Wyoming Water Research Program
Annual Technical Report
FY 2004

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 through the Universitys Office of Water Programs. The primary purposes of the WRP 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 of the Office of Water Programs 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. In addition, during FY04, the Director through the Office of Water Programs has supported two graduate students. These students received M.S. degrees in December of 2004 and May of 2005.

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, 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 Office of Water Programs Director, Larry Pochop, was appointed in October 1999 and the Associate Director, Greg Kerr, was appointed in July 2004. 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. This approach supports student training and keeps administrative costs at a minimum.

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:	
Principal Investigators:	Michael A. Smith, Philip A. Rosenlund, Thomas L. Thurow

Publication

1. Smith, M. A., T. L. Thurow, and D. Legg. 2005. Predicting herbage standing crop on Wyoming rangeland from winter and spring precipitation. Abstracts 58th Annual Meeting Society for Range Management.
2. The Wyoming state map describing the predicted forage crop on rangeland was disseminated on the state climatologists web page twice, early and late April 2005. Annually, at the end of April, this map will be published.

Abstract:

A useful predictor of forage yields for the upcoming growing season has been lacking for Wyoming and this region. Available data from three long term sites where native forage yields had been harvested annually were analyzed for the relationship of the yield to seasonal precipitation. Realizing that precipitation zone, elevation, and ratio of cool to warm season grasses might make a realistic early season predictor unlikely, 19 sites around the state in a variety of regions were established to provide the infrastructure for the development of locally realistic predictors. As this effort was started during a drought and state government realized that there was no relevant soil moisture information, the Wyoming Dept of Agriculture and Governor's office funded the installation of soil moisture monitoring equipment at all the sites of forage yield sampling.

The optimum predictor of forage yield from the highest elevation site was precipitation during one week in April. Subsequently lower elevation sites had windows of precipitation that were longer and started earlier, running from mid March into June. These sites we hypothesized to thaw and start growing earlier. They had more warm season grasses that require warmer temperatures to grow. A generalized model for the state may not provide a sufficiently early date with a reliable predictor.

Problem and Research Objectives:

Timely, locally relevant, within year drought prediction tools for each major land resource area within Wyoming were not available. The few sites with existing data were not developed or extent of their geographic relevance examined. The overall goal of this research was 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 were canvassed concerning volunteering to establish vegetation production sampling sites in different land resource areas in Wyoming near their weather site or existing weather recording stations. Inquiries were made of NRCS, CES, CD's, BLM, ARS, and USFS. 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 was continued.

Simple linear regression analysis for each of the three sites with long term data was used iteratively to examine all possible combinations of precipitation summed over date intervals within 1 January to harvest date to discover regressions (step 1 models) with slopes greater than "0" . Coefficient of correlation, R^2, was noted for each to indicate date intervals with highest prediction for that site.   A second step involved validating these step 1 models with data from the other locations around Wyoming. The precipitation summed over the date interval in the model was used to predict forage yields. The output of this procedure was correlated with observed values to discover those step 1 models with outputs correlated to the observed values. Those step 1 models with slopes greater than "0" when correlated with observed data were referred to as step 2 models. In the third step, the date intervals were converted to categories of short, medium, and long intervals occurring early or late in the year relative to the forage harvest date. Step 2 models were used with these date categories to predict herbage yields. Those models with relatively high R^2 when the output was correlated with observed values from validation sites were categorized as step 3 models. In step 4, the step 3 models were examined for reliance on a single data point, linearity, and equality of variances of residuals. In step 5, those models passing step 4 were sequentially examined for stability by removing each data point in turn and determining if the regression slope remained significantly greater than "0". The five models passing the step 5 test were retained. An analysis goal was 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.

Principal Findings and Significance:
A major thrust of this research was to establish cooperatively managed forage yield data collection sites in major land resource areas (or ecoregions) broadly distributed within Wyoming. These regions included 10-14" ppt. Southeast High Plains, 15-17" ppt. Southern Plains, 10-14" ppt. Northern Plains, 15-19" ppt. Blackhills, 5-9" ppt. Bighorn Basin, 5-9" Wind River Basin, 7-9" ppt. Green River/Great Divide Basins, and two of the several 10-14" ppt. Foothills zones in western Wyoming.

An opportunity developed because of funding (approximately $20,000) from Wyoming Dept of Agriculture, the Governors Office, BLM, and USFS to augment the vegetation sampling sites with soil moisture monitoring equipment. These TDR based units (Campbell Scientific CR 616 probes with CS 200 data logger)are placed to measure water content in the top 1 ft., 2nd ft., and 3rd ft. of the soil profile. Data loggers record data daily. Data is downloaded and forwarded to the State Climatologist at 1-2week intervals. Cooperator production sites (18) were established including the following counties-cooperators, Albany- CES, CD, Converse-CES and USFS, Laramie-CES, ARS (HPGRS), Cambell-CES, Johnson-CES, Washakie-TNC, Sublette-CES,BLM, Sweetwater-BLM, Park-Meeteetse CD, Goshen Co-CES, Crook Co-CES, Natrona Co-BLM, Carbon Co-NRCS/CD AND BLM, Fremont- BLM, CES, CD, Hot Springs- CES. The site in Carbon County near Saratoga, maintained for 18 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 21 year set from HPGRS near Cheyenne and an 18 year set from BLM Casper area. Conservatively estimated in kind resources dedicated to the collection of soil moisture and productivity information on an annual basis are $12,000 for an indefinite period into the future.

Analysis of data of all sites and from the Saratoga site indicates, as has previous treatments of Saratoga 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 site/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 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 (Fig. 1) that produces the highest level of correlation between precipitation and summer forage yields. HPGRS data (Fig. 2) indicates an earlier starting, wider window, 23 March-21 June, extending into summer. Casper area data (Fig. 3) are less definitive but have a window of 5 March-25 May. Beginning of the predictive period appears to be related to elevation and associated temperatures.

The apparent differences between these sites include elevation and vegetation community composition. Elevations are Saratoga 7200 ft., Cheyenne 6100 ft., and Casper 5100 ft. The plant communities are all largely cool season species, however there is a larger C-4, warm season species, component at Cheyenne and Casper. We hypothesize that since elevations are influential to temperature and subsequently in how early the soil thaws in spring, plants start growth sooner at successively lower elevations. Since the relatively higher precipitation months continue into June, the window of influence is also wider at the lower elevation sites where warm season species occur. Snow may be wetter and melt faster at the lower elevations with warmer temperatures, reducing the snow blowing and sublimation that reduces the effectiveness of winter snow for plant growth.

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 with the limited data we had from the cooperator locations.

The validation models that survived five screening steps have relatively lower R^2 than the "best" models from individual sites and respond to relatively late season precipitation. Four were based on models of Cheyenne productivity while one was from Saratoga data. The "best" of these models has been demonstrated to be related to the observed data from sites within the state (Fig. 4). It was based on Cheyenne data and explained 52% of the variation in observed productivity. The validation models undoubtedly suffered from the high level of variation encountered in the sites across Wyoming.

Unfortunately, the validation model does not provide sufficiently early warning of impending drought conditions. In a drought environment most of the plant growth would have ended by the time precipitation needed for this model occurs. Although the "best" relationships from individual sites may not be as robust as the validation model, they provide notice of impending drought conditions sufficiently early that economically effective decisions can be

made regarding destocking, increased stocking, or finding alternative forages during an agricultural drought. In addition, assessing precipitation during the critical period for plant growth will permit discrimination of whether agricultural drought or hydrologic drought is the issue for the season.

Locally developed relationships between precipitation and herbage yields appear to be preferred to the statewide model based on the dates found to produce the "best" models and the relatively low R^2 of the statewide model. Additional sites have been added to the network of sites across Wyoming to determine annual herbage yields, bringing the number to 19 locations and soil moisture monitoring equipment at each location has been installed. Future assessment of data from these locations will permit each geographic area to have a locally effective predictor of herbage yields and opportunity to improve the state wide model will be apparent.

This research can be viewed as successful on several fronts. Relevant models of herbage yields based on antecedent precipitation predict herbage yields sufficiently early for economically effective decision making in Wyoming. Infrastructure for the development of locally relevant models is in place across much of the state. The project has been used to leverage the installation of soil moisture stations in the same locale as the herbage yield sites. The models developed to date have been used to develop statewide prediction maps for herbage yields in the upcoming growing season. These maps provide real time tools for BLM and rancher's planning of grazing strategies for the upcoming season.

Student Training:

A graduate assistant in Renewable Resources has conducted sampling and analysis duties. The student funded by this project will be graduating with an MS this year in December. Additionally five Renewable Resource undergraduate students have participated in field sampling.

Information Dissemination:

Smith, M. A., T. L. Thurow, and D. Legg. 2005. Predicting herbage standing crop on Wyoming rangeland from winter and spring precipitation. Abstracts 58th Annual Meeting Society for Range Management.

The Wyoming state map describing the predicted forage crop on rangeland was disseminated on the state climatologist's web page twice, early and late April 2005. Annually, at the end of April, this map will be published.

Cooperative Extension Service publications will be developed within the year to provide producers, land management agencies, and CES field staff results of this research. This document will be available on the CES publications web page and limited hard copies.

Results will be disseminated through the CES web site and county offices statewide. Other print and visual/audio media will also be used. The Wyoming State Climatologist will utilize model results to publish a map of projected forage yield categories.

A presentation showing interim results was made to the Priority and Selection Committee in 2002 and 2003. The committee includes a Wyoming Department of Agriculture representative. The final report will be made to this group in July 2005.
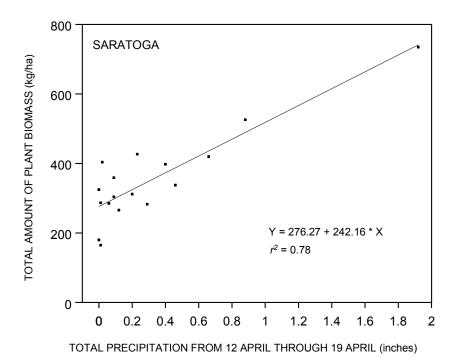
Figure 1. Relationship of precipitation to herbage yield at Saratoga, Wy.
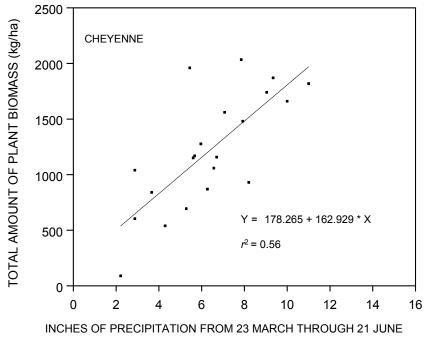

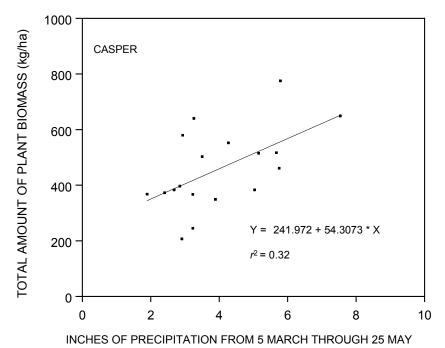Figure 2. Relationship of precipitation to herbage yield at Cheyenne, Wy.

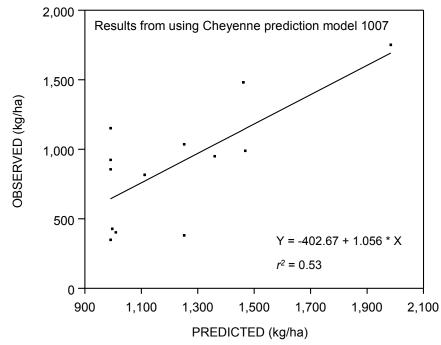Figure 3. Relationship of precipitation to herbage yield at Casper, Wy.

Figure 4. Statewide model prediction of herbage standing crop compared to yields at cooperator sites.

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:	2/29/2006
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Geochemical Processes, Groundwater, Surface Water
Descriptors:	
Principal Investigators:	Katta J Reddy, David E Legg, Richard A Olson

Publication

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 CBNG 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 and year 2 data collected from March 2003 to April 2004. The CBNG product water samples from discharge points and corresponding disposal ponds were collected during the summer months of 2003 and 2004. 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. Samples were also analyzed for abundance of macroinvertebrates and vegetation species. The results of year 1 and year 2 data show how quality of CBNG discharge and disposal pond waters change, predominantly salt concentration and SAR as a function of watershed physical and chemical characteristics. Macroinvertebrates were more abundant and have higher taxa richness in CHR, BFR, and LPR watersheds than in PR and TR watersheds. Similarly, there were more vegetation species encountered in and around ponds in CHR, BFR, and LPR watersheds than in PR and TR watersheds. 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 CBNG 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 CBNG 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 CBNG extraction in Wyoming. Commonly 2 to 10 CBNG 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 CBNG 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 CBNG 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 CBNG 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 CBNG 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 CBNG disposal ponds over time.

Objectives
The overall objectives of this research are to:
1.   Collect, analyze, and monitor pH, DO, EC, DOC, major cations (e.g., Ca, Mg, Na, and K), major anions (e.g., alkalinity, SO_4^{2-}, Cl^-, F^-, NO_3^-, and PO_4^{2-}), and trace elements (e.g., Al, As, Ba, B, Fe, Cd, Cu, Cr, Mn, Mo, Se, Pb, and Zn) from produced water samples at discharge points and disposal ponds over a period of 3 years (2003, 2004, 2005);
2.   Identify statistical differences of produced water test parameters between discharge points and associated ponds;
3.   Identify statistical differences of produced water test parameters between watersheds of a particular water type (wells and ponds);
4.   Predict geochemical changes (speciation, adsorption, and precipitation) for critical metals such as Fe, Ba, As, and Se in the disposal pond from produced water and associated disposal pond sediment;
5.   Identify trends in major cation, major anion, and trace element concentrations of produced water at discharge points and associated ponds;
6.   Compile a list of aquatic macroinvertebrate and wetland plant species associated with disposal ponds; and
7.   Transfer research results to user groups through project demonstrations, workshops, and local meetings.
This final report outlines research progress accomplished for year 1 and 2 from March 2003 to April 2005. 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
    <u>Site Selection.</u> We selected twenty-six sites within five Wyoming watersheds to obtain CBNG 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 (LPR) and Powder River (PR) watersheds. We sampled three sites from Cheyenne River (CHR) watershed and four sites from Belle Fourche River (BFR) watershed, and five sites from Tongue River (TR) watershed (Figure 1).

Sample Collection and Analysis. Before sample collection, a pilot study was conducted to determine sampling location within the CBNG pond waters. Chemical, plant, and aquatic macroinvertebrates were also examined to determine the sampling locations to obtain a representative sample. CBNG 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.

CBNG water samples from each discharge well and corresponding pond will be collected during the summer of 2003, 2004, and 2005. Collecting samples once a year during the same season may preclude any seasonal fluctuations in pond water quality parameters. Before sample collection, field measurements including pH, conductivity, temperature, ORP (oxidation and reduction potential), and dissolved oxygen will be taken in each well and pond Locations for pond measurements and field samples will be taken directly away from discharge well, and will be chosen upon pH stabilization at different distances from discharge point to avoid interference from the mixing zone. These measurements will be conducted using an Orion Model 1230 Multi-Probe. Duplicate water samples of wells and ponds will be taken from each site as well as 2 trip blanks (112 total water samples). Water samples will be analyzed for: Ca, Na, Mg, K, Fe, Al, Cr, Mn, Pb, Cu, Zn, As, Se, Mo, Cd, Ba and B by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), and SO_4^{2-}, Cl^-, F^-, NO_3^-, and PO_4^{2-} will be analyzed using Ion Chromatography (IC). In addition, these samples will be analyzed for dissolved organic carbon due to the appearance of organic matter in disposal ponds. Dissolved organic carbon will be analyzed using a Tekmar-Dohrmann 8000 Total Organic Carbon analyzer (TOC). The quality control/quality assurances protocols such as duplicate sampling and analysis, trip blanks, and known concentrations of reference standards will be included. Laboratory measurements of pH, electrical conductivity, alkalinity and total dissolved solids will be accomplished using standard laboratory procedures (APHA, 1992). Sodium adsorption ratios will be calculated from Ca, Na and Mg concentrations. All analyses will be performed following CFR 40, Part 1, Chapter 36 procedures (WYDEQ, 2001). In addition, water quality data will be modeled with MINTEQA2 (Brown and Allison, 1992), EPA water quality geochemical model to check data accuracy, predict ion activities, and calculate true SAR (SARt).

Disposal pond sediments will be collected during the summer of 2003, 2004, and 2005 using 4.5cm diameter PVC corer. Sample locations will be located directly away from discharge well and will be chosen upon pH stabilization at different distances from discharge point. Typically, sediment will be collected approximately 3 meters from discharge point and consists of a 20cm core. A sediment core will be taken from every pond, placed in a 1L polypropylene bottle, and then completely filled with pond water. Once at the lab, all samples will be frozen. Two samples from each watershed (10 total samples) will be separated into exchangeable, carbonate bound, Fe/Mn oxide bound, organically bound, and residual mineral fractions to determinate the fate of As, Ba, Fe, and Se. Each fraction will be dissolved in an appropriate solution and extracted. The extract will then be analyzed for As, Ba, Fe, and Se on ICP-MS as described by Tressier et al. (1979).

Since Wyoming and surrounding states do not have sampling protocols for macroinvertebrates in lentic systems, a minimal effort approach for sampling was selected. Four

macroinvertebrate samples (collected from the four cardinal directions) will be collected from the water column using a D-net with 1mm mesh and from sediment using an 8cm diameter core sampler. Water column samples will be combined as well as sediment samples to form a composite sample for the water column and sediment column for each pond. Samples will be taken from 2 ponds in each different watershed (20 total samples) and preserved in 95% ethanol. At the laboratory, samples will be sorted from vegetation and debris, and preserved in 75% ethanol (Merrit and Cummins, 1996). Aquatic macroinvertebrate samples will be sent to a certified laboratory specializing in analysis of aquatic macroinvertebrate communities (Aquatic Biology Associates, Inc) for identification to lowest taxonomic level. Laboratory data will include total taxa present and community richness. Vegetation identification will be performed on location for predominant wetland and aquatic plant species in and around ponds. Samples of unknown species will be collected and brought back to the lab for identification.

The primary questions of interest are to identify chemical differences between water types (discharge well vs. pond), between watersheds of a particular water type, and between years with watersheds of a particular water type. Due to a "natural pairing" of the discharge well and associated discharge pond, paired t-tests will be used to identify chemical differences between water types (discharge wells vs. associated ponds) with years as replications (3 years) (alpha = 0.05; SAS, 2000). One-way ANOVAs will be used to identify element differences between watersheds of a particular water type. Tukey mean separation test will be performed if there are significant differences between watersheds to further identify these differences (alpha = 0.05; SAS, 2000). Randomized Complete Block Design Factorial Analysis will be conducted to identify element differences between years within watersheds of a particular water type. Again, a Tukey mean separation test will be performed if there are significant differences between years or watersheds (alpha = 0.05; SAS 2000). A trend analysis will be conducted to identify any changes in element concentrations over 3 year time period for the five watersheds (alpha = 0.05; SPSS, 2001). Results from sediment fractionation will be used in One-way ANOVAs to determine differences between specific element fractions (exchangeable, carbonate bound, Fe/Mn oxide bound, organic matter bound, and residual of As, Se, Ba, and Fe) of an individual watershed. Tukey mean separation test will be performed if there are significant differences between watersheds to further identify these differences (alpha = 0.05; SAS, 2000).

Task Completion List.
2003 Sample Season
- Water chemistry completed for all samples (anions, cations, trace metals, DOC)
- MinteqA2 modeling completed
- Statistical analysis completed for year 1 data (T-tests, ANOVAs)
- Compiled CBNG water quality data and contacted landowners of results
- Aquatic macroinvertebrate samples analyzed
- Vegetation species list completed

2004 Sample Season
- Water chemistry completed for all samples (anions, cations, trace metals, DOC)
- MinteqA2 modeling completed
- Statistical analysis completed for year 2 data (T-tests, ANOVAs)
- Preparing to send CBNG water quality results to participating landowners
- Aquatic macroinvertebrate samples sorted and sent to laboratory
- Vegetation species list near completion
- Sediment fractionation analysis for year 1 and 2 in progress

Results

Chemical results comparing year 1 to year 2 are presented in figures 2, 3 and 4. All error bars represent standard mean error for individual watershed data. Discharge well water pH did not vary much between watersheds and years, but discharge pond pH are higher than associated discharge wells. Alkalinity for both discharge wells and ponds tend to increase as we move geographically from CHR up to PR then slightly decrease at TR. Sodium Adsorption Ratio for both discharge wells and ponds tend to increase as we move geographically from CHR up to TR. Discharge well water SAR tends to increase from year 1 to 2 across watersheds, but this trend does not continue to the ponds. Discharge pond SAR follow a similar pattern as the discharge well SAR except for a substantial decrease at TR discharge pond from year 1 to year 2. This decrease may be due to sulfur burner water amendment process, an acidification process that is commonly done in this area to reduce discharge water SAR for irrigation. Calcium and magnesium vary between watershed and years with calcium decreasing from discharge wells to associated ponds and magnesium not varying much between discharge wells and associated ponds. Sodium is a major cation in both discharge wells and ponds in all watersheds and appears to increase from year 1 to year 2 in LPR, PR, and TR discharge ponds. Trace metals iron, arsenic, and selenium tend to increase from year 1 to year 2 and from discharge wells to associated discharge ponds. Figure 5 identifies year 1 macroinvertebrate data. The CHR, BFR, and LPR watersheds have a much higher percentage of non-insects caught and larger overall abundance of aquatic organisms than the PR and TR watersheds. Collector-gatherers and predators are the most represented functional feeding groups in all watersheds. Table 1 identifies vegetation encountered in and around discharge ponds across all five watersheds. More vegetation species were observed in and around CHR, BFR, and LPR discharge ponds than in PR and TR discharge ponds. This may be a function of pond age.

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, CBNG Industry, WY Landowners and Citizens, NRCS personnel, Conservation Districts personnel, WY Cooperative Extension Agency, USGS, EPA, Colorado, Montana. Landowners were informed of individual well/pond water quality on their property. Year 2 water quality data will be mailed to individual landowners before year 3 sampling.

Publications

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.

Jackson, R.E., and K.J. Reddy. 2004. Water quality of major rivers in reference to CBM product water discharge in the Powder River Basin, Wyoming. Journal of American Water Resources Association. (in preparation)

Presentations

1. Wyoming Water Development Commission Annual Meetings, November 30th 2004, Cheyenne, Wyoming.

2. 1st Annual Coalbed Natural Gas Research, Monitoring, and Applications Conference. Aug 17-19, 2004. Laramie, Wyoming.
3. University of Wyoming 2003 Graduate Student Symposium March 2nd, 2004, Laramie, Wyoming. This presentation won Best Project Presentation Award.
4. USDA-CSREES National Water Quality Conference: Integrating Research, Extension and Education scheduled January 11-14, 2004 in Clearwater, Florida.
5. Wyoming Water Development Commission Annual Meetings, December 4th, 2003, Cheyenne, Wyoming.
6. Rangeland National Annual Meetings, Water Quality Division, scheduled January 24-30, 2004 in Salt Lake City, Utah.
7. American Society of Agronomy (Soil and Water Ecology Section) Meetings, Denver, Colorado. November 5, 2003
8. Wyoming Department of Environmental Quality Meeting, Cheyenne, Wyoming. August 21, 2003.
9. EPA-USGS Meeting for Tongue River and Powder River Long-term Monitoring Network. Sheridan, Wyoming. June 5, 2003
10. Missouri River Basin Natural Resources Meeting, Benedictine, Kansas. June 2-4, 2003 (invited).
11. American Society of Surface Mining and Reclamation Symposium, Billings, Montana. June 5-6, 2003.
12. Wyoming Water Development Commission, River Basin Meeting, Kaycee, Wyoming. June 16, 2003.
13. Wyoming Department of Environmental Quality (Water Quality Division) Meeting, Cheyenne, Wyoming. May 10, 2003. This meeting included representatives from U.S. EPA Region VIII, BLM, CBM Industry, Colorado State University.

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DeBruin, R.H., R.M. Lyman, R.W. Jones, and L.W. Cook. 2000. Coalbed methane development in Wyoming. Information Pamphlet number 7. Wyoming State Geological Survey, Laramie, WY.
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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 .
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Merritt, R.W. and K.W. Cummins. 1996. An introduction to the aquatic insects of North America 3rd edition. Kendall/Hunt, Dubuque, Iowa.
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.
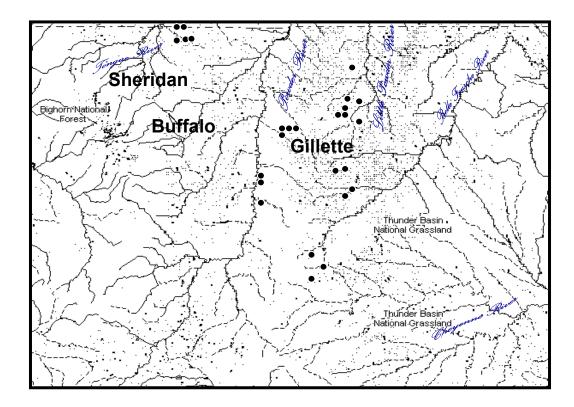
Figure 1. Map of study sites in the Powder River Basin, Wyoming (not to scale).
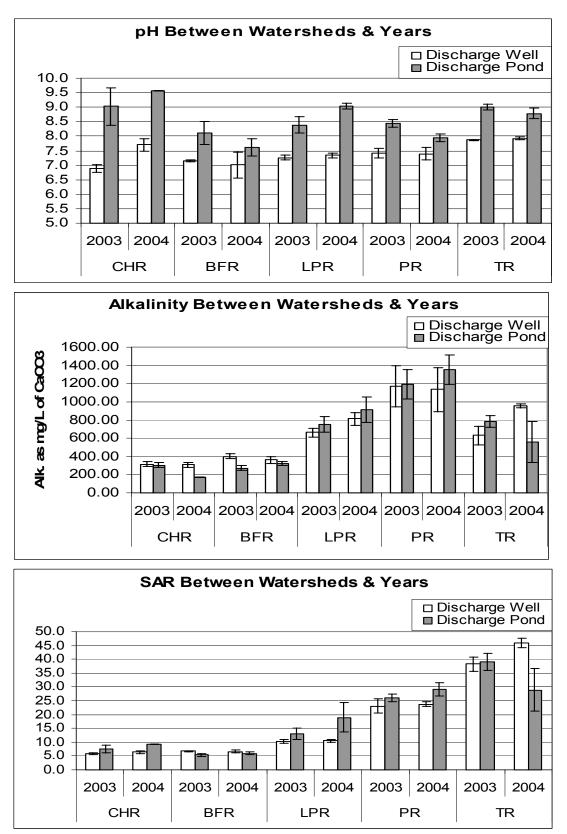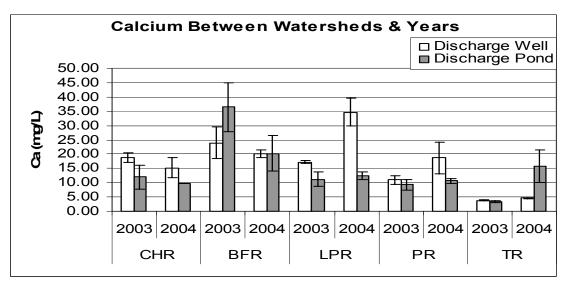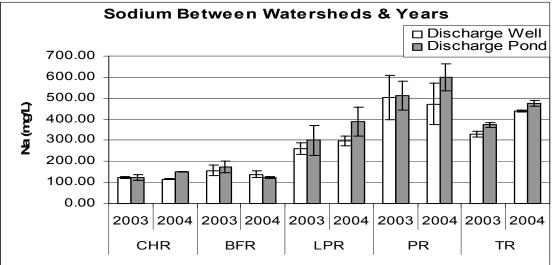
Figure 2. CBNG discharge well and disposal pond water pH (top), Alkalinity (middle), and SAR (bottom) between two sample years as a function of watershed.
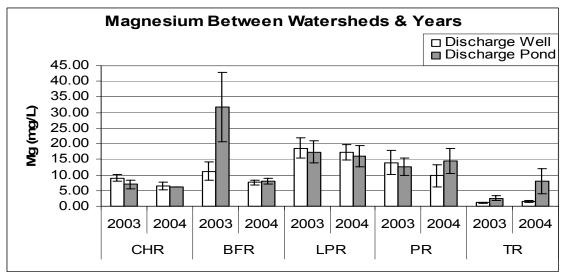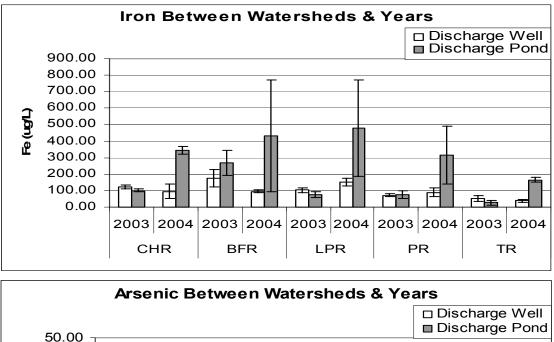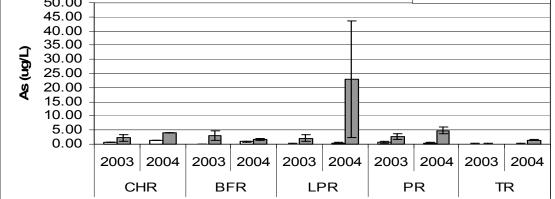
Figure 3. CBNG discharge well and disposal pond water Ca (top), Mg (middle), and Na (bottom) between two sample years as a function of watershed.
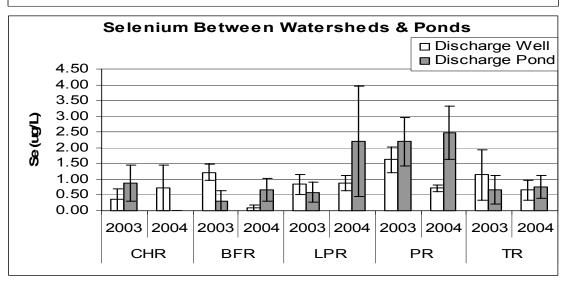
Figure 4. CBNG discharge well and disposal pond water Fe (top), As (middle), and Se (bottom) between two sample years as a function of watershed.

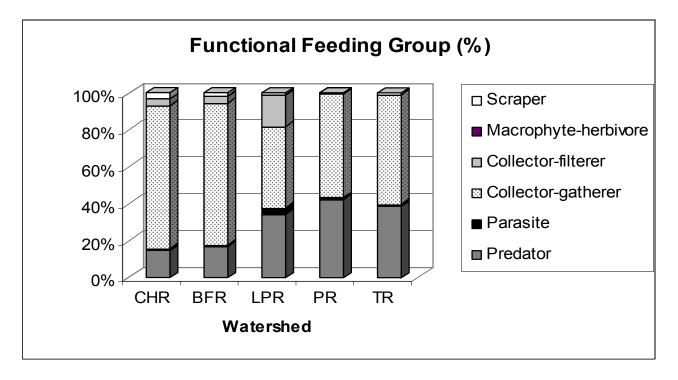| Basin	CHR	CHR	BFR	BFR	LPR	LPR	PR	PR	TR	TR
% Non insects	15.9	59.5	68.9	68.2	43.6	43.6	1.5	12.2	0	1.9
% *Ephemeroptera*	6.8	3.6	9.7	3.5	9.7	4.7	30.8	7.5	0	0
% *Trichoptera*	0	0	0.3	0	0	0	0	0	3.3	0
% *Coleoptera*	0	0.5	2.6	0.7	3.4	0.5	6	3.2	10	9.3
% *Diptera* (non-midge)	0	0.1	0.3	0	0.2	16.3	0	0	0	0
% *Diptera-Chironomidae*	4.8	23.2	1.3	14.6	7.1	2.2	16.5	11.2	6.7	13
Total abundance (m2)	63	390	96	106	149	295	33	47	8	14
Total number of taxa	15	29	19	24	20	30	11	20	7	10
Hilsenhoff Biotic Index (modified)	8.08	7.74	8.03	8.17	7.91	7.77	8.1	8.18	7.71	8.02

Figure 5. Percent insect taxa, abundance, and HBI (top table) for individual discharge ponds in 2003 and percent functional feeding group per watershed (bottom graph) for 2003.

Table 1. Vegetation commonly encountered in and around CBNG discharge ponds in all watersheds.

Grasses	*Hordeum jubatum*
	Pascopyrum smithii
	Distichlis spicata
	Elytrigia intermedia
	Bromus japanicus
	Bromus tectorum
Grass-Like	*Juncus balticus*
	Scirpus meridimus
	Scipus americanus
	Carex parryana
Macrophytes	
	Polygonium amphibium
	Potomogeton pectanatus
Forbs	*Rupia maritima*
	Solanum rostratum
	Kochia scoparia
	Euphorbia humistata
	Astraglas bisulcatus
	Melilotus officinalis
	Cirsium arvense
	Cleome serrulata
	Grindelia squarrosa
	Xanthium strunarium

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:	2/29/2006
Funding Source:	104B
Congressional District:	1
Research Category:	Engineering
Focus Category:	Agriculture, Management and Planning, Non Point Pollution
Descriptors:	
Principal Investigators:	Drew W Johnson, George Floyd Vance, Renduo Zhang

Publication

1. Hao, X. and R. Zhang. 2004. A hybrid mass-conservative scheme for simulating variably saturated flow in soils with large outflow flux. Proceedings of Computational Methods in Water Resources 2004 Conference. UNC-Chapel Hill, North Carolina.
2. Hao, X., R. Zhang, and A. Kravchenko. 2005. Effects of Root Density Distribution Models on Root Water Uptake and Water Flow under Irrigation. Soil Science,170:167-174.
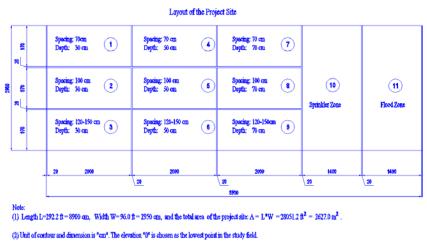
Abstract:

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:

The research site is at the University of Wyoming's College of Agriculture Research and Extension Center located in Albany County. Use of this research site has proven to be beneficial to the study. Its location is convenient for frequent site visits and extension personnel are able to assist us with site preparation and operation. All necessary drip irrigation equipment was installed in the spring and summer of 2004. Installation was a time consuming process as drip irrigation tape pulling (shanking) equipment could not be used because it is difficult to ensure proper drip line burial depth with this type of installation. All drip lines were trenched to proper depth. Shown in Figure 1 is the subsurface drip irrigation (SDI) system design and dimensions of the field site. Nine SDI zones were installed with variable burial depth and spacing. Irrigation tape was place at burial depths 30 cm, 50 cm and 70cm. The shallowest depth is being used in this study to see if soil surface saturation and seed germination are possible when only using SDI technology. Deeper installation depths are more representative of a typical application and may provide greater water use efficiencies. However, the deeper design must be augmented with some surface irrigation to achieve seed germination. Shown in Figure 2 are the valves and computer controls for the research site and also open trenches where dip lines were installed. Due to installation delays, the site was not ready for seeding until the end of the summer and shown in Figure 3 is the site being planted with alfalfa for the 2005 growing season. The site is operational and field measurements will begin in 2005. In addition to field equipment installation, permeability spatial variability measurements were made at the site this last year with results shown in Figure 4. These measurements will be used when modeling water distributions and when relating system design to site productivity values. We have carried out some initial modeling related to subsurface irrigation. These numerical experiments were conducted to study the special boundary conditions charactering the dripper and soil relationship. We also have improved the irrigation simulation model for a better mass balance. (Hao and Zhang, 2004, 2005).

The project study site is ready for applications of both surface and subsurface irrigation starting in the spring. Based on information obtained during next year's growing season, we expect that our results will be useful in understanding the relationship between SDI row spacing and emitter distance on the SDI tape to that of alfalfa production, water use, and potential SDI applications in Wyoming. As an added benefit, we envision our results will be useful as a comparison to current agricultural practices that have low water use efficiencies. Data obtained from next year's field, laboratory and modeling efforts will be used for a future grant application (*e.g.*, USDA, WSARE, Department of Agriculture, etc.) to enhance and continue our SDI research for Alfalfa production in Wyoming.

Figure 1 – Research site dimensions and SDI design.

Figure 2 – Computer and valve controls for the SDI research site and open trenches for SDI lines.

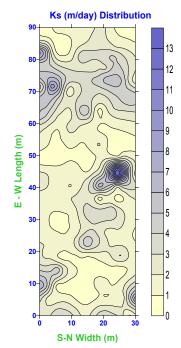Figure 3 - Seeding the site with alfalfa.

Figure 4–Spatial variability of permeability at the research site.

Student Training:

Two graduate students were supported with project funding this past year. One student was responsible for experimental design and equipment installation and both students assisted with site permeability measurements and modeling work. These students are receiving training related to water resources engineering through academic course work, research project activities and opportunities to interact with irrigators. Three undergraduate students assisted with site permeability measurements and irrigation equipment installation.

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

Meetings/Presentations/Publications:

Hao, X. and R. Zhang. 2004. A hybrid mass-conservative scheme for simulating variably saturated flow in soils with large outflow flux. Proceedings of *Computational Methods in Water Resources 2004 Conference*. UNC-Chapel Hill, North Carolina.

Hao, X., R. Zhang, and A. Kravchenko. 2005. Effects of Root Density Distribution Models on Root Water Uptake and Water Flow under Irrigation. *Soil Science*,170:167-174.

Hao, X., and R. Zhang, 2005. A Mass-Conservative Switching Method for Simulating Water Flow in Saturated-Unsaturated Soils. J. Hydrology (in press).

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:	2/28/2006
Funding Source:	104B
Congressional District:	1
Research Category:	Social Sciences
Focus Category:	Economics, Water Quantity, None
Descriptors:	
Principal Investigators:	Edward B Barbier

Publication

1. Chaudhry, A. 2005. Water, Public Capital and Growth in Municipalities 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 opportunities 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 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 and fodder) and municipal and industrial users (for production). 2) Identification of possible future trade-offs and conflicts over water use by these two key production sectors in Wyoming. 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 has been 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 this study has focused on analyzing water-growth relationships in Wyoming for two distinct, and potentially competing, uses: irrigated agriculture, and other productive water uses (municipal and industrial).

The modeling has been 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 publicly provided 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 this project's research has been to modify the water-growth model and apply it to two principal production sectors in the state of Wyoming.

The analysis has involved 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) for the irrigated agriculture and the municipal & industrial sectors. 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).

When fully completed, 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.

Both empirical studies will be completed in Fall 2005.

Methodology and Anticipated Results:

Analyzing water-growth relationships for the two main categories of sectoral use, irrigated agriculture and municipal & 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. Details of this model for water use in irrigated agriculture are summarized in Barbier and Chaudhry (2004). The work of applying this model to empirical data across Wyoming is likely to be completed in Summer 2005.

Analyzing municipal and industrial use involved combining the modeling approach developed in Barbier (2004) with a model of public capital and economic growth by Shioji (2001) and Barro (1990). 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 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 in Wyoming where potential conflicts and tradeoffs between the two water-using sectors may occur in the future.
- 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, was 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 was 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 (2004) model could be readily adapted to analyze water-growth relationships for producers in the municipal & industrial use sector but not for irrigated agriculture. The main effort in 2003 therefore to develop 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.

Another major focus in the first year of the project was to identify useful contacts in the State and Federal agencies concerned with water use in Wyoming, and to identify and collect the

appropriate hydrological, demographic and economic data necessary for the project. The following summarizes our efforts in 2003:

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.

Summary of Progress FY 2004:

We finished developing an economic model of water use in the agricultural economy of Wyoming, taking into account that irrigated water is a privately provided good. A paper summarizing this model was presented at a major international conference (Barbier and Chaudhry 2004). This model links relative water demand i.e. water withdrawal vs. water availability at a farm level to economic growth. One of the main results of the analytical model is that under conditions of moderate or mild water scarcity i.e. when water use is less than water availability, farm income will be positively related to water use. Under conditions of extreme water scarcity, when water use is reaching the limit of water availability we can expect to see

decline in farm income. Our model shows that farm water availability is an important determinant of long run welfare of the agricultural sector.

A separate analytical model was developed for the case of water use in municipal uses. As mentioned earlier, water in municipal uses has been modeled as a publicly provided good as in Barbier (2004) and Barro (1990). A result that emerges from this study is that water use relative to water availability as well the level of water-related public capital owned by the municipality have long run effects on economic growth of the municipal sector. We are currently involved in finalizing the results of the analytical model for the municipal water use.

A major focus of this study is to test the hypotheses derived from the analytical models in Wyoming. To this end, the first step is to construct an index of relative water scarcity for Wyoming counties. As stated in Barbier (2004), the ratio of water withdrawal, r, to water availability, w, can be effectively used as a measure of relative water scarcity. USGS uses this index to measure water scarcity at a basin wide level in the US but these data are not available at the county level. County level information is important because all economic and demographic data are available at county or state level. One of the aims of the project FY 2004 has been to construct this data for Wyoming counties. Discussions were held with WWDC staff in Cheyenne as well experts in Laramie. A brief description of methodology used is given below.

Jacob and Brosz (2000) have provided data for unappropriated waters available for future consumptive use in Wyoming. These data are given for each river basin in Wyoming and they give us an idea about how much water is still available that could potentially be used in the future. These data capture the legal water availability of water within each basin by incorporating the interstate compacts and statues that govern water use in Wyoming and neighboring states. Water may be naturally available in the State but if interstate compacts award its use to another State, the effective limit to water use is in fact the legal right to water (Jacob *et. al*. 2003). Apportioning these basin-wide figures into counties contained in these basins would give us an idea how much each county can expect to expand its water use in future.

As mentioned earlier, the USGS measures water withdrawals and consumptive use for each county in Wyoming for the years 1985, 1990, 1995 and 2000. If water is being consumed in county it must be the case that it is legally available for use in that county. Summing consumptive water use and the unappropriated waters available for each county would provide legally available water supplies in that county.[1] Unfortunately, consumptive use information is not given for surface and groundwater separately. Hence the next best strategy is to use surface water withdrawals instead. Adding surface water withdrawal to the unappropriated waters available for use gives us a measure of the total water supplies, albeit a rough one. Using the data for water withdrawal and total water available we have computed r/w i.e. total surface water withdrawal/(total surface water withdrawal + unappropriated water available for future use).

People Contacted
- Barry B. Lawrence, Jon Wade, John Jackson, Wyoming Water Development Commission
- Larry Otto Pochop, Office of Water Programs, University if Wyoming
- Garry Watts, Consultant

As the final step of the analysis we are using the above data to econometrically estimate the impact of water scarcity on agricultural and municipal & industrial sectors in Wyoming. The relative water demand index combined with the economic and demographic data from the BEA and US Bureau of Census will help us not only test the hypotheses proposed by the analytical

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[1] This is a very strong assumption since a large part of water withdrawn is returned to the water system via return flows. Hence, adding water withdrawn to the B1 may overestimate the legal availability of water in a county.

models but also identify which sectors and counties are currently facing downward pressures on economic growth due to water scarcity. The results of these empirical estimates are likely to be available in Fall 2005.

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." 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. 2005. "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

Jacobs, James, Patrick Tyrell and Donald Brosz, 2003 "Wyoming Water Law: A Summary" University of Wyoming Agricultural Experiment Station

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:	Climate and Hydrologic Processes
Focus Category:	Agriculture, Hydrology, Irrigation
Descriptors:	
Principal Investigators:	Drew W Johnson, Greg Kerr

Publication

1. Kunz, W., 2005. Return Flows, Re-Diversion, and Losses Associated With the Bear River In Wyoming and Utah, M.S. Thesis, Department of Civil Engineering, University of Wyoming, Laramie WY.

Abstract:

The Bear River is the longest river in the United States without an ocean outlet. It originates in the Uinta Mountains of Utah and flows north to Wyoming, Idaho, and back to Utah and releases its water into the Great Salt Lake. With the extreme drought experienced in the late 90's and early part of the new millennium, the accuracy to which water is allocated has become increasingly important. The Bear River is a vital lifeline to farmers, ranchers, industry and municipalities in Utah, Wyoming, and Idaho; therefore, knowledge of its water losses, gains and general fluctuations are of vital importance. The Bear River between Woodruff Narrows reservoir and Pixley diversion dam is a reach with 17 irrigation diversions that cause enormous amounts of return flow in the system. This study examines many factors that may be of interest to the irrigators in the Bear River region. Not only are estimates for conveyance loss being developed, but so are approximations of gains, seasonal losses, and re-diversion proportions. Also included in the study are estimates of travel time and return flow timing to aid irrigators in approximating the time that water may become available to them. Preliminary results indicate that conveyance losses are approximately 1% per mile, while system loss averages to be 41% of inflow. The analysis also shows gains to be 62% of diverted flow with diverted flow being approximately 111% of inflow to the system. Channel travel time is approximately 5 days from Woodruff Narrows Reservoir to Pixley dam.

Current Project Status:

Four additional gages have been installed along the Bear River and data was collected for the 2004 irrigation season. One of these gages is shown in Figure 1 below. By installing additional gages, shorter reaches were created and estimates of conveyance losses were developed for each reach.

Figure 1 – Newly installed gaging station on the Bear River

Ongoing work is directed towards refining our calculations. Flow data will be collected for the 2005 irrigation season and analyzed for conveyance losses and compared to the preliminary results obtained for the 2004 irrigation season. Also, estimates for return flows are currently limited to the entire reach, with the new gages, better estimates about where return flows occur may be

obtained by repeating the analysis over the shorter reaches and for smaller time increments (monthly as opposed to annual values). This change in time scale may lead to better estimates of return flow timing within the shorter reaches. Finally, a GIS based model to delineate return flow paths is being developed as part of this study. This model along with the installation of real time telemetry on the newly installed gages may result in a real-time model for water usage in the study area. The Bureau of Reclamation office in Provo Utah is assisting us with telemetry installations.

The project is on track in both research objectives and training potential. Two graduate students were supported with project funding. One completed his MS degree this spring. Students on the project are receiving training related to water resources engineering through academic course work, research project activities and opportunities to interact with State agency personnel and irrigators.

Student Support
William Kunz, MS Civil Engineering, University of Wyoming
Trenton Franz, MS Civil Engineering, University of Wyoming

Meetings/Presentations/Publications
Kunz, W. (2005), Return Flows, Re-Diversion, and Losses Associated With the Bear River In Wyoming and Utah, M.S. Thesis, Department of Civil Engineering, University of Wyoming, Laramie WY.
"Re-diversion Proportions on the Bear River", Bear River Advisory Group, Cokeville Wyoming, October 2004.
"Bear Lake Eco Symposium and Annual Meeting of Bear River affiliates" September 2004
"Conveyance Losses on the Bear River" Wyoming State Engineers office, Utah State Engineers Office, Cokeville Wyoming, January 2004.
"Conveyance Losses on the Bear River", Bear River Advisory Group, Kemmer Wyoming, July 2003.

Information Transfer Program

No formal information dissemination projects were supported by FY04 funding through this program. However, on an annual basis, information dissemination efforts include reports by the Director to State entities, and publications and other information dissemination efforts by the PIs of the projects funded under this program. The Director reports annually to the Wyoming Water Development Commission and to the Select Water Committee (of the Wyoming Legislature). The Director also serves as the University of Wyoming Advisor to the Wyoming Water Development Commission and attends their monthly meetings. This provides a means of coordinating between University researchers and Agency personnel. The project PIs report to the Institutes Advisory Committee on an annual basis. Presentations discussing final results are made by PIs of projects which were completed during the year at the Committees July meeting. Presentations discussing interim results are made by PIs of continuing projects at the Committees winter meeting. All PIs are encouraged to publish in peer reviewed journals as well as participate in state-wide water related meetings and conferences. A number of PIs, of projects previously completed, reported at the Basin Advisory Group meetings which are part of the State funded and supported water planning process. Publications are listed elsewhere in this report. Additional information dissemination activities reported by PIs of FY04 funded projects include the following.

Project: Drought Prediction Model Development and Dissemination in Wyoming The Wyoming state map describing the predicted forage crop on rangeland was disseminated on the state climatologists web page twice, early and late April 2005. Annually at the end of April this map will be published.

Project: Geochemistry of Coalbed Natural Gas Produced Water Across Five Wyoming Watersheds 1st Annual Coalbed Natural Gas Research, Monitoring, and Applications Conference. Aug 17-19, 2004. Laramie, Wyoming. University of Wyoming 2003 Graduate Student Symposium March 2nd, 2004, Laramie, Wyoming. This presentation won Best Project Presentation Award. USDA-CSREES National Water Quality Conference: Integrating Research, Extension and Education scheduled January 11-14, 2004 in Clearwater, Florida. Wyoming Water Development Commission Annual Meetings, December 4th, 2003, Cheyenne, Wyoming. Rangeland National Annual Meetings, Water Quality Division, scheduled January 24-30, 2004 in Salt Lake City, Utah. American Society of Agronomy (Soil and Water Ecology Section) Meetings, Denver, Colorado. November 5, 2003. Wyoming Department of Environmental Quality Meeting, Cheyenne, Wyoming. August 21, 2003. EPA-USGS Meeting for Tongue River and Powder River Long-term Monitoring Network. Sheridan, Wyoming. June 5, 2003. Missouri River Basin Natural Resources Meeting, Benedictine, Kansas. June 2-4, 2003 (invited).

Project: Water Scarcity and Economic Growth in Wyoming Barbier, E.B. and A. Chaudhry. 2004. Water and Growth in an Agricultural Economy. 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. 2005. Water, Public Capital and Growth in Municipalities and Industries. Mimeo. Department of Economics and Finance, University of Wyoming.

Project: Conveyance Losses and Travel Times of Reservoir Releases Along the Bear River from Woodruff Narrows Reservoir to Cokeville Wyoming Re-diversion Proportions on the Bear River, Bear River Advisory Group, Cokeville Wyoming, October 2004. Bear Lake Eco Symposium and Annual Meeting of Bear River affiliates September 2004 Conveyance Losses on the Bear River Wyoming State Engineers office, Utah State Engineers Office, Cokeville Wyoming, January 2004. Conveyance Losses on the Bear River, Bear River Advisory Group, Kemmer Wyoming, July 2003.

Project: Combining Modern and Paleo-Climate Data to Enhance Drought Prediction and Response (Project completed Feb 03). Jackson, S.T. 2004. Droughts, megadroughts, and gigadroughts: a long view of drought risk from paleoclimatology. Invited presentation, Wyoming Water Forum, Cheyenne. 2 March 2004. Jackson, S.T., 2004. Ecological dynamics: Environmental change, individualistic response, and community consequence. Invited presentation, The Dynamic Structure of Life. Inaugural Symposium for Professor Rob Hengeveld. Institute of Ecological Science, Vrije Universiteit, Amsterdam, Netherlands. 1 April 2004. Jackson, S.T., 2003. Climate extremes and episodic invasions: Is ecology catastrophic, or merely dynamic?. Invited presentation, Long-Term Ecological Research Network workshop on Disturbance, Legacy and Disequilibrium: The Way the World Works. Sevilleta, New Mexico, 29 May 2003. Jackson, S.T., 2003. Climate variability and biological invasions: a long view. Invited presentation, University of Wyoming Conference on Bioinvasions. Laramie, Wyoming, 9 June 2003. Jackson, S.T., J.L. Betancourt, S.T. Gray, M.E. Lyford & J. Norris. 2004. Late Quaternary vegetational and climatic change in the Bighorn Basin. Symposium on Rockshelter Research in the Bighorn Mountains, 62nd Annual Plains Anthropological Conference, Billings, Montana, October.

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	13	0	0	0	13
Masters	5	0	0	0	5
Ph.D.	4	0	0	0	4
Post-Doc.	0	0	0	0	0
Total	22	0	0	0	22

Notable Awards and Achievements

Rich Jackson (PhD candidate) received the 2004 AMERICAN WATER RESOURCES ASSOCIATION JAMES B. WARNER SCHOLARSHIP. Rich Jackson is a graduate student supported in the project Geochemistry of CBM Retention Ponds Across the Powder River Basin, Wyoming with K.J. Reddy, R.A. Olson, and D.E. Legg as PIs.

Rich Jackson (PhD candidate) received the 2004 BEST GRADUATE STUDENT PAPER AWARD from the Graduate School, University of Wyoming. Rich Jackson is a graduate student supported in the project Geochemistry of CBM Retention Ponds Across the Powder River Basin, Wyoming with K.J. Reddy, R.A. Olson, and D.E. Legg as PIs.

Publications from Prior Projects

1. 2002WY4B ("Combining modern and paleo-climate data to enhance drought prediction and response") - Articles in Refereed Scientific Journals - Gray, S.T., C.L. Fastie, S.T. Jackson, and J.L. Betancourt, 2004. Tree-Ring-Based Reconstruction of Precipitation in the Bighorn Basin, Wyoming, Journal of Climate, American Meteorological Society, Vol. 17, October, pgs 3855-3865.
2. 2002WY4B ("Combining modern and paleo-climate data to enhance drought prediction and response") - Other Publications - Gray, S.T., L.J. Graumlich, J.L. Betancourt, and G.D. Pederson, 2004. A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D. Geophysical Research Letters, 31:L12205, doi:10.1029/2004GL019932.
3. 2002WY4B ("Combining modern and paleo-climate data to enhance drought prediction and response") - Other Publications - Gray, S.T., 2004. Long-term perspectives on Wyoming drought: lessons from the tree-ring record. Pp. 97-101, in J. Curtis and K. Grimes, eds. Wyoming Climate Atlas.
4. 2001WY2021B ("Field Evaluation of the Fate of Wastewater Components from Septic Systems") - Articles in Refereed Scientific Journals - Bedessem, Marjorie E., Thomas V. Edgar, and Robert Roll, 2005. Nitrogen Removal in Laboratory Model Leachfields with Organic-Rich Layers, J. Environmental Quality, 34: 936-942.

5. 2002WY5B ("The Wyoming Climate Atlas") - Other Publications - Curtis, Jan, 2005. Home weather stations. On-line addition to Wyoming Climate Atlas, http://www.wrds.uwyo.edu/wrds/wsc/climateatlas/homeweatherstation.html.
6. 2002WY3B ("Product accessibility and dissemination for the Water Research Program at the University of Wyoming") - Other Publications - Lesmeister, Crystal K., 2004. Assessment of the Catch-Can Test for Measuring Lawn Sprinkler Application Rates, M.S. Thesis, Department of Civil & Architectural Engr., Dec.