-1990) showing Wyoming mean annual precipitation.

Principle findings and significance:

(1) Climate change in a rural state such as Wyoming as been insignificant since the climate record has not been contaminated by major land use changes over the decades.
(2) Model data such as PRISM can achieve accurate climate data where large spatial gaps between weather stations exist.
(3) Water vapor, perhaps the most important green house gas, can be accurately measured using GPS signal delay measurements: http://www.gpsmet.noaa.gov/labreview/2002/2002-GPSMET-TECH_REVIEW.pdf).

Student Support:

During the last year of this study, geography and art major Kate Grimes, now a graduate of the University of Wyoming provided invaluable technical assistance and was made co-author of this atlas. Throughout the process, she was instrumental in developing the atlas format, GIS PRISM maps, and other graphic reformatting.

References:

Wyoming Climate Atlas: On-Line version:
http://www.wrds.uwyo.edu/wrds/wsc/climateatlas/title_page.html

Real-time monitoring of E.Coli contamination in Wyoming

Basic Information

Title:	Real-time monitoring of E.Coli contamination in Wyoming
Project Number:	2002WY6B
Start Date:	3/1/2002
End Date:	2/29/2004
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Water Quality, None, None
Descriptors:	
Principal Investigators:	Paul E. Johnson

Publication

1. Johnson, P.E. 2002. Biodetection with flow cytometry: better, faster, cheaper, Biodetection Technologies, Knowledge Press, Brookline, Massachusetts, Volume 1: 71-83.
2. Johnson, P.E., P. Lebaron, T. Deromedi, and J. Baudart, 2004. Tests of a Fountain Flow System for Real-time Quantification of Rare Microorganism in an Aquatic Environment. Accepted for the 2004 International Society of Analytical Cytometry, Montpellier, France.

Problem and research objectives:

The state of Wyoming supports 108,767 miles of rivers and streams and 325,048 acres of lakes (USEPA website). The Clean Water Act (CWA) requires states to designate uses for surface waters such as these and monitor the quality of the water in support of its use. Under section 305(b) of the CWA, Wyoming is required to include the results of these water assessments in biennial reports submitted to the United States Environmental Protection Agency (USEPA). Fecal coliform contamination is one water quality standard tested and included in these reports. Fecal coliform monitoring is an indicator of the sanitary quality of the water and can determine the extent of fecal contamination in the water from warm-blooded animals. Fecal contamination is important from a public standpoint when the surface water's designated use includes contact recreation such as beach use, boating, or swimming (USEPA report, 1986).

Wyoming's 2002 305(b) report to USEPA included a 303(d) list of the State's surface waters with water quality impairments not allowing those reaches to support their designated use(s). Reasons for impairments include metal contamination from copper, selenium, cadmium and silver, excess siltation, high phosphate and chloride levels, high pH, habitat degradation, oil deposits, and fecal contamination. Of the 45 water reaches included in the list, 22 are for fecal coliform exceedences, with all having contact recreation designated uses. This illustrates that fecal contamination of surface waters is an important issue for the State of Wyoming.

This project is developing and proving the concept of an economical system capable of real-time detection of individual *E. coli* in surface waters in Wyoming, including streams, rivers, and lakes, in order to quantify fecal coliform contamination. Our goal is a detection limit of < 5 *E. coli* cells per 100 ml of water in 15 minutes of analysis time, with a minimum detection efficiency of 50% and a false detection rate of < 1%. We are proving the concept of a low-cost, portable testing system that screens water in the field. This system will also support a more economical testing regime than any currently in use, allowing for more frequent and comprehensive water monitoring, thus minimizing human pathogen exposure, e.g. in contact recreation. This proof of concept allows for the design and fabrication of a remote monitoring system that will automatically screen water in real time. Alternative methods necessitate the shipping of bulk water samples or concentrates to laboratories and labor-intensive screening technologies, which may include bulk water concentration, incubation, and culturing. These factors combine to impede overall routine monitoring for fecal coliforms in the field and preclude widespread, routine screening of surface waters.

Based on USGS Year I funding (in partnership with the Wyoming Water Development Commission), we developed and tested a low-cost, portable, highly sensitive, self-contained single cell detection system for *E. coli* in surface waters, which will greatly exceed the current testing procedures in both speed and reliability. Project objectives are**:** 1) low-cost detection of *E. coli* in Wyoming surface waters, 2) allows rapid (<<1hour) enumeration of *E. coli* concentration, 3) sensitive, will allow for enumeration of concentrations < 5 cell/100 ml with minimal number of false positive detections, 4) portable for field monitoring, 5) simple to use, does not require substantial training, and 6) development of proof of concept for remote monitoring.

Methodology:

The innovative technique employed in this research has the potential to detect foodborne and waterborne pathogens in real time at the level of a single bacterium in a volume of air or water through the use of specific fluorescent antibodies. The resulting fluorescence is detected with a CCD imager using a novel integration scheme called Fountain Flow (FF). Our system is called the Wyoming Biodetection System or WBS.

Our proprietary and patented (pending) WBS is based on immunofluorescence identification:

- An antibody specific to the cell species of interest is labeled with a fluorescent molecule or fluorochrome.
- The labeled antibody is mixed in solution with the cell species of interest. The antibodies attach to specific sites on the cells (antigens).
- The cells are passed in a stream of liquid toward a low-cost laser diode, which illuminates the fluorochromes causing them to fluoresce at a different wavelength.
- A low-cost CCD (charge coupled device) 2-D detector detects a burst of fluorescence emission each time a marked cell is illuminated by the laser diode while passing in front of the detector.
- The number of marked cells is then counted via computer. Antibodies can be chosen that are highly specific to the cells of interest.

In our current USGS/NSF-funded research, an operational CCD/FF apparatus was assembled and used to demonstrate the practical and economic feasibility of real time detection of *E. coli* to image and count (via computer) individual microorganisms. **The NSF-funded research focuses on detection of *E. coli* O157:H7 in ground beef, while the USGS-funded research involves detection of *E. coli* in Wyoming surface waters.** This device enabled the flow cytometry feasibility demonstrations to date and established the suitability of the FF cytometer to ***effectively detect single pathogenic microorganisms*****.** Emphasis is placed on signal-to-noise enhancement. This allows for multicolor detection providing enhanced reliability using several markers. In this detection system, fluid is transported through a hole that is large enough (2-mm dia.) to prevent clogging. Our imaging technique allows automated measurement of individual cells while they transit this flow cell.

In Fountain Flow a sample of fluorescently-labeled bacteria suspended in a transparent or translucent aqueous solution flows up a tube toward imaging optics, where sample particles can be imaged onto a CCD camera and counted or measured photometrically. The imaging optics include, with a single color instrument, a filter isolating the wavelength(s) of fluorescent emission. The ideal situation occurs when a particle flowing up the flow tube is imaged in the same pixel(s).

Principal findings and significance:

Our US Geological Survey proposal outlined the following five goals: 1) optimize fluorescent labeling of *E. coli*, 2) perform laboratory measurements on quantified *E. coli* samples to determine the detection efficiency and sensitivity of the monitoring system, 3) test methods of removing background detritus, 4) test methods of counting quantified samples of *E. coli* in a background matrix, and 5) enumerate *E. coli* in stream and lake water samples. Progress toward these goals is listed below.

In Year I testing, our team has demonstrated success in proving the concept of the WBS. Bacteria labeling, recovery of bacteria from authentic Wyoming surface water, and enumeration efficiency of the WBS have all been successfully accomplished. Year II goals were to develop the concept to the point were it was proven to be effective in enumerating bacteria in actual surface water samples. Critical problems encountered in Year II were 1) discrimination of autofluorescing detritus in the water from bacteria of interest, 2) testing of optimum reagents for bacteria staining, and 3) improvement of system counting reliability and accuracy.

Year I Results

FLUORESCENT LABELING

The fluorescent labeling of *E. coli* was the first goal accomplished. A protocol was designed using an R-phycoerythrin (R-PE) labeled antibody to *E. coli* K12, the benign test microorganisms used in our preliminary research. The antigen/antibody reaction was optimized to ensure fluorescent emission strong enough to be detected with the system with as little waste of unattached antibody as possible. This optimization can be scaled up or down according to sample size.

E. COLI DETECTION METHOD AND EFFICIENCY OF FF

In order to determine the efficiency of the Fountain Flow (FF) technique, comparisons were made between FF and Whipple-grid counting. For FF, samples of fixed *E. coli* K12 were labeled with propidium iodide dye and flowed through the FF system at 2.2 ml/hr. A 13-mW 475-nm laser diode was used to illuminate the stained bacteria at an illumination angle of 45 degrees. The exposure time of the CCD imaging the flow was 400 ms. Multiple frames were recorded and software used to quantify the detections made. The original overnights of the *E. coli* K12 were dilution-plated and counted with a Whipple grid to obtain the total number of cells in the sample. This number was compared with the number of cells counted by the our system, the Wyoming Biodetection System or WBS. Efficiencies of ~50% are obtained with cells and ~90% when comparisons are made with hemocytometer counts of microbeads, even when the microbeads are fainter than cells. This discrepancy is largely due to cell clumping, which doesn't significantly affect our Whipple-grid results, but has a large effect on FF counts. Typically, one ml of flowing liquid produces 900 images. This large amount of data necessitates counting in real time so that data archiving is not necessary. Detection efficiency is computed by comparing the counts from the WBS with the Whipple-grid counting method or by the mTEC filtration method (described in the next section).

FILTERING BACKGROUND DETRITUS

The USEPA introduced the mTEC enumeration method for *E. coli* in 1986. This method is currently employed by the USGS Water Resource Office in Cheyenne, WY and was demonstrated to us by USGS staff hydrologist Melanie Clark in a visit to our site. This membrane filter method provides a direct count of *E. coli* in water, based on the development of colonies that grow on the surface of the membrane filter. We first established that filtration through a 10-µm filter was necessary to remove any autofluorescing material from the water sample. We then used the mTEC method to test the efficiency of bacteria recovery after this initial filtration. An overnight culture of *E. coli* K12 was diluted by a factor of 10 using Crow Creek Reservoir (Wyoming) water as the diluent. (Because it is non-pathogenic, K12 was used in the preliminary research.) Crow Creek water simulates water samples that will be collected in the field, which contain sand, other dirt particles, and a small percentage of organic material. Fifteen ml of the sample was vacuum filtered through a 10-µm filter to remove debris, and then subsequently filtered through a 0.45-µm filter to separate bacteria from the solute. The 0.45-µm filter was then placed onto the surface of an mTEC agar plate. A second 15 ml sample, the control, was filtered only through the 0.45-µm filter. This 0.45-µm filter was also placed onto an mTec agar plate. Both plates were incubated at 35.2^{o}C for two hours and then at 44.5^{o}C for 22 hours. The colonies were enumerated the next day. Tween 80 was added to some samples to attempt to increase the recovery fraction. Similarly, sonication was also applied to some samples. **Results from spiked Crow Creek Reservoir water are summarized with the following mean bacteria separation efficiencies: 1) 62% (±5%) with no surfactant, 2) 33% (±2.5%) in a 2% Tween 80 solution, and 3) 33% in 2% Tween 80 following 10 minutes of sonication.**

Year II Results

BACKGROUND AUTOFLUORESCENCE: THE PROBLEM AND ITS SOLUTION

During the summer and fall of 2003, it became evident that our major stumbling block in terms of enumeration of small numbers of *E. coli* in Wyoming surface waters would be autofluorescence of natural debris. Tests of water from both Crow Creek and the Laramie River, which tested negative for bacteria, produced fluorescent particles of a wide range of sizes. We first attempted to remove particles by a combination of filtration and centrifugation. All water was allowed to settle for a period of ca. 1 hour and was subsequently filtered through a 20-micron filter. What remained were autofluorescing particles that were ca. the size of a bacterium. We tried illumination of the particles with both a green and a blue laser, and the particles autofluoresced in response to illumination in both cases. The emission spectra were examined through a series of filters to determine a wavelength where emission was attenuated or absent. Unfortunately, the particles fluoresce broadly, over the entire visible spectrum from blue to deep red. Examination of the particles through an epifluorescent microscope showed that the fluorescing particles were a combination of organic particles and crystalline particles.

After discussions with several fresh water microbiologists, we chose several lines of attack. First, we attempted to bleach the particles by exposing them to intense ultraviolet light. Second, we attempted to remove the pigments in the particles by centrifugation of the suspension, treating the particulate matter with ethanol, and re-suspending the particulate matter in water. Neither of these techniques reduced fluorescence to an acceptable level.

Finally, discussions of this issue with colleagues produced the suggestion (from Huang et al., 1996 in **Biofouling**, 9:269-277) that it was possible to quench autofluorescence in particulate matter, without affecting the immunofluoresence from labeled bacteria, with the application of an inexpensive dye, crystal violet. We tried this with laser excitation in the blue and green, and found that this technique works well with Laramie River water when illuminated with a blue laser. We now believe that technique might be widely applicable for suppressing autofluorescence of particulate matter in surface waters. We plan to test this method on a variety of Wyoming surface water samples.

DEVELOPMENT OF AN ALTERNATIVE SYSTEM FOR RARE CELL DETECTION

At the same time that we examining ways of reducing autofluorescence of particulate matter in surface water samples, we developed and a technique for using our system to separate bacteria according to shape and size. This would enable differentiation of bacteria from other organic and inorganic particles by size and morphology.

CELL VIABILITY DISCRIMINATION

With collaborators at the University of Paris, Dr. Philippe Lebaron and Mr. Philippe Catala, we developed a staining protocol for using CV6 to label cells that are metabolizing esterase. Preliminary tests have shown that when viable cells are stained with CV6, they fluoresce very brightly in the green, and are quite easy to detect. Thus, we can not only detect cells, but measure their viability as well.

DEVELOPMENT OF AN EPIFLUORESCENT SYSTEM AND CALIBRATION TESTING

TESTING RESULTS

While the WBS prototype that we tested in Year I gave encouraging results, we were not happy with the accuracy and reliability of the results. One issue was the need more sophisticated counting software that would properly count individual bacteria once, even when the same bacterium is seen on subsequent frames, in different positions. A second issue was the need for an epi-illuminated system that produced nearly uniform illumination of the entire orifice of the WBS. We made software and hardware modifications that successfully addressed both issues. Testing this system on 2.5 micron fluorescent Carmine beads (Molecular Probes, Eugene, OR) showed agreement between Whipple grid measurements of beads filtered onto a 0.2 micron filter and WBS measurements to within 10%. (This is approximately equal to the limitation from counting statistics for the low numbers of particles that we are counting (100-400.) Comparison of automated image counting and "hand" counting produces nearly identical results.

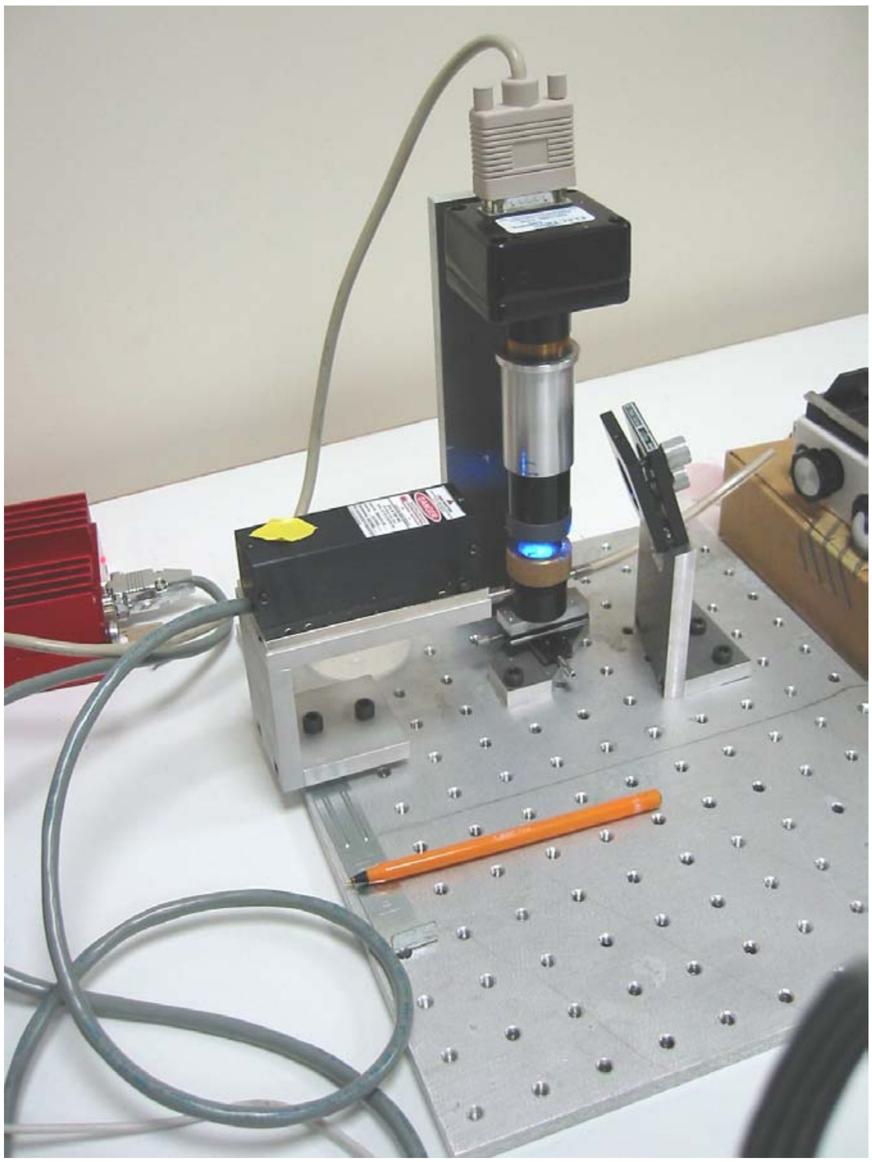

Figure 1. *The Wyoming Biodetection System with a 475 nm solid-state 13-mW laser.*

Summary of Goals for Follow-on Research

During the summer of 2004, we intend to finish the preparation of a manuscript to a refereed journal. This will include a description of the instrument design, but will include specific test results on the efficiency of detection of E. coli that has been inoculated at known concentrations into water from the Laramie River and/or Crow Creek. In addition, the P-I will attempt to secure funding for the version of this instrument that will use particle shape and size recognition to eliminate false counts from debris.

Students supported through this project:

During Year I, the P-I employed two undergraduate and two graduate students, in this research. The interaction among personnel of varying backgrounds (including microbiology, pharmacy, and physics) has provided a highly educational experience for everyone in research biodetection technology. During Year II, the P-I employed one undergraduate and one graduate student, in this research.

Patents pending:

- Johnson, P.E., High Throughput Analysis of Samples in a Translucent Flowing Liquid, patent pending.
- Votaw, A. and P.E. Johnson, Methods for Separating Microorganisms From a Food Matrix for Biodetection, patent pending.
- Johnson, P.E., LED Illuminated Particle Detection Apparatus and Methods, patent pending.

Drought prediction model development and dissemination in Wyoming

Basic Information

Title:	Drought prediction model development and dissemination in Wyoming
Project Number:	2002WY7B
Start Date:	3/1/2002
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	1
Research Category:	Biological Sciences
Focus Category:	Agriculture, Drought, Management and Planning
Descriptors:	Agriculture, Bio indicators, Decision models, Drought, Ecosystems, Range management, Risk management
Principal Investigators:	Michael A. Smith, Philip A. Rosenlund, Thomas L. Thurow

Publication

Problem and research objectives:

Timely, locally relevant, within year drought prediction tools for each major land resource area within Wyoming are not available. The few sites with existing data have not been developed or extent of their geographic relevance examined. The overall goal of this proposed research is to develop a timely, locally relevant, within year drought prediction tool for each major land resource area within Wyoming, focusing on the relationships of precipitation variables and annual forage production on rangeland by accomplishing the following objectives.

1. Cooperatively with CES and land management agencies, establish herbage yield and quality measurement sites representative of the predominant soils and precipitation pattern/amounts in major land resource areas in Wyoming and continue sampling the existing long-term forage production harvest site near Saratoga.
2. Locate and access existing annual forage production data from agency files within Wyoming.
3. Obtain and summarize relevant precipitation records for reporting stations nearest to vegetation sampling sites.
4. Analyze relationships of monthly and seasonal precipitation with annual peak standing crop forage yields and quality.
5. Provide cooperators with sampling and analysis tools for each to continue to strengthen predictive capabilities for their site.
6. Widely disseminate to the broad constituency of land managers and users in Wyoming, the most useful drought prediction methods resulting from this study.

Methodology

Cooperating agencies will establish vegetation production sampling sites in different land resource areas in Wyoming near their weather site or existing weather recording stations. Existing sources of long term vegetation production/weather records were sought. These included those from Cheyenne, USDA-ARS-HPGRS and records of Natrona County collected by BLM. A 17 year record of productivity and weather data from a site near Saratoga will be continued.

Regression techniques will be used to determine the best seasonal or monthly weather variable for prediction of the upcoming growing season productivity. Multi-variate regression analysis and time series analysis will examine the precision of the predicted forage production associated with adding successive climatic inputs received during the year prior to cessation of plant growth. An analysis goal is to identify a weather variable existing early enough in the year for livestock producers to respond to predicted forage production by making relevant stocking level adjustments before financial hardship or resource damage are probable.

Results will be disseminated through the CES web site and county offices statewide. Other print and visual/audio media will also be used.

Principal findings and significance

A graduate assistant has conducted sampling and analysis duties. Additional students have participated in field sampling. Cooperator production sites(15) were established including the following counties-cooperators, Converse-CES and HS, Platte-CES, Laramie-CES (HPGRS), Cambell-CES, Johnson-CES, Washakie-TNC, Sublette-CES, Park-Meeteetsee CD, Goshen Co-CES, Crook Co-CES, Natrona Co-BLM, Carbon Co-NRCS/CD. The site in Carbon County, maintained for 17 years jointly by UW and Saratoga Cons. Dist., was again sampled. In aggregate, these sites provide a geographic dispersion oriented largely toward east of the continental divide where effective precipitation for forage growth largely comes in spring. We assisted cooperators with aid in sampling and weighing materials as needed. Long term data sets recruited for this effort in addition to the data from the Saratoga site, includes a 20+ year set from HPGRS near Cheyenne and a multiyear sets from BLM Casper area.

Analysis of data from the Saratoga site indicates, as has previous treatments of this data, that winter precipitation is not an effective predictor of growing season productivity. Normal winter precipitation wets the upper few centimeters of the soil providing moisture for early growing species. Precipitation received in April (Fig. 1), particularly 12-19 April. produces the highest level of correlation with forage yields of the months/season tested. May and June precipitation are less effective predictors of growth but are valuable in extending the green season and maintaining higher forage quality. Soil moisture in May (Fig. 2) is also an effective predictor, however an end of April decision point for stocking decisions related to predicted forage production, is better for economically effective decisions for most managers.

Additional analysis of Saratoga data indicates that there is a distinct window of time in April that produces the highest level of correlation between precipitation and summer forage yields. HPGRS data (Fig. 3) indicates an earlier starting, wider window extending into summer. Casper area data (Fig. 4) are less definitive with a early start date and indistinct end date. Beginning of the predictive period appears to be related to elevation and associated temperatures. Continuation of the analyses of long term sets will involve integrating temperatures and perhaps soil properties.

Current analyses suggest that relatively effective predictive models may be developed for a geographic locale. However, the differences in the dates when precipitation begins to effectively predict and the length of time in the window producing the best prediction suggests that universally applicable models may not be possible.

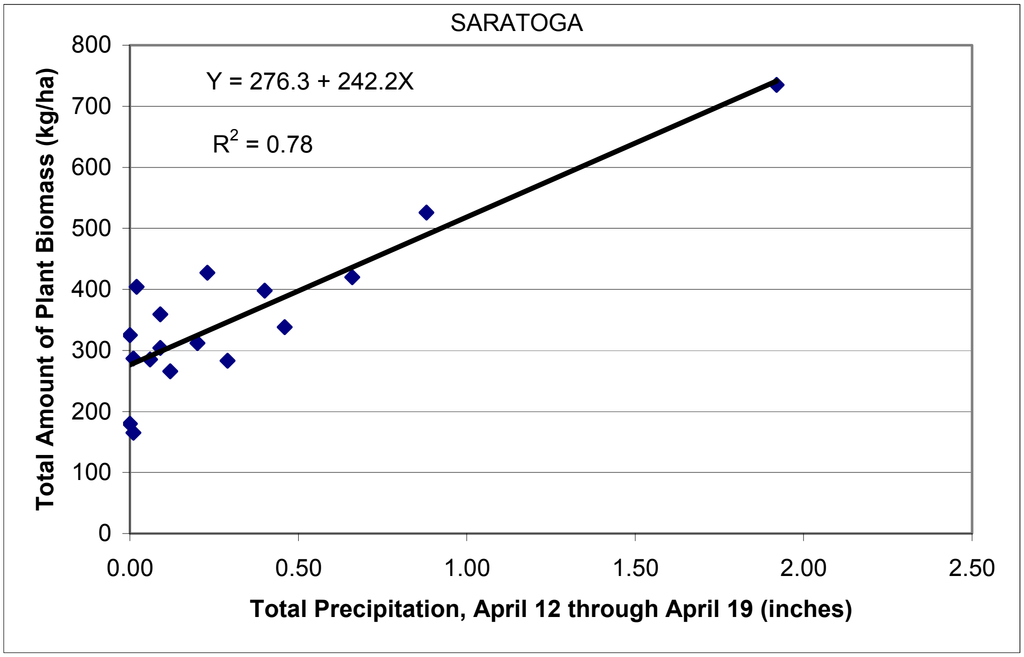

Figure 1. April 12-19 precipitation vs forage yields at Saratoga

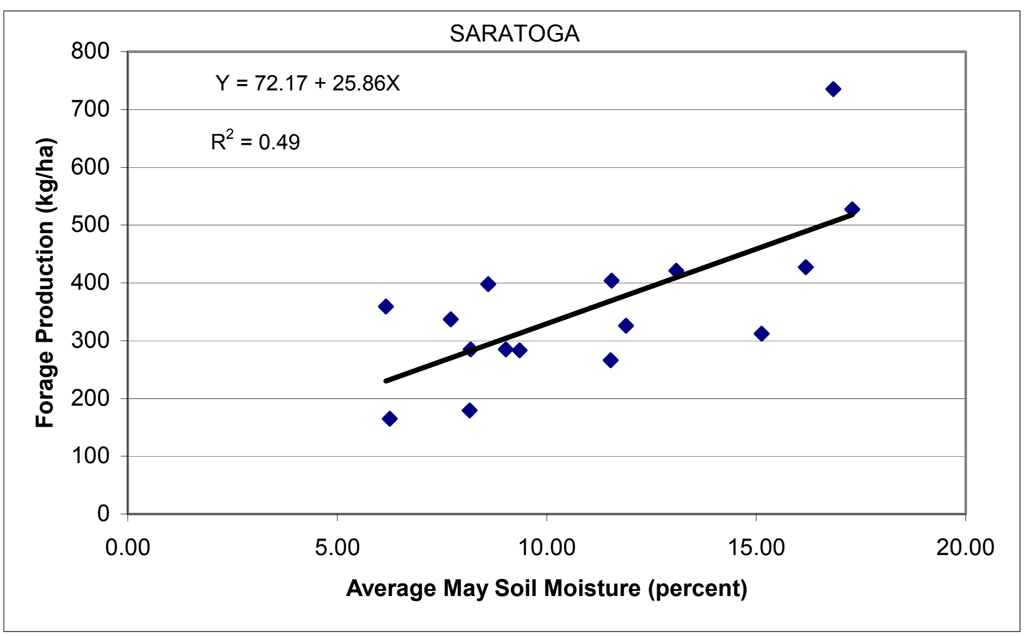

Figure 2. May soil moisture vs. forage production (no sage removed) for check plots, 1987-2002

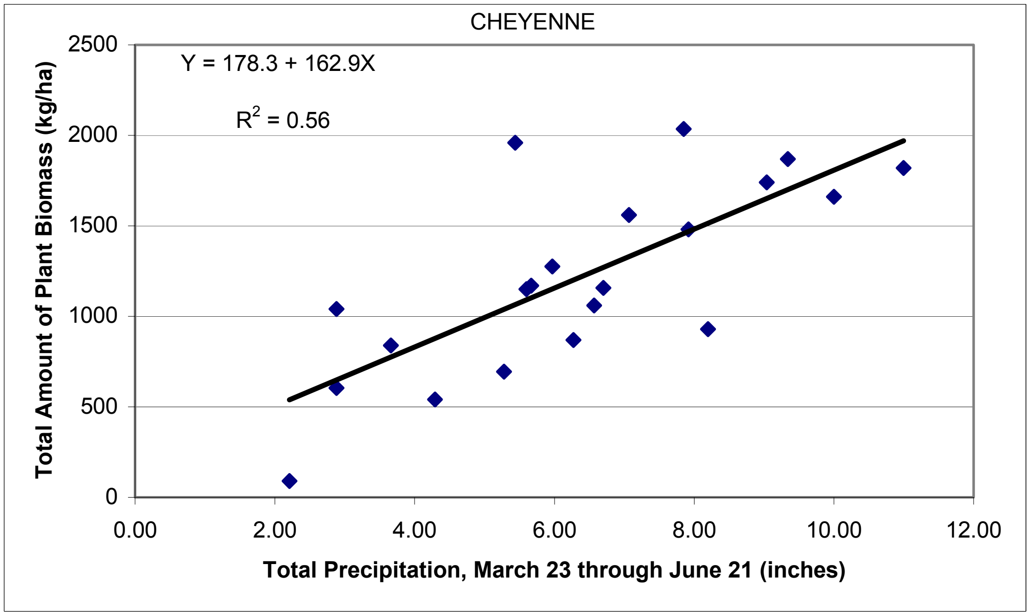

Figure 3. March 23 - June 21precipitation vs forage yields at Cheyenne

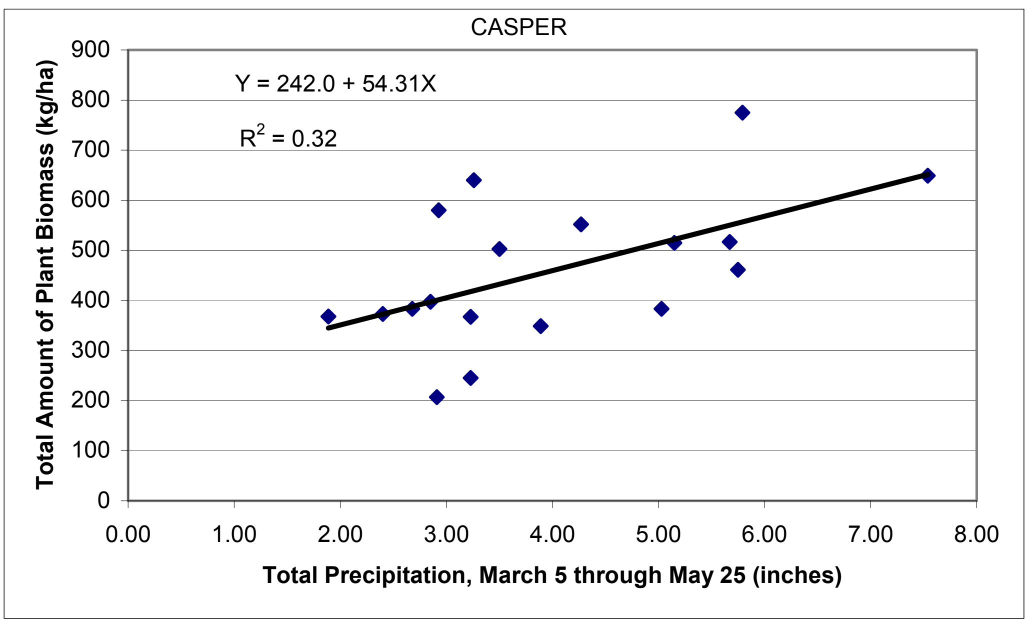

Figure 4. March 5 - May 25 precipitation vs forage yields at Casper

Geochemistry of CBM Retention Ponds Across the Powder River Basin, Wyoming

Basic Information

Title:	Geochemistry of CBM Retention Ponds Across the Powder River Basin, Wyoming
Project Number:	2003WY10B
Start Date:	3/1/2003
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Geochemical Processes, Groundwater, Surface Water
Descriptors:	
Principal Investigators:	Katta J Reddy, David E Legg, Richard A Olson

Publication

1. Jackson, R.E., K.J. Reddy, R.E. Olson, and D.E. Legg. 2004. Geochemistry of coalbed methane disposal ponds across the Powder River Basin, Wyoming. In Proceedings of Society of Range Management 2004 Annual Meetings, Salt Lake City, Utah.

Abstract:

The Wyoming Water Research Program (2002) funded the project geochemistry changes of coalbed methane (CBM) disposal pond waters across the Powder River Basin (PRB) in collaboration with the US Geological Survey and the Wyoming Water Development Commission. Objectives of this research were to monitor the geochemical changes and water quality of CBM disposal ponds in Tongue River Basin (TRB), Powder River Basin (PRB), Little Powder River Basin (LPRB), Belle Fourche River Basin (BFRB), and Cheyenne River Basin (CRB) over a period of 3 years. This report summarizes results from year 1 data collected from March 2003 to February 2004. The CBM product water samples from discharge points and corresponding disposal ponds were collected during the summer months of 2003. Samples were analyzed for pH, dissolved oxygen (DO), electrical conductivity (EC), major cations (e.g., Ca, Mg, Na, and K), major anions (e.g., alkalinity, sulfate, chloride, fluoride, nitrate, and phosphate), and trace elements (e.g., Al, As, Ba, B, Fe, Cd, Cu, Cr, Mn, Mo, Se, Pb, and Zn). Sodium adsorption ratio (SAR) was calculated from the measurements of Ca, Mg, and Na. The results of year 1 data show how quality of CBM discharge and disposal pond waters change, predominantly salt concentration and SAR as a function of watershed physical and chemical characteristics. Letters to local landowners have been drafted and will be sent near future to inform them of CBM water quality on their property. All aquatic macroinvertebrate samples have been prepared to be analyzed. Samples will be sent to a professional consulting company that specializes in aquatic macroinvertebrate identification. CBM pond sediment fractionation analysis is in progress. The proposed research helps water users (landowners, agriculture and livestock producers, and ranchers) and water managers (state, federal, and local agencies) with the planning and management of CBM product water within the Powder River Basin.

Statement of Critical Regional or State Water Problems:

Demand for natural gas (methane) is increasing within the United States because of the energy shortage. Further, methane is a clean form of burning fossil fuel. Several states within the United States (e.g., Wyoming, Colorado, Montana, New Mexico, and Utah) are exploring methane extraction from their coal resources. As an example, in the Powder River Basin (PRB) of Wyoming, it is estimated that there are 31.7 trillion cubic feet of recoverable CBM (coalbed methane). Currently, the CBM development in this basin is occurring at a rapid pace as demand for natural gas has increased in the United States (DeBruin et al., 2000).

Methane is formed deep in confined coalbed aquifers through biogeophysical processes and remains trapped by water pressure. Recovery of the methane is facilitated by pumping water from the aquifer (product water). It is estimated that a single CBM well in the Powder River Basin may produce from 8 to 80 L of product water per minute, but this amount varies with aquifer that is being pumped and the density of the wells. At present, more than 16,000 wells are under production in the PRB and this number is expected to increase to at least 30,000. Based on information provided by the Wyoming Geological Survey, approximately 2 trillion L of product water will eventually be produced from CBM extraction in Wyoming. Commonly 2 to 10 CBM extraction wells are placed together in a manifold system discharging to a single point and releasing into constructed unlined disposal ponds. These disposal ponds are constructed with initial well pumping. The Wyoming DEQ considers this water as surface water of the state with Class 4C designation.

Various metals such as Fe, Ba, As, and Se in the CBM pond waters are expected to go through several geochemical processes including desorption and dissolution, ion complexation (speciation), and adsorption and precipitation. These processes in turn control the quality of product water in disposal ponds as well as the water that is infiltrating into the shallow ground water. Very little information is available on the geochemistry of CBM product water and associated disposal ponds in the Powder River Basin (Rice et al., 1999; McBeth et al., 2003a and b). The studies conducted by Rice et al. (1999) only examined the chemistry of CBM discharge water at wellhead. McBeth et al. (2003a and b) studies examined the chemistry changes of product water both at wellhead and in disposal ponds of the Powder River Basin. However, to our knowledge no studies involved the monitoring of the geochemical processes that product water undergoes in disposal ponds across the Powder River Basin. The CBM product water discharged to the surface is managed and regulated by several state and federal agencies. To effectively manage this water resource there is a need to understand the geochemical changes that occur in CBM disposal ponds over time.

Objectives:

The overall objectives of this research were to:

1. Collect product water samples from discharge points and disposal ponds over a period of three years and analyze for pH, DO, EC, major cations (e.g., Ca, Mg, Na, and K), major anions (e.g., alkalinity, sulfate, chloride, fluoride, nitrate, and phosphate), and trace elements (e.g., Al, As, Ba, B, Fe, Cd, Cu, Cr, Mn, Mo, Se, Pb, and Zn);
2. Monitor the pH, DO, EC, major cations (e.g., Ca, Mg, Na, and K), major anions (e.g., alkalinity, sulfate, chloride, fluoride, nitrate, and phosphate), and trace elements (e.g., Al, As, Ba, B, Fe, Cd, Cu, Cr, Mn, Mo, Se, Pb, and Zn) of product water at discharge points and associated ponds over a period of 3 years;
3. Predict geochemical changes (speciation, adsorption, and precipitation) for critical metals such as Fe, Ba, As, and Se in the disposal pond;
4. Quantify relationships between CBM water quality, aquatic macroinvertebrates and vegetation.
5. Assess the diversity of benthic macroinvertebrates found in disposal ponds; and
6. Transfer research results to user groups through project demonstrations, workshops, and local meetings.

This final report outlines research progress accomplished for year 1 from March 2003 to February 2004. This report consists of objectives, methods and procedures, site selection, sample collection and analysis, results, clientele network, presentations, and student education and training.

Methods and Procedures:

Site Selection

We selected twenty-six sites within five Wyoming watersheds to obtain CBM well and associated pond data. Site selection was coordinated with a network of working partners. These working partners include: Wyoming Department of Environmental Quality (WY-DEQ), Wyoming Water Development Commission (WY-WDC), Coalbed Methane Industry, Wyoming Landowners and Citizens, U.S. Geological Survey (USGS), Wyoming State Geological Survey (WYSGS), U.S. Environmental Protection Agency (USEPA), Colorado, and Montana. We sampled seven sites in each of the Little Powder River and Powder River watersheds. We sampled three sites from Cheyenne River watershed and four sites from Bell Fourche River watershed, and five sites from Tongue River watershed (figure 1).

Sample Collection and Analysis

Before sample collection, a pilot study was conducted to determine sampling location within the CBM pond waters. Chemical, plant, and aquatic macroinvertebrates were also examined to determine the sampling locations to obtain a representative sample. CBM water samples from each well and corresponding ponds were collected during the summer of 2003. Before sample collection, field measurements including pH, conductivity, temperature, ORP, and dissolved oxygen were taken in each well and pond.

These measurements were conducted using Model 1230 Multi-Probe Field Kit. Duplicate water samples of wells and ponds were taken from each site as well as three trip blanks (112 total water samples). These water samples were analyzed for: Ca, Na, Mg, K, Fe, Al, Cr, Mn, Pb, Cu, Zn, As, Se, Mo, Cd, Ba and B by ICP-MS. Sulfate, chloride, fluoride, nitrate, and phosphorus were analyzed on IC. In addition to these analyses, samples were analyzed for dissolved organic carbon due to appearance of organic matter in disposal ponds. Dissolved organic carbon was analyzed using a Tekma-Dohrmann 8000 TOC. The quality control/quality assurances protocols such as duplicate sampling and analysis, trip blanks, and known concentrations of reference standards were included. Laboratory measurements of pH, electrical conductivity, alkalinity and total dissolved solids were accomplished using standard laboratory procedures. Sodium adsorption ratios will be calculated from Ca, Na and Mg concentrations. All analyses were preformed following CFR 40, Part 1, Chapter 36 procedures (Wyoming DEQ, 2001).

Sites used to sample pond sediment were located directly away from discharge and locations were chosen upon pH stabilization at different distances from discharge point. Typically sediment was collected approximately three meters into pond from discharge point. Sediment was taken from every pond and at least two samples from each watershed (10 total samples) will be separated into different mineral fractions and each fraction will be dissolved in an appropriate solution and extracted. Each clear extract will be analyzed for Fe, Ba, As and Se on ICP-MS as described by Tessier et al. (1979). Macroinvertebrates were collected from the water column and sediment from two ponds in each different watershed (20 total samples). Identification to lowest taxonomic level will be conducted using a certified laboratory specializing in analysis of benthic invertebrate communities. Vegetation species list of all vegetation that was present in and around ponds was conducted for every pond. Multiple detailed digital photos were taken at all study sites. Exact locations of sites were conducted using Garmin GPS unit.

Results:

The results from year 1 studies are presented in figures 2 and 3. These results suggest that moving from south towards northwest of the Powder River Basin increases the pH of CBM discharge water in disposal ponds. Electrical conductivity (dissolved salt concentration) also increases moving from south towards northwest of the Powder River Basin. However, salt concentration of CBM discharge water decreased in Tongue River basin when compared with Powder River basin. Dissolved sodium was major cation in both CBM discharge well and disposal pond water with minor concentrations of calcium and magnesium. The sodium adsorption ratio (SAR) increased in both discharge wells and disposal ponds from Cheyenne River Watershed to Tongue River Watershed with an observed SAR approaching 35 in Tongue River Watershed. Data analysis and interpretation of dissolved organic carbon and sediment trace elements is in progress.

Clientele Network:

Several contacts were made with different clientele groups to obtain access to the sampling sites and permission to collect samples. These contacts or clientele included WY-DEQ, WY-WDC, CBM Industry, WY Landowners and Citizens, NRCS personnel, Conservation Districts personnel, WY Cooperative Extension Agency, USGS, EPA, Colorado, Montana.

Graduate Student Support:

Rich Jackson, Ph.D. student, majoring in Rangeland Ecology and Watershed Management with Water Resources Option

Part-time Student Support:

Michelle Patterson, graduate student in Rangeland Ecology and Watershed Management with Water Resources Option
Jonathon Anderson, graduate student in Soil Science
Keri Bousman, undergraduate student in Rangeland Ecology and Watershed Management

Presentations:

1. University of Wyoming 2003 Graduate Student Symposium March 2nd, 2004, Laramie, Wyoming. This presentation won Best Project Presentation Award.
2. USDA-CSREES National Water Quality Conference: Integrating Research, Extension and Education scheduled January 11-14, 2004 in Clearwater, Florida.
3. Wyoming Water Development Commission Annual Meetings, December 4th, 2003, Cheyenne, Wyoming.
4. Rangeland National Annual Meetings, Water Quality Division, scheduled January 24-30, 2004 in Salt Lake City, Utah.
5. American Society of Agronomy (Soil and Water Ecology Section) Meetings, Denver, Colorado. November 5, 2003
6. Wyoming Department of Environmental Quality Meeting, Cheyenne, Wyoming. August 21, 2003.
7. EPA-USGS Meeting for Tongue River and Powder River Long-term Monitoring Network. Sheridan, Wyoming. June 5, 2003

8. Missouri River Basin Natural Resources Meeting, Benedictine, Kansas. June 2-4, 2003 (invited).
9. American Society of Surface Mining and Reclamation Symposium, Billings, Montana. June 5-6, 2003.
10. Wyoming Water Development Commission, River Basin Meeting, Kaycee, Wyoming. June 16, 2003.
11. Wyoming Department of Environmental Quality (Water Quality Division) Meeting, Cheyenne, Wyoming. May 10, 2003. This meeting included represents from U.S. EPA Region VIII, BLM, CBM Industry, Colorado State University.

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McBeth, I.H., K.J. Reddy, and Q.D. Skinner. 2003a. Chemistry of coalbed methane product water in three Wyoming watersheds. Journal of American Water Resources Association. 39:575-585 .

McBeth, I.H., K.J. Reddy, and Q.D. Skinner. 2003b. Chemistry of trace elements in coalbed methane product water. Journal of Water Research. 37:884-890 .

Rice, C.A., Ellis, M.S, and Bullock, J.H., Jr. 1999. Water co-produced with coalbed methane in the Powder River Basin, Wyoming: Preliminary compositional data. Open-File Report 00-372. U.S. Geological Survey, Denver, CO.

Tressier, A., Campbell, P.G.C, and Bisson, M. 1979. Sequential extraction procedure for the separation of particulate trace elements. Analytical Chemistry. 51:844-850.

Wyoming Department of Environmental. 2001. SAP: Water Quality Rules and Regulations, Chapter 1. Department of Environmental Quality and Water Quality Division, Cheyenne, Wyoming.

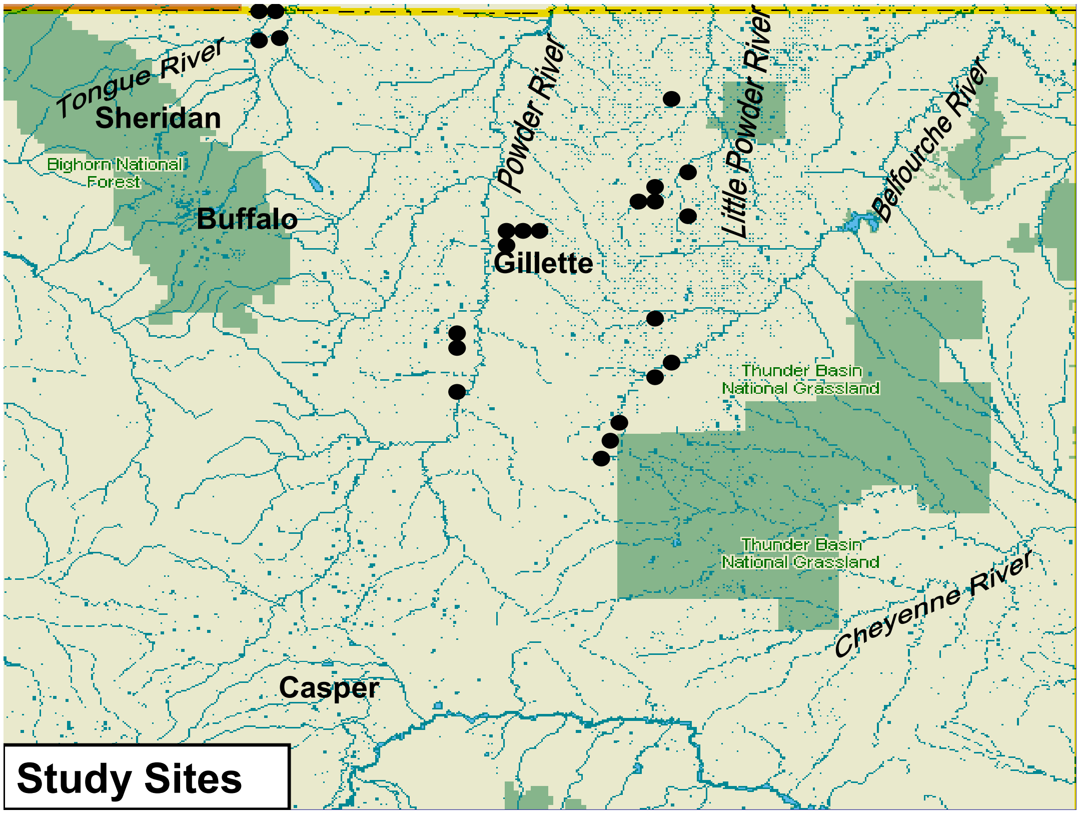


Figure 1. Map of study sites in the Powder River Basin, Wyoming (not to scale).

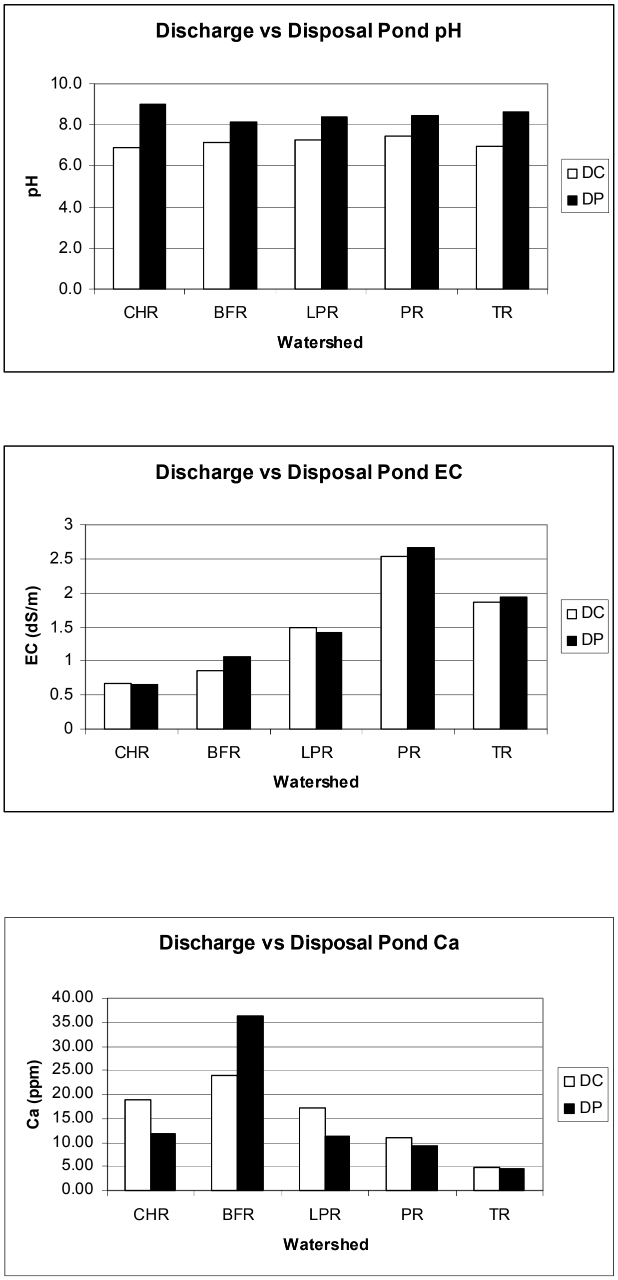
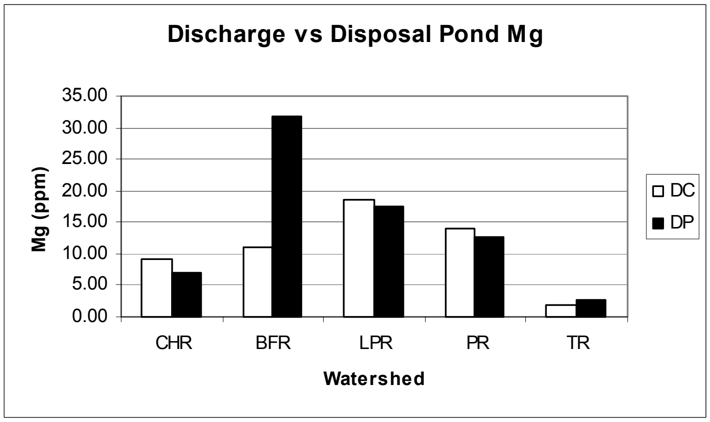
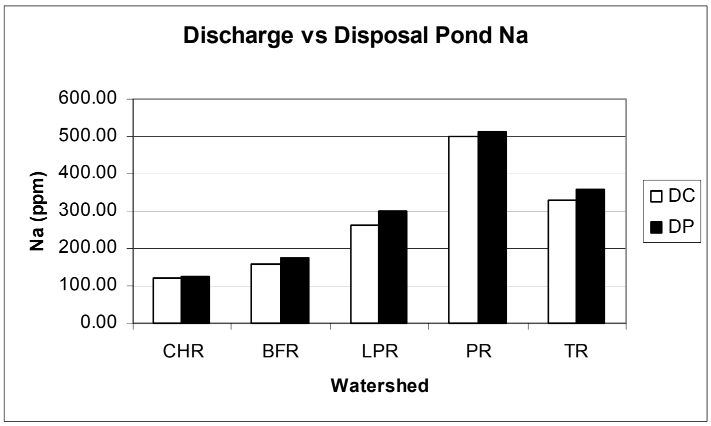


Figure 2. CBM discharge and disposal pond water pH (top), EC (middle), and Ca (bottom) as a function watershed.





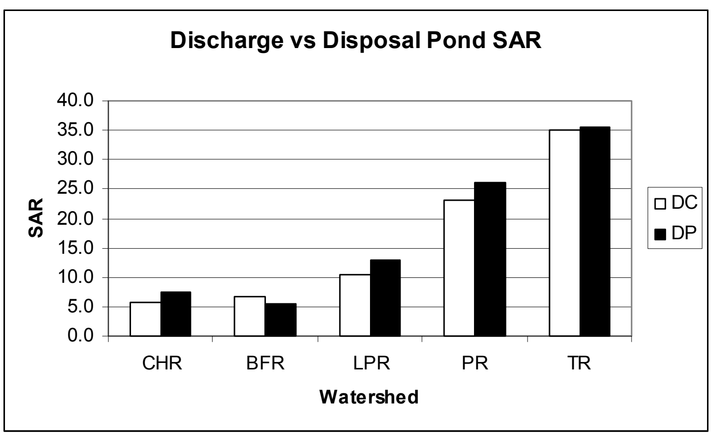


Figure 3. CBM discharge and disposal pond water Mg (top), Na (middle), and SAR (bottom) as a function watershed.

Subsurface Drip Irrigation Systems: Assessment and Development of Best Management Practices

Basic Information

Title:	Subsurface Drip Irrigation Systems: Assessment and Development of Best Management Practices
Project Number:	2003WY11B
Start Date:	3/1/2003
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Agriculture, Management and Planning, Non Point Pollution
Descriptors:	
Principal Investigators:	Drew W Johnson, George Floyd Vance, Renduo Zhang

Publication

Abstract:

Development of best management practices (BMP) for irrigated agriculture has become essential because efficient use of water is crucial with the ongoing drought in Wyoming and because irrigated agriculture contributes to nonpoint source pollution of our ground and surface waters. Proper management of water and the appropriate application of fertilizers can increase agricultural productivity while minimizing water quality degradation. Microirrigation, such as subsurface drip irrigation (SDI), offers the opportunity for precise application of water and fertilizers. Such irrigation methods are being developed as environmentally-friendly farming practices and systems. In the proposed study, field experiments and computer modeling will be conducted to quantify both water and fertilizers uptake by crops, and the potential of nitrate leaching into ground water in subsurface drip and flood irrigated fields. Detailed field data and comprehensive numerical simulations will help us to understand many theoretical and technical questions in the applications of SDI. The study will provide the necessary information for developing and/or improving irrigation management to enhance crop (e.g. alfalfa) productivity and to minimize ground and surface water contamination.

Current Project Status:

An overview of project goals and procedures was presented to the Midvale Irrigation District Manager and landowners in July 2003. While the landowner originally contacted during proposal preparation opted not to proceed with the study, two other landowners expressed interest in working with us but desired the test site be large (> 40 acres). After obtaining cost estimates from SDI manufactures, it was determined that our initial funding level was inadequate to proceed with the experiment at this larger scale. In attempt to obtain additional funding for a 40 acre test site, a proposal was submitted to the Western States Agriculture Research and Education (WSARE) program. Unfortunately, the proposal was declined funding and we have decided to proceed with the original smaller scale study. The research site was moved to the University of Wyoming's College of Agriculture Research and Extension Center located in Albany County. Employees at the experimental farm assisted with site preparation and will also assist with planting and harvesting. A photograph of the site is provided in Figure 1. A design (*e.g,* drip emitter depth and spacing, flood and sprinkler zones) has been completed and we are in the final stages of having the system installed. Installation of the drip tape proved to be very labor intensive and we are currently making test runs of the system before alfalfa planting. The system design is also shown Figure 1.

While the project was delayed by moving the test site, overall the project is still on track for both research objectives and training potential. The ongoing drought has caused some difficulties because there is a lack of irrigation water available for the test site. We will be using Laramie City water to supplement our irrigation water supply as needed during this growing season. Measurements are ongoing with this growing season. Two graduate students were supported with project funding this first year. One student assisted with modeling work and the other has focused on experimental design. Three undergraduate were also employed to help with system installation. All these students are receiving training related to water resources through academic course work, research project activities and opportunities to interact with district managers and practitioners.

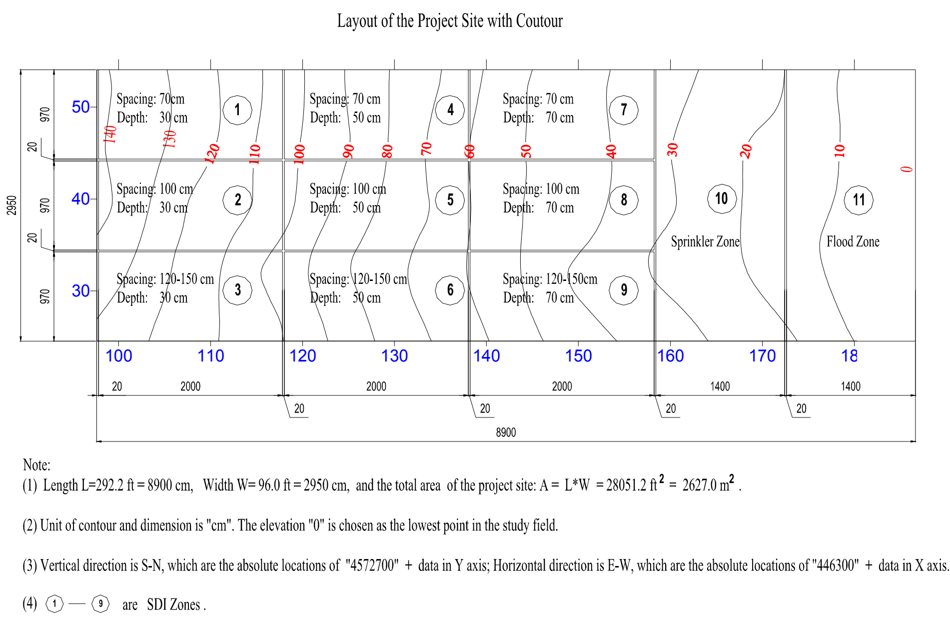


Figure 1 – Photograph of experimental site and site design drawing

Meetings/Presentations:

“Best Management Practices for Subsurface Drip Irrigation” Midvale Irrigation District manager and irrigators. July, 2003

Student Support:

Youquan Jiang, PhD, Civil Enngineering, University of Wyoming
Xinmei Hao, PhD, Renewable Resources, Unveristy of Wyoming
Christopher York, BS Civil Engineering, University of Wyoming
Diogo Lousa, BS Civil Enignering, University of Wyoming
Dan McGillvary, BS Civil Engineering, University of Wyoming

Water Scarcity and Economic Growth in Wyoming

Basic Information

Title:	Water Scarcity and Economic Growth in Wyoming
Project Number:	2003WY12B
Start Date:	3/1/2003
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Economics, Water Quantity, None
Descriptors:	
Principal Investigators:	Edward B Barbier

Publication

1. Barbier, E.B. 2004. Water and Economic Growth, Economic Record, 80: 1-16.
2. Barbier, E.B. and A. Chaudhry. 2004. Water and Growth in an Agricultural Economy. Paper to be presented at the Thirteenth Annual Conference of European Association of Environmental and Resource Economists, Budapest University of Economic Sciences and Public Administration, Budapest, 25-28 June 2004.
3. Chaudhry, A. 2004. Water, Public Capital and Growth in Municipal and Industries. Mimeo. Department of Economics and Finance, University of Wyoming.

Abstract:

The persistence of drought conditions over much or all of the state of Wyoming in recent years has raised concern as to whether water availability relative to use may be limiting economic growth and development in certain regions or even state-wide. This research aims to address this issue by analyzing the relationship between relative water availability and economic growth across the counties and key water-using sectors in Wyoming, irrigated agriculture and other productive uses (municipal and industrial). Three broad results are anticipated: 1) An empirical analysis of the relationship between the rate of water utilization and economic growth across the individual counties of Wyoming and over time (i.e. annually). 2) An empirical analysis over time (i.e. annually) of a water-growth relationship for two key water-using sectors in Wyoming's economy: irrigated agriculture (i.e. the annual crop sector fodder and municipal and industrial users (for production). 3) Identification of those counties and sectors whose economic development is especially at risk from chronic water scarcity, as measured in terms of moderate and/or extreme hydrological stress conditions.

Problem and Research Objectives:

The persistence of drought conditions over much or all of the state of Wyoming in recent years has raised concern as to whether water availability relative to use may be limiting economic growth and development in certain regions or even state-wide. The primary objective of this study is to analyze the relationship between relative water availability and economic growth across the counties and key water-using sectors in Wyoming. Jacobs and Brosz 2000) indicate that 80-85% of water consumed in Wyoming is for irrigated agriculture (approximately 2.6 million acre-feet). Ignoring evaporation from reservoirs, all other water uses in Wyoming (domestic, municipal, livestock and industrial – including mineral and energy) account for 160,000 acre-feet of water consumption. Thus it is important to analyze water-growth relationships in Wyoming for two distinct uses: irrigated agriculture, and other productive water uses (municipal and industrial).

The modeling approach is based on adapting the approach by Barbier (2004), which depicts the influence of water utilization on the growth of the economy through a model that includes this congestible public good as a productive input for private producers. The result is that the aggregate rate of water utilization by all producers is related directly to the growth of the economy. In Barbier (2004), this relationship was empirically tested through a statistical analysis across countries, and allowing for the fact that some countries face moderate or extreme conditions of water stress. The aim of the proposed research is to modify the water-growth model and apply it to the state of Wyoming.

Two types of analysis are being conducted. The first involves examining empirically the relationship between the rate of water utilization and economic growth across the individual counties of Wyoming and over time (i.e. annually). The degree of water stress faced by certain counties in some years will be incorporated specifically into the analysis. The second analysis also involves examining the water-growth relationship over time but for the two sector principal uses: irrigated agriculture and all other productive uses of water. Analyzing the latter category of use is particularly important, as surface water consumption for domestic and municipal use is anticipated to increase from 60,000 to over 148,000 acre-feet in 2020, and industrial consumption is projected to rise from 85,000 to over 845,000 acre-feet in 2020 (Jacobs and Brosz 2000).

Both the county and sector-level analyses will not only reveal the extent to which overall economic growth in Wyoming is affected by water availability relative to use but also identify those counties and sectors whose economic development is especially at risk from water scarcity. Such information may be critical to future water use planning in Wyoming, and for the design and implementation of institutional and allocation mechanisms for water supply in the state.

Methodology and Anticipated Results:

The methodological approach for the empirical panel analysis of the relationship between the rate of water utilization and economic growth across the individual counties of Wyoming and over time will be a straightforward application of the model developed by Barbier (2004). In contrast, analyzing water-growth relationships for the two main categories of sectoral use, irrigated agriculture and municipal and industrial use, requires two distinct modeling approaches.

For example, irrigated water is a privately provided good, usually supplied by farmers to themselves through exercising their prior appropriation rights. A different modeling approach is required to determine how the aggregate rate of water utilization for irrigated farming affects growth in this sector of the economy. Preliminary efforts to develop such a model for water use in irrigated agriculture are summarized in Barbier and Chaudhry (2004). Future work will focus on applying this model to empirical data across Wyoming.

In the case of municipal and industrial use, combing the modeling approach developed in Barbier (2004) with a model of public capital and economic growth by Shioji (2001) seems appropriate. In this approach we suggest that water is provided to producers as a publicly provided but congestible good, and we focus on investment in water-related infrastructure (e.g. water delivery, cleaning and storage) as well as the total volume of water availability (Chaudhry 2004). The result is that the aggregate rate of water utilization by all producers is related directly to the growth of production in this sector of the economy.

In sum, we anticipate the following three results from the study:

- An empirical analysis of the relationship between the rate of water utilization and economic growth across the individual counties of Wyoming and over time (i.e. annually).
- An empirical analysis over time (i.e. annually) of a water-growth relationship for two key water-using sectors in Wyoming's economy: irrigated agriculture (i.e. the annual crop sector fodder and municipal and industrial users (for production).
- Identifying those counties and sectors whose economic development is especially at risk from chronic water scarcity, as measured in terms of moderate and/or extreme hydrological stress conditions.

Summary of Progress in FY2003:

A graduate assistant, Ms Anita Chaudhry, has been appointed to the project. Ms. Chaudhry is undertaking this project as part of her PhD studies, supervised by the principal investigator, Professor Edward Barbier.

Professor Barbier outlined the scope and aims of the project at the 2003 Stroock Forum at the University of Wyoming on 16 September 2003 in a presentation, “Water Scarcity, Wyoming and River Basins”.

One of the aims of the project in FY2003 has been to develop the various methodologies for analyzing water use and growth in the two main sectors, irrigated agriculture and municipal/industrial use. It was decided that the Barbier (2003) model could be readily adapted to analyze water-growth relationships for producers in the water/industrial use sector but not for irrigated agriculture. We are therefore in the process of developing an appropriate model for the latter sector, taking into account that irrigated water is a privately provided good, usually supplied by farmers to themselves through exercising their prior appropriation rights.

A major focus in the first year has been to identify useful contacts in the State and Federal agencies concerned with water use in Wyoming, and to collect the appropriate hydrological, demographic and economic data necessary for the project. The following summarizes our progress to date in this area:

People contacted

- State Engineer's Office: Patrick Tyrrell
- Wyoming Water Development Commission: Barry B. Lawrence
- United States Geological Service: Bob Swanson, Timothy T. Bartos
- Water Resources Data System: Jan Curtis, Debra Cook

Hydrological data

- United States Geological Service (http://water.usgs.gov/watuse/)

This source contains estimated water use data for Wyoming by county (or watersheds) for the year 1990 and 1995. For each year, data on surface and groundwater withdrawals and consumptive use is available for the following sectors: public supply, commercial water use, domestic, industrial, mining, livestock, irrigation, power generation (fossil fuels as well as hydroelectric power generation). These data are the most useful for our purpose because of its break-down by county and industry.

- Wyoming Water Plans (http://waterplan.state.wy.us)

This source contains data by basin. Data are available for water flows and use for different industries. But in almost all cases, there is a single estimate of water use, often a multiple year average, rather than time series information.

The water plans however, are useful because they provide an excellent overview of water uses, interstate compacts as well as current developments in the basin. They also contain projections of various water uses up till 2030.

All basins except Snake/Salt River Basin, Platte River Basin and Wind/Bighorn River Basin have a water plan that is ready and available on the web.

Economic and demographic data

- Bureau of Economic Analysis (http://www.bea.doc.gov)

This site contains data on gross state product, wages, and property income, by industry up till 2001. These data are available for each industry (e.g. agriculture, forestry, mining, construction, nondurable goods etc.) The site also contains personal income, per capita personal income and population data on Wyoming up till 2001. Moreover, personal income data broken down by industry and county is also available for the year 2001.

- US Bureau of Census (http://www.census.gov)

This site is very useful because it contains the demographic data for the State for 1990 and 2000. Data are also available for various social (e.g. school enrollment, urban-rural residence, children born per 1000 women etc.), economic (employment by industry, income distribution etc.) and housing characteristics. There are also projections available for the year 2002.

To summarize, we have made excellent progress on locating the data for this project. However, we lack the data for total freshwater availability (i.e., average annual surface runoff and groundwater recharge from endogenous precipitation, including surface inflows from other states). Total water availability is needed to measure relative water demand (i.e. freshwater utilization relative to availability). Currently, the only data on total freshwater availability that are known for Wyoming is from the USGS *Water Resources Data Report* for 2002, which contains information at basin level for a single year.

Most of the modeling effort in FY2003 has focused on developing the basic models relevant to water use and growth in Wyoming. The basic modeling approach for determining how the aggregate rate of water utilization for irrigated farming affects growth in the agricultural sector of the Wyoming economy has been developed (Barbier and Chaudhry 2004). Preliminary work has begun on developing a water of public capital, water use and growth in the municipal and industrial sector (Chaudhry 2004). Future work will focus on applying both of these models to empirical data across Wyoming.

Student Support:
Ms Anita Chaudhry is the graduate research assistant employed fulltime on this project, as part of her PhD in Economics studies.

References:
Barbier, E.B. 2004. "Water and Economic Growth." *Economic Record* 80: 1-16.

Barbier, E.B. and A. Chaudhry. 2004. “Water and Growth in an Agricultural Economy.” Paper to be presented at the Thirteenth Annual Conference of European Association of Environmental and Resource Economists, Budapest University of Economic Sciences and Public Administration, Budapest, 25-28 June 2004.

Chaudhry, A. 2004. “Water, Public Capital and Growth in Municipal and Industries.” *Mimeo.* Department of Economics and Finance, University of Wyoming.

Jacobs, James J., and Donald J. Brosz. 2000. “Wyoming’s Water Resources.” University of Wyoming, Agricultural Experiment Station, August.

Shioji, Etsuro. 2001. “Public Capital and Economic Growth.” *Journal of Economic Growth* 6:205-227.

Conveyance Losses and Travel Times of Reservoir Releases Along the Bear River from Woodruff Narrows Reservoir to Cokeville Wyoming

Basic Information

Title:	Conveyance Losses and Travel Times of Reservoir Releases Along the Bear River from Woodruff Narrows Reservoir to Cokeville Wyoming
Project Number:	2003WY13B
Start Date:	3/1/2003
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	1
Research Category:	Not Applicable
Focus Category:	Agriculture, Hydrology, Irrigation
Descriptors:	
Principal Investigators:	Drew W Johnson, Greg Kerr

Publication

Abstract:
This study will investigate conveyance losses on the Bear River between Woodruff Narrows Reservoir, WY and Cokeville, WY. There are three main reasons for this study. First, conveyance loss information may allow irrigators near Cokeville WY to use Woodruff Narrows storage water. Second, it will provide better understanding of conveyance losses and return flow timing and thus, allow downstream Wyoming irrigators to better plan for utilizing reservoir releases. Third, information obtained in this study will be useful in future decision-making related to the development of a wildlife refuge that has been approved for this part of Wyoming. Stream flow data and the hydrologic budget approach will be used to determine conveyance losses for the Bear River. Through this analysis, major mechanisms influencing flow will be determined and quantified. The method to be used requires the comparison of quantities for inflow and outflow in order to determine conveyance losses. These measurements will be obtained from USGS stream gages, existing recorders on diversion in Wyoming and Utah and from continuous stage recorders to be installed over this reach of the Bear River.

Current Project Status:
An overview of project goals and procedures was presented to Bear River Basin Advisory Group, Kemmerer Wyoming in July 2003. With assistance from Advisory Group members (*e.g.* Jade Henderson), all major diversions and tributaries gauging information was obtained and analyzed for prior water years. A preliminary water budget analysis on these years indicated that additional gages were needed to be installed along the Bear River to account for return flows between the major diversions. Four additional gages have been installed and collection of data is ongoing. In addition, to better perform the water budget analysis, we have added telemetry to the newly installed gages and all major diversions along the study stretch of the Bear River. Telemetry installation was provided by the US Bureau of Reclamation and was an outcome of a January 2004 meeting between personnel from WY State Engineer's Office, Utah Division of Water Rights and the interstate Compact Commission's engineer-manager. With telemetry capabilities, we plan to develop a real-time water budget analysis approach which may be useful for decision makers and irrigators when managing water supply. Utah Division of Water Rights has indicated they want to participate in the study and help model Woodruff Narrows Reservoir's lag times, return flows, etc.

The ongoing drought may cause some difficulties for this study. Last year there was insufficient water for reservoir releases necessary to obtain incremental loss measurements. If this continues in 2004, alternative methods to estimate losses other than those originally proposed will need to be explored.

Overall the project is on track in both research objectives and training potential. A graduate student is being supported with project funding and is receiving training related to water resources through academic course work, research project activities and opportunities to interact with State agency personnel and irrigators.

Meetings/Presentations:
"Conveyance Losses on the Bear River", Bear River Advisory Group, Kemmer Wyoming, July 2003.
"Conveyance Losses on the Bear River" Wyoming State Engineers office, Utah State Engineers Office, Cokeville Wyoming, January 2004.

Student Support:
William Kunz, MS Civil Engineering, University of Wyoming

Information Transfer Program

A critical component of the Water Research Program is the coordination of research activities between researchers, agency personnel, and private interests. In addition, in order to produce quality research, coordination is required for determination of research priorities, dissemination of information on research opportunities, and identification of research expertise. This coordination serves as an information transfer activity through meetings, conferences, and informal communications. An example is the service of the Director as University of Wyoming advisor to the Wyoming Water Development Commission which conducts joint meetings with the Wyoming Legislatures Select Water Committee. The Director reports annually to the Commission and the Select Water Committee.

The Water Research Program has been developed upon the concept that it is the responsibility of the PIs of the research projects supported by 104 funds to participate in and conduct information dissemination activities. In addition to PI participation during the duration of research projects, the Director, through the Office of Water Programs, provides travel support for PIs of completed 104 projects. When appropriate, results are also available through the Wyoming Water Resources Data Systems library. Wyoming is fortunate to have the Wyoming Water Resources Data System (WRDS), which is a clearinghouse of hydrological and climatological data for the State of Wyoming. WRDS is funded by an allocation from the Wyoming Water Development Commission and offers a wide range of products and services to its users. As of 01 September 2001, a State supported Climatologist Office was created and has been combined with WRDS.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	6	0	0	0	6
Masters	5	0	0	0	5
Ph.D.	3	0	0	0	3
Post-Doc.	0	0	0	0	0
Total	14	0	0	0	14

Notable Awards and Achievements

Publications from Prior Projects

1. 2000WY1B ("Hydrologic Impacts of Improved Irrigation Efficiencies and Land Use Changes") - Articles in Refereed Scientific Journals - Venn, B.J., D.W. Johnson, and L.O. Pochop, 2004. Hydrologic Impacts due to Changes in Conveyance and Conversion from Flood to Sprinkler Irrigation Practices, J. of Irrigation and Drainage Engineering, 130:192-200.
2. 2001WY1781B ("Erosion Potential Model Development and Channel Monitoring") - Other Publications - Baxter, J. C., G. V. Wilkerson, and J. H. Johnson, 2002. Erosion potential modeler (Version 3.0): Reference manual. Available at http://wwweng.uwyo.edu/ civil/ research/water/epmodeler.html. University of Wyoming, Laramie. Baxter, J. C., G. V. Wilkerson, and J. H. Johnson, 2002. Erosion potential modeler (Version 3.0): Reference manual. Available at http://wwweng.uwyo.edu/civil/research/water/epmodeler.html. University of Wyoming, Laramie.
3. 2001WY1781B ("Erosion Potential Model Development and Channel Monitoring") - Other Publications - Wilkerson, G. V., J. C. Baxter, and J. H. Johnson, 2002. Erosion potential modeler (Version 3.0): Technical manual. Available at http://wwweng.uwyo.edu/ civil/ research/water/epmodeler.html. University of Wyoming, Laramie. Wilkerson, G. V., J. C. Baxter, and J. H. Johnson, 2002. Erosion potential modeler (Version 3.0): Technical manual. Available at http://wwweng.uwyo.edu/civil/research/water/epmodeler.html. University of Wyoming, Laramie.
4. 2001WY1781B ("Erosion Potential Model Development and Channel Monitoring") - Other Publications - Wilkerson, G. V., 2002. A GIS model for evaluating the impacts of coal bed methane surface water discharges. Abstracts with Programs - 2002 Annual Meeting of the Geological Society of America, Boulder, CO. Wilkerson, G. V., 2002. A GIS model for evaluating the impacts of coal bed methane surface water discharges. Abstracts with Programs - 2002 Annual Meeting of the Geological Society of America, Boulder, CO.
5. 2000WY4B ("Testing of Hydrologic Models for Estimating Streamflow in Mountainous Areas of Wyoming") - Dissertations - Riley, James D., 2003. Hydrologic modeling of winter streamflow in mountainous areas of southeast Wyoming, Master of Arts Thesis in Geography/Water Resources,

Dept. of Geography and Recreation, A&S College, University of Wyoming, Laramie.

6. 2002WY2B ("Testing of hydrologic models for estimating streamflow in mountainous areas of Wyoming") - Conference Proceedings - Ostresh, Lawrence M., James D. Riley, Hugh Lowham, and Bruce Brinkman, 2002. Gridding winter precipitation data in Wyoming mountains, poster session presented at Great Plains/Rocky Mountain Division of the Association of American Geographers, Missoula, MT, Oct. (presented by Ostresh), availability referenced in Volume 2, Supplemental Information Report.
7. 2001WY1901B ("Testing of Hydrologic Models for Estimating Streamflow in Mountainous Areas of Wyoming") - Conference Proceedings - Ostresh, Lawrence M., James D. Riley, Bruce Brinkman, and Hugh Lowham, 2003. Effect of land cover on winter streamflow in southeastern Wyoming mountains, poster session presented at the National Meetings of the Association of American Geographers, New Orleans, LA, March, (presented by Ostresh), availability referenced in Volume 2, Supplemental Information Report.
8. 2001WY1901B ("Testing of Hydrologic Models for Estimating Streamflow in Mountainous Areas of Wyoming") - Other Publications - Lowham, Hugh, Lawrence Ostresh, James Riley, Bruce Brinkman, and Justin Montgomery, 2003. Testing of hydrologic models for estimating low flows in mountainous areas of WyomingVolume 1, User Guide, Project Report, Available from Wyoming Water Development Commission, 6920 Yellowtail Road, Cheyenne, WY, 82002 or University of Wyoming, Water Resources Data System, Laramie, WY, 82071.
9. 2001WY1901B ("Testing of Hydrologic Models for Estimating Streamflow in Mountainous Areas of Wyoming") - Other Publications - Lowham, Hugh, Lawrence Ostresh, James Riley, Bruce Brinkman, and Justin Montgomery, 2003. Testing of hydrologic models for estimating low flows in mountainous areas of WyomingVolume 2, Supplemental Information, Supplemental to Project Report, Available from Wyoming Water Development Commission, 6920 Yellowtail Road, Cheyenne, WY, 82002 or University of Wyoming, Water Resources Data System, Laramie, WY, 82071.
10. 2002WY4B ("Combining modern and paleo-climate data to enhance drought prediction and response") - Articles in Refereed Scientific Journals - Gray, S. T., J. L. Betancourt, C. L. Fastie, and S. T. Jackson, 2003. Patterns and sources of multidecadal oscillations in drought-sensitive tree-ring records from the central and southern Rocky Mountains, Geophys. Res. Lett., 30(6), 1316, doi:10.1029/2002GL016154.
11. 2002WY4B ("Combining modern and paleo-climate data to enhance drought prediction and response") - Articles in Refereed Scientific Journals - Gray, S.T., S.T. Jackson, and J.L. Betancourt, 2004. Tree-ring Based Reconstruction of Precipitation Variability for Northeastern Utah. J. of the American Water Resources Association (in press).
12. 2002WY4B ("Combining modern and paleo-climate data to enhance drought prediction and response") - Dissertations - Gray, S.T. 2003. Long-term Climate Variability and its Implications for Ecosystems and Natural Resource Management in the Central Rocky Mountains. Ph.D. Dissertation, Botany, A&S College, University of Wyoming, Laramie.
13. 2002WY4B ("Combining modern and paleo-climate data to enhance drought prediction and response") - Conference Proceedings - Gray, S.T., S.T. Jackson, and J.L. Betancourt. 2002. Tree-ring based reconstructions of precipitation variability in northeastern Utah. Proceedings of the 2003 Pacific Region Climate Workshop (PACLIM), Pacific Grove, California. http://tenaya.ucsd.edu/~dettinge/PACLIM/Abstracts_PACLIM03.pdf
14. 2002WY4B ("Combining modern and paleo-climate data to enhance drought prediction and response") - Other Publications - Gray, S.T., S.T. Jackson, and J.L. Betancourt, 2003. Tree-ring Based Reconstruction of Precipitation Variability in Northeastern Utah. Contributed paper, PACLIM (Pacific-Region Climate Dynamics) Workshop, Monterey, California, April.