

Colorado Water Resources Research Institute

Annual Technical Report

FY 2000

Introduction

As water managers work to solve the integrated water problems facing Colorado today, the dimensions of each issue demand a better understanding of basic water science, technology and policy. Whether water managers work in water supply, flood control, water quality protection or environmental enhancement, they face increasingly integrated issues that transcend traditional scientific and institutional boundaries. Population growth in the arid West has brought with it an increasing demand for traditional consumptive uses -- irrigation, municipal water supply, and power generation and the newer demands of restoration of endangered species, water quality protection, and water-based recreational opportunities.

To better support Colorado's changing water education, information and research needs, and to better coordinate the outreach efforts of the Agricultural Experiment Station, Cooperative Extension, and the CSU Forest Service, the CSU Water Center was formed in the mid-1990s. In 1999 the Water Centers Board of Directors authorized the merger of the Water Center and the Colorado Water Resources Research Institute (CWRRI). The merger provides better cooperation among the agencies and the CSU Water Center/CWRRI and supports the future water research, education and outreach efforts of all. The merger also resulted in the appointment of a Water Quality Specialist who is housed in the CWRRI/CSU Water Center offices (see CWRRI/CSU Water Center Activities and Accomplishments).

CWRRI Activities and Accomplishments

Water Quality Specialist Assigned to CWRRI/CSU Water Center -- CSU Cooperative Extension and the CSU Agricultural Experiment Station undertook a year-long strategic planning exercise to better focus CSU's water programs. A group of water leaders from around the state and an internal committee of CSU faculty conducted an in-depth evaluation of current strengths and weaknesses, water education needs, and major trends affecting water outreach needs in Colorado. One need identified to enhance CSU water outreach efforts was a tighter linkage of the water programs of Cooperative Extension, the CSU Water Center, and the Agricultural Experiment Station. To improve this linkage, Reagan Waskom has been named an Extension water resources specialist. Reagan received a B.S. in Agronomy from Texas A&M University in 1981, a M.S. in Crop Science from Texas A&M University in 1985, and a Ph.D. in Soil Science from Colorado State University in 1997. As Extension Water Resources Specialist, he is responsible for conducting statewide educational and applied research programs on water quality, water quantity, water policy, and natural resource issues related to water use. Reagan is located in the CWRRI/CSU Water Center offices.

USDA/CSREES Grant Awarded Through CSU Water Center -- In FY2000, the Cooperative State Research, Education, and Extension Service (CSREES), under its Higher Education Programs Food and Agricultural Sciences National Needs Graduate Fellowships in Water Science Program, awarded a \$207,000 grant to Jim Loftis, Professor of Civil Engineering, CSU, and Jessica Davis, Professor of Soil and Crop Sciences at CSU. The award provides three fellowships to conduct research on water management issues of critical importance to agriculture in the Western U.S. The award was the result of the cooperative efforts of the CSU Water Center, the Department of Civil Engineering, and the Soil

and Crop Sciences Department. The fellowships are administered by the CSU Water Center.

CSM Receives Doctoral Fellowships for Hydrogeology Research -- Colorado School of Mines (CSM) was awarded six doctoral fellowships from the Graduate Assistantships in Areas of National Need (GAANN) program of the U.S. Department of Education. The fellowships will be awarded to Ph.D students conducting research in the general area of computational contaminant transport processes. The principal investigator is Dr. John McCray, Department of Geology and Geological Engineering, Colorado School of Mines.

Annual Water Resources Seminar Organized -- This one-credit seminar (GS592) is held every Fall semester and is open to all interested faculty, students and off-campus water professionals. The Fall 2000 seminar focused on Allocating Colorado's Liquid Gold: Meeting the Needs of the New West.

Additional CWRRI Activities Involving Local, State and Federal Agencies and Other Organizations:

The CWRRI/CSU Water Center Director has contributed to the following activities involving water in Colorado:

helped organize the Colorado Watershed Assembly, an umbrella organization for watershed groups across the state;

participates in the Larimer-Weld Water Issues Group and serves on the City of Fort Collins Water Board;

is a member of the National Water Quality Monitoring Council and the Colorado Water Quality Monitoring Council;

serves on the Bureau of Reclamations Research Steering Committee; and

supports and participates in activities of the Colorado Water Congress, a state-wide organization of water users and managers.

In addition, a CWRRI graduate student helped plan and develop Basin Planning meetings held around the state by the Colorado Water Conservation Board.

Research Program

Federal Program

On October 13, 1999, the Advisory Council on Water Research Policy (ACWRP)* for the Colorado Water Resources Research Institute met in Denver to hear oral progress reports on the previous year's research projects, determine priorities for needed research, and select projects for FY2000 funding by CWRRI.

The Advisory Committee listed topics for future water research emphasis by CWRRI as follows (no priority established, only topics):

Knowledge is needed about the distribution, habitat, and life history of each threatened native species in Colorado to ensure species survival without being rated an endangered species.

What are alternative strategies that would maintain and improve populations of threatened and endangered species (the key indicators of habitat health and how those indicators should be measured) and how can we ensure indicators are in appropriate ranges while maintaining Colorado's economic vitality?

Can groundwater recharge in deep aquifers, in the form of groundwater "banking," be a major source of water supply in the future?

What are appropriate water quality standards for reuse of treated wastewater?

The interface between irrigation and non-point source pollution needs to be better quantified. For example, what are the quantities of selenium concentrations in irrigation return flows today and how do they differ from historical levels under non-irrigation conditions? What are the biological impacts of current levels of selenium vs. historical levels? Are there other constituents in irrigation return flows needing attention?

The CWRRI Advisory Council on Water Research Policy's mandate is to address two functions: to advise CWRRI regarding research to be undertaken as part of the federally supported, state-based water research program; and to seek state and local water research funding to provide the state match required. The ACWRP recommended continued federal/state funding for two projects begun in FY99:

Description and Interpretation of Salinization in the Lower Arkansas River Valley, Colorado -- The Principal Investigators are Timothy K. Gates and John W. Labadie, Department of Civil Engineering, Colorado State University; Co-Investigators are Grant E. Cardon, Department of Soil and Crop Sciences, Colorado State University, Israel Broner, Department of Chemical and Bioresource Engineering, Colorado State University, and James C. Valliant, Extension Irrigation Specialist, Cooperative Extension, Colorado State University. Partial funding for this project was provided by the CSU Agricultural Experiment Station.

Distribution, Habitat and Life History of Brassy Minnow in Eastern Colorado -- The Principal Investigator is Kurt Fausch, Department of Fishery and Wildlife Biology, Colorado State University. Funding for this project was also provided by the Colorado Division of Wildlife.

With the limited funds remaining, a third project was formulated around the highest water research priority identified by the ACWRP at its initial meeting on February 12, 1999 -Forest Management, Water Yield, and Water Quality. The Principal Investigator is Lee MacDonald, Department of Earth Resources, Colorado State University. Additional research funds for this project were provided by the Northern Colorado Water Conservancy District, Denver Water, and the Colorado River Water Conservation District.

A fourth project, Water Quality Monitoring System Effectiveness, was formulated in response to the ACWRP's request for an assessment of the science underpinning Colorado's ability to perform source water assessments per the regulations of the Safe Drinking Water Act. The proposal had a number of TMDL implications for Colorado, another topic of concern to the Advisory Committee. The Principal Investigator is Jim Loftis, Department of Civil Engineering, Colorado State University. Additional research funds for this project were provided by Denver Water.

State Program -- South Platte Mapping and Analysis Program (SPMAP) This project was created to address the data and tool development needs of water-user groups in the Lower South Platte River Basin from below Denver to the state border. One of the primary functions of this software is to provide the tools needed by water-user organizations to estimate agricultural demands on groundwater wells that require augmentation. To develop a consensus on the tasks needed for this project an

advisory committee was formed. The committee is comprised of representatives from the Northern Colorado Water Conservancy District, the South Platte Lower River Group, Inc., the Colorado State Engineer's Office, Groundwater Appropriators of the South Platte, the Central Colorado Water Conservancy District, the Lower South Platte Water Conservancy District, and the cities of Greeley and Fort Collins.

Since 1995 Dr. Luis Garcia, Professor of Chemical and Bioresource Engineering Colorado State University, has been working with the members of the advisory committee. The water managers and university researchers form a 'team' that works closely on all aspects of the research. Funding for the project was provided by the water organizations participating in the advisory committee, the Colorado Water Resources Research Institute, Colorado State University Cooperative Extension, and the U.S. Bureau of Reclamation.

As part of this project, three main components were identified for tool and/or data development. These components are collectively called the South Platte Mapping and Analysis Program (SPMAP). The ArcView Geographic Information System component (SPGIS) contains spatial data assembled for this project and can be used to develop input files for the South Platte Consumptive Use (SPCU) Model, which in turn can be used to develop input for a Stream Depletion Factor interface (SDF View).

Table 1. South Platte Mapping and Analysis Program Tools

SPGIS-South Platte Geographical Information System - This is a Geographical Information System (GIS) based tool with data populated for the South Platte River Basin. This tool can be used to create input files for the CU Model based on spatial data for crops extent and weather station and well locations.

SDF View-Stream Depletion Factor (SDF) Graphical User Interface - This interface can be used to determine SDF values based on user input. These values can then be entered into the CU Model.

SPCU-South Platte Consumptive Use Model - This is a sophisticated model and interface for estimating consumptive use. The model contains multiple evapotranspiration and effective precipitation methods and can determine water use needs based on inputs from databases and the user.

Copies of the software and documentation can be downloaded from the Internet site:
<http://www.ids.colostate.edu/projects/splatte>.

The project completion report, "South Platte Mapping and Analysis Program (SPMAP): Decision Support Tools for the Lower South Platte," is available from CWRRRI (Completion Report No. 193).

* ACWRP membership is provided for in CWRRRI's by-laws. Below is a list of members of the CWRRRI Advisory Council on Water Research Policy.

CWRRRI ADVISORY COMMITTEE ON WATER RESEARCH POLICY

Appointed by position

Senator Jim Dyer, Chair, Senate Agriculture, Natural Resources and Energy Committee

Representative Diane Hoppe, Chair, House Agriculture, Livestock and Natural Resources Committee

Greg Walcher, Executive Director, Department of Natural Resources Jane Norton, Executive Director, Department of Public Health and Environment Don Ament, Commissioner, Department of Agriculture

Appointed by CWRRI Director

Fred Anderson, Former Legislator Sara Duncan, Denver Water Eric Kuhn Manager, Colorado River Water Conservation District John Porter, Dolores Water Conservancy District David Robbins, Hill & Robbins, Water Attorney Ralph Curtis, Rio Grande Water Conservation District

Ex Officio

Milan Rewerts, Director, Cooperative Extension Jim Hubbard, Director, Colorado State Forest Service

Basic Information

Title:	Water Quality Monitoring Effectiveness: Denver Water Case Study
Project Number:	B-04
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Not Applicable
Focus Category:	Water Quality, Management and Planning, Education
Descriptors:	Water quality, Water quality monitoring, Watershed management
Lead Institute:	Colorado Water Resources Research Institute
Principal Investigators:	Jim C. Loftis

Publication

Problem and research objectives

Water quality monitoring programs are increasingly being held accountable for the information they produce, especially as more information driven management programs are implemented. Many municipalities along the front range of Colorado are facing pressures to expand their raw water monitoring programs as land uses within watersheds continue to change, supplying municipal water increases, and as the Safe Drinking Water Act (SDWA) regulations tighten. Budgets for monitoring, however, are under financial constraint.

Because of the financial and information constraints being placed on water quality monitoring programs, there is a need to evaluate municipal watershed monitoring programs to insure they are meeting information needs while operating in an efficient manner. The means to evaluate water quality monitoring programs have been evolving over the years, but the practical application of the technology has been limited.

Objectives of this project include:

- Assembling existing water quality monitoring system design theory;
- Developing a means to use such theory in evaluating the information effectiveness of existing municipal watershed monitoring programs; and
- Applying the theory developed to Denver Water's watershed monitoring program as a case study.

Denver Water operates an extensive water quality monitoring program that extends over its entire source water area to the terminal reservoirs that feed the treatment plants. This raw water monitoring system evolved over the years as operational needs and various regulatory information requirements arose. Denver Water has agreed to have its monitoring program evaluated as a means of testing the existing technology for evaluating the effectiveness of water quality monitoring programs.

Methodology synopsis

The existing water quality monitoring system design theory as applied to drinking water utilities is depicted by the following five steps given by Ward et al. (1990):

1. Define and document surface water information needs of the water utility management.
2. Define and document information needs that can be produced by monitoring.
3. Design monitoring network.
4. Document data collection procedures.
5. Document information generating and reporting procedures.

This present knowledge on evaluation of water quality monitoring programs includes the following considerations:

- 1) Are the information objectives of the monitoring system clearly stated and documented? Are the objectives clearly related to management decision making? What is the legal basis (often same basis for decision making) for spending public money obtaining the desired information?
- 2) Is there a well-defined and documented data analysis protocol that converts data to the above information goals? The goal of such protocols is to ensure that the analysis of the data, to produce the desired information, is scientifically sound and defensible. Also, specifying the data analysis methods, before the data are collected, reduces the 'found' data problem that is developing in the field of water quality monitoring. This problem stems from the fact that any

data analysis method can be used with 'found' data to generate desired results - on both sides of an issue. By specifying precisely how data will be analyzed before it is collected, this problem is greatly reduced. In other words, the data are collected in a manner that is dictated by the way it will be analyzed to obtain the desired information.

- 3) Is there a widely accepted reporting format used to convey the information to the decision makers? The operation of most monitoring systems begins to break down, badly, at this point. In general, the 'discipline' of water quality monitoring is still searching for effective and efficient ways to communicate complex water quality information to decision-makers and the public. Progress is being made (for example the Consumer Confidence Reports in which Denver Water is a leader), but there is a need to devote the CCR type of attention to all water quality information.
- 4) Are the operating procedures and practices for the entire monitoring system clearly defined, understood, and documented? What QA/QC practices are used at each step in the process? What training is available for monitoring employees? The monitoring system is deemed to include components similar to the following:
 - a. Sampling methods
 - b. Laboratory methods
 - c. Data handling
 - d. Data analysis
 - e. Reporting
 - f. Information utilization

Thus, each component is carefully examined for completeness and quality control as well as documentation. The examination often has to address consistency in operation of the monitoring system over time. Changes in operations often result in additional variance in the data that masks water quality changes. Changes are more likely to occur in a monitoring program with no documentation and poor training.

Principal findings and significance

Introduction to the Denver Water Case Study

The Denver Water Department as it is known today originated in 1918 and from that time began planning and developing a water supply system to meet the needs of the people of Denver and the surrounding areas. At this time, Denver Water serves nearly everyone in the City and County of Denver and about 40% of those who live in the suburbs. The present purpose of Denver Water is best summarized in its mission statement:

“Denver Water will provide our customers with high quality water and excellent service through responsible and creative stewardship of the assets we manage. We will do this with a productive and diverse work force. We will actively participate in and be a responsible member of the water community.”

The supply of water is presently provided by an accumulated drainage area of 4,000 square miles (2.5 million acres) and a network of 13 reservoirs. This vast amount of land providing the water is contained primarily within 8 counties of Colorado and is located on both sides of the Continental Divide. This source watershed region can be characterized as mostly mountainous and almost all the water comes from snowmelt.

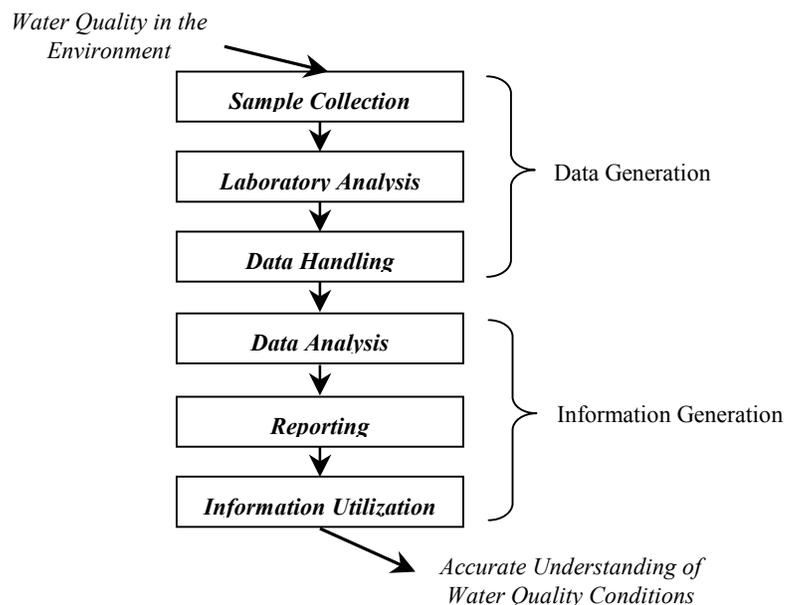
Although the water quality is known to be good in the source watersheds, Denver Water has identified the need for information pertaining to specific questions about the quality of the water. Through this project, a water quality information system has been developed to provide the detailed information Denver Water requires to better carry out the mission statement of providing high quality water through responsible and creative stewardship of the assets managed.

Evaluation of current monitoring program

As a starting point in evaluation the current Denver Water monitoring program, the flow of information was traced as data collected on water quality in the environment were transformed to provide an understanding of water quality conditions. This process identified areas of the monitoring system needing improvement by highlighting disruptions in the flow of information. This is shown conceptually in Figure 1 (from Ward et al. (1990)). It became evident that Denver Water was focusing their monitoring program on the first 3 steps, generally viewed as the data generation phase, while the information generation phase was neglected somewhat. These practices contribute to the “data-rich but information poor” syndrome described by Ward et al. (1986) where the acquisition of data is viewed as the endpoint of the monitoring system. The lack of defined information goals is indicative of this situation which makes quantifying a successful monitoring program difficult as no milestones exist for measuring achievement.

In the case of Denver Water, monitoring objectives prior to this project consisted of identifying short term impacts to water entering terminal reservoirs immediately prior to treatment. Long-term objectives were neither clearly formulated nor written down. Due to insufficient documentation regarding objectives, no relation of monitoring to management decision making is present in the current system. This disruption in the production of information is evident when examining Denver Water’s attention to data analysis. The absence of documented monitoring objectives leaves little need for data to be converted to specific information. Thus, the ‘found data’ scenario described previously becomes reality as raw data abounds without a prescribed method for its analysis. Contributing to the need for improved data analysis was the inability of the current sampling frequency to provide data suited for producing statistical information.

FIGURE 1



Again, no information is communicated to managers or the public via reporting as there is no defined need for information. Operating procedures were adequately addressed by Denver Water who maintain their own certified laboratory where samples are analyzed using prescribed methods, and data are stored in a data management system.

As a result of the evaluation conducted on Denver Water's watershed monitoring project, it is evident that effectiveness of the monitoring system could be enhanced by clear, documented information objectives. Presently, without this necessary component, Denver Water's ability to efficiently produce reliable, significant information describing water quality is lacking. Documented monitoring objectives coupled with data analysis methods and reporting mechanisms will provide for the flow of information from the environment to managers (for decision making), which is characteristic of a successful water quality monitoring system.

Recommendations for Denver Water's Watershed Monitoring System

The results of the evaluation process conducted on Denver Water's watershed monitoring program were used in establishing recommendations for methods to improve the existing program. The major findings of the evaluation were converted into the following recommended improvements.

- Defining and documenting information objectives of the monitoring system.
- Determination of a statistically based sampling frequency which is a function of the quality of the information to be produced.
- Defining and documenting data analysis procedures to meet the information objectives identified and creating a data analysis protocol to ensure the analysis of the data is scientifically sound and defensible.
- Developing reporting formats enabling information produced by the monitoring system to reach the end user in an effective, easily understood manner.

A brief description of implementing these recommendations follows. This incorporation of the evaluation results, with respect to the project focus, is considered an extension of applying the current monitoring design theory to Denver Water's watershed monitoring program.

Need for design

Denver Water identified the 1996 amendments of the SDWA (PL 104-182) as providing a legal basis for their monitoring program. Specifically, the ideas of public right to know and increased information needs highlighted by the Consumer Confidence Reporting (1414(c)(4)) and Source Water Assessment Program (1453), which both contain implications for monitoring the source water quality of a drinking water utility, were cited. These legal implications were coupled with the desired need of information for management purposes to create a comprehensive list of monitoring system information requirements. Then, a comparison between the information requirements identified and information that can be produced by monitoring was completed. The end result of this is shown in Table 1 where management goals (information needs) identified are associated with the necessary monitoring product able to produce useful information pertaining to the goal. The formulation of this relationship between management goals and monitoring provides the needed link facilitating information flow through the monitoring program.

Data analysis

Also, the need for data analysis in the production of information is highlighted by the link of management goals and monitoring. A data analysis protocol was developed using commonly accepted methods while avoiding attributes indicative of water quality data analysis. These attributes include:

TABLE 1

INFORMATION NEED	MONITORING PRODUCT
<i>Source Water Quality: How it Affects Water Treatment</i>	- Detection of trends over time in surface water
<i>Nutrient Loading</i>	- Detection of trends over time in surface water - Calculation of loads to reservoirs
<i>Development within Watersheds</i>	- Determination of average conditions in surface water - Detection of trends over time in surface water

- Multiple observations
- Outliers
- Changing sampling frequencies
- Missing values
- Censored data
- Non-normality
- Seasonality
- Serial Correlation

Analysis method selection was carried out to address non-normality, seasonality, and serial correlation while the remaining attributes are managed through operation of the monitoring program. The methods recommended for Denver Water’s monitoring program are nonparametric (no statistical distribution assumed), with the exception of determining average conditions (measures of central tendency). For central tendency analysis, a distribution will be fit to the data and methods chosen accordingly. Serial correlation was determined not to be a factor as the scale of interest is confined to the period of record (Loftis et al. 1991). Seasonality was addressed through use of data analysis methods designed to address its impacts (seasonal Kendall test for trend) and the recommendation to complete analysis within seasons (average conditions/load estimation).

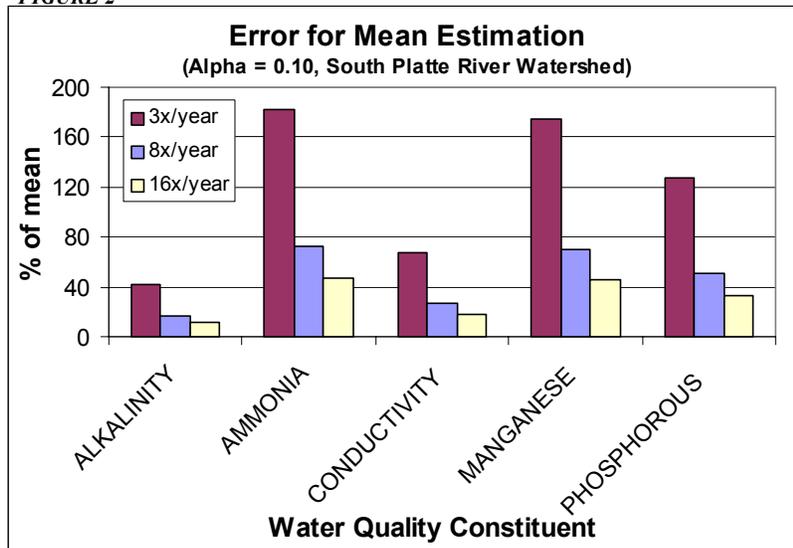
Network design

The design of the monitoring network is generally considered to consist of defining a sampling frequency, identifying water quality variables to sample, and locating sites at which to sample. Denver Water’s sampling locations and variables were well established and coincided well with the monitoring objectives identified. Current sampling frequencies of three samples per year were deemed inadequate because of the statistical shortcomings therein, including the inability to estimate error on a seasonal basis given the current frequency. Analysis of historical water quality data was completed to determine an improved sampling frequency. Within the watershed area Denver Water uses as a source of supply, 41 United States Geological Survey (USGS) water quality stations were found to have adequate data for analysis. For each station, 5 water quality variables (alkalinity, total phosphorous, manganese, specific conductance, and ammonia-nitrogen) were analyzed, as indicators, for normality, central tendency, and variability. Plots of temperature and flow data for each station were created to define separate seasons in which the values of water quality parameters would tend to be similar. This resulted in two seasons being formed: high flow/high temperature and low flow/low temperature. The specific months of each season are shown in Table 2.

TABLE 2

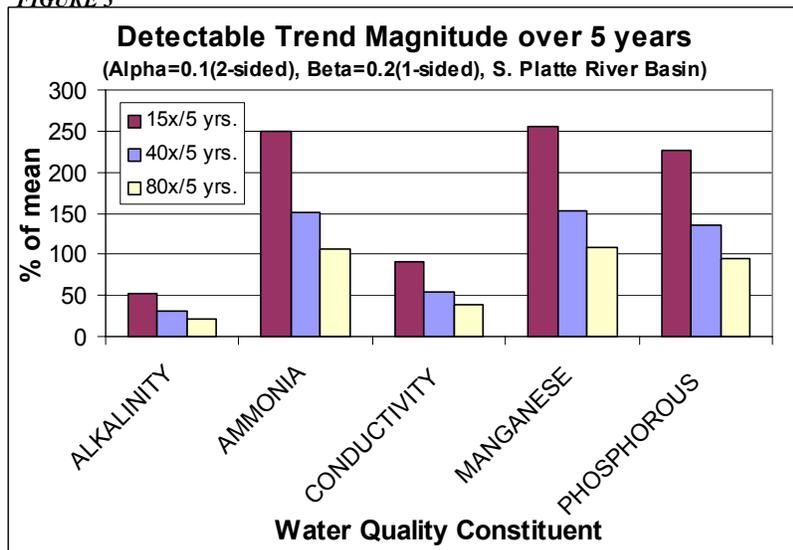
Season	Designation	Months
1	Low Flow/Low Temperature	Jan, Feb, Mar, Apr, Sept, Oct, Nov, Dec
2	High Flow/High Temperature	May, June, July, Aug

FIGURE 2



historical mean) associated with estimating means, detecting trends, and estimating mass loadings. The figures are shown only for the South Platte watershed, which is one of Denver Water’s sub-watersheds. As discussed earlier, mean estimation will be carried out seasonally, but errors for this are shown on yearly basis for presentation purposes.

FIGURE 3



estimate a mass load for phosphorous within +/- 15% of the historical mean. A 90% confidence level is assumed for all calculations.

Reporting

Annual reports should include basic summary statistics for each season, load estimates with confidence intervals, and estimated trend magnitudes with results of seasonal Kendall tests for significance. For those stations and variables where a "rating curve" method is appropriate, the recommended procedure for load calculations is the "smearing" estimate of mass described in Helsel and Hirsch (1992). A recommended tabular reporting format is currently being developed.

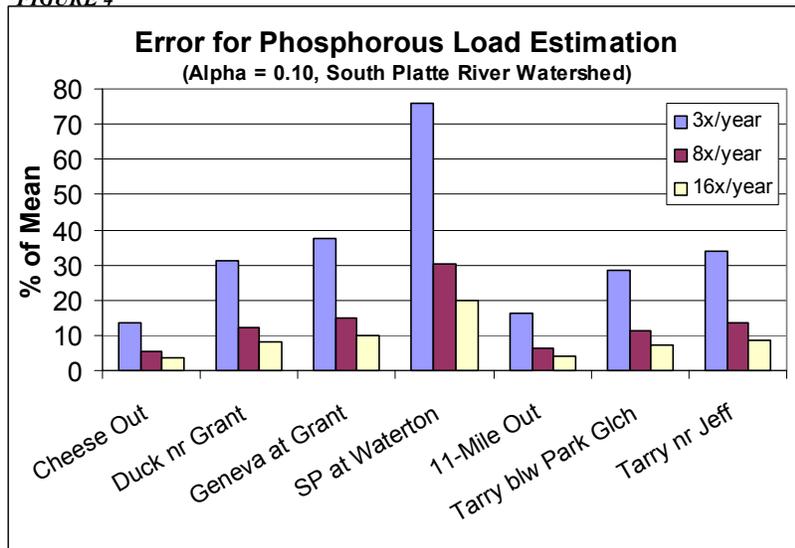
Sample size calculations were used to assess the impacts of sample size on uncertainty associated with estimating means (and mass loads) and testing for trends of water quality variables based on formulae given by Gilbert (1987) and Lettenmaier (1976) respectively. This was carried out for distinct sub-watersheds contained within the rather large watershed of Denver Water. Examples of these results are shown in Figures 2 – 4 which depict the error (represented by the half width of the confidence interval as a percentage of the

Resulting from this exercise for the entire Denver Water source area is the recommendation that 8 samples be taken per year. This is further defined to be 4 samples taken during the high flow season (or monthly sampling) and 4 samples taken during the low flow season (or bi-monthly sampling). Generally speaking this sampling frequency would give an error of +/- 50% of the historical mean when estimating means (on average for all water quality variables), detect a trend of +/- 75% of the historical mean over a 5 year period (for all water quality variables), and

Significance

This research has developed and demonstrated an approach for evaluating and improving the

FIGURE 4



effectiveness of a water quality monitoring program for a large municipal water provider. While the results of the study have been favorably received by Denver Water staff, the proof of its value will come if and when the recommendations resulting from the study are actually implemented. If therecommendations are adopted successfully, then Denver Water can serve as a role model for other large municipal water providers who wish to improve their own water quality monitoring programs and the management decisions that rely upon them.

Literature Cited

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Ward, Robert C., Jim C. Loftis, and Graham B. McBride. 1990. "Design of Water Quality Monitoring Systems." Van Nostrand Reinhold, New York, NY, 231 p.

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Basic Information

Title:	Forest Management, Water Yield, and Water Quality: A State-of-the-Art Assessment
Project Number:	B-05
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Not Applicable
Focus Category:	Water Quality, Water Quantity, Ecology
Descriptors:	Water quality, Water quantity, Land-water interactions, Watershed management
Lead Institute:	Colorado Water Resources Research Institute
Principal Investigators:	Lee H. MacDonald, Lee H. MacDonald

Publication

1. MacDonald, Lee H., John D. Stednick, Edward L. Huffman, and Charles A. Troendle. 2001. Managing Colorado's Forests for Water Yield and Water Quality: Opportunities, Risks, and Constraints, 21st Annual American Geophysical Union Hydrology Days, April 2-5 2001, Colorado State University, Fort Collins, Colo.

Problem and research objectives

GOALS:

Provide a state-of-the-art summary on how forest management in Colorado affects water quantity and quality; and to identify the gaps in knowledge that can be addressed by future research.

SPECIFIC OBJECTIVES:

1. Identify the forest management issues of primary concern for water management in Colorado;
2. Summarize the state-of-the-art with respect to how past and present forest management is affecting annual water yields, low flows, and peak flows;
3. Determine the potential for altering current streamflow regimes through forest management;
4. Summarize the state-of-the-art with respect to the effects of forest management on water quality;
5. Assess the different risks to water quality posed by forest management activities, including the no action alternative;
6. Recommend areas where additional research is needed and feasible.

PRODUCT:

A scientific “white paper” approximately 50-100 pages in length that addresses the above objectives.

Methodology synopsis

1. Compile existing knowledge on the effects of forest management on water yield and water quality;
2. Compile information on historic and current forest cover and forest land use in Colorado;
3. Compile information on how changes in forest cover and forest management affect water yield and water quality;
4. Determine the effect that historic and current land use has on water yield and water quality;
5. Determine the possibilities for increasing water yields from forested areas and the effects of different management scenarios on water quality;
6. Identify current gaps in knowledge concerning forest management effects on water yield and quality, and identify the research necessary to fill these gaps.

Principal findings and significance

1. Qualitative comparisons and small-scale studies indicate that forest density has increased relative to late 1800s and early 1900s;
2. Water yield: overall trends
 - a. Increased forest density has decreased discharge;
 - b. Troendle and Nankervis estimated a 14% decline in streamflow (185,000 ac-ft) for National Forest lands in the North Platte basin from 1860 to 2000;
 - c. Biggest decline was from 1900-1940;
3. Water yield: current effects
 - a. Forest harvest, blowdown, fuels reduction efforts all increase water yields;

- b. Predicted increases in water yields from National Forest lands from current management activities are small;
- c. Larger increases in higher elevation forests which have more precipitation and denser tree canopies;
- d. Projected increases from Arapaho-Roosevelt Nat'l Forest:
 - i. Timber Harvest: 777 ac-ft/yr
 - ii. Fuels reductions: 1614 ac-ft/yr
 - iii. Total of 2391 ac-ft/yr represents an 0.014% increase;
- e. Similar magnitude of increases expected from Grand Mesa-Uncompaghe-Gunnison National Forests;
- f. Pike-San Isabel National Forest:
 - i. Estimated water yield increase of 4849 ac-ft/yr based on 1984 plan, or 0.38%;
 - ii. Actual increases probably much less because harvest only about 15% of projected values;
- g. Routt National Forest:
 - i. Estimated water yield increases due to timber harvest about 4,800 ac-ft/yr;
 - ii. Blowdown and projected beetle kill could increase water yields by as much as 60,000 ac-ft/yr;
- h. San Juan National Forest:
 - i. Decreasing timber harvest is expected to decrease water yields by up to 240 ac-ft/yr, or a decline of 0.00001%;
- i. White River National Forest:
 - i. Projected water yield increase of 280 ac-ft/yr or 0.013%, but actual amount less due to lower than projected rates of timber harvest;

4. Water yield: potential effects

- a. Increased timber harvest, if applied over large areas, could increase flows by relatively large amounts; Troendle and Nankervis (2000) estimated potential water yield increases from National Forest land of 50-55,000 ac-ft/yr in North Platte River;
- b. Current constraints on forest management (e.g. wildlife, access, roadless areas, unstable areas) may limit the extent to which these projected increases in flows can be realized;
- c. Storage is critical because:
 - i. The additional runoff comes on the rising limb of the snowmelt hydrograph;
 - ii. Water yield increases are greater in wet years, smaller in dry years;
 - iii. Modeled changes in flow are too small to be detectable given standard accuracy of discharge measurements;

5. Research needs: water yield

- a. Already understand effects of forest management on streamflow, but need additional analyses to:
 - i. Identify basins of greatest interest/concern;
 - ii. Document historic changes in forest cover and predicted flows in basins of greatest concern;

- iii. Determine whether storage is available;
- iv. Determine if potential increases are realistic given management constraints;

6. Water quality:

- a. Erosion rates in undisturbed forests extremely low;
- b. Water from forest lands very high quality;
- c. High-severity wildfires can increase peak flows and erosion rates by two or more orders of magnitude;
- d. Frequency of high-severity fires and relative risk across landscape largely unknown;
- e. MacDonald et al. (2000) estimated erosion hazard risk (SURFERO) by wildfires, but little data to validate model;
- f. Fuel treatments—either mechanical or prescribed fire—may result in chronic inputs of sediment, especially from unpaved roads;
- g. Very little data!
- h. Research needs: fire effects
 - i. Need to improve ability to predict effects of wildfires and fuel treatments on runoff, erosion, and water quality;
 - ii. Improved predictive capability will require better understanding of causal processes, and fire recurrence intervals with and without fuel treatments;
 - iii. Need to integrate sediment production rates over long time periods to rigorously compare benefits of fuel treatments relative to periodic wildfires, and compare impacts to aquatic systems of chronic vs. pulsed inputs;
 - iv. Improved estimates of runoff and erosion risks from wildfires are needed to help identify which areas should be treated, and in what order of priority.

Basic Information

Title:	Description and Interpretation of Salinization in the Lower Arkansas River Valley, Colorado
Project Number:	B-02
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Not Applicable
Focus Category:	Water Quality, Groundwater, Agriculture
Descriptors:	Salinity, Drainage, Irrigation, Water quality, Groundwater quality, Saline soils, Data analysis, Data storage
Lead Institute:	Colorado Water Resources Research Institute
Principal Investigators:	Timothy K. Gates

Publication

1. Gates, T.K., J.P. Burkhalter, J.W. Labadie, J.C. Valliant, and I. Broner. 2001. Monitoring and modeling flow and salt transport in a salinity-threatened irrigated valley. Tentatively accepted for publication in the Journal of Irrigation and Drainage Engineering, ASCE.
2. Burkhalter, J.P., T.K. Gates, and J.W. Labadie. 2000. Model and field studies to manage saline shallow water tables in the Lower Arkansas Valley, Colorado. Proc. of the Intern. Conf. on Irrigation and Drainage in the New Millenium, USCID, Fort Collins, Colo.
3. Burkhalter, J.P., T.K. Gates, and J.W. Labadie. 2000. Modeling and analysis of saline-high-water-table problems in the Lower Arkansas River Valley, Colorado. Colorado Water. Colorado Water Resources Research Institute, Colorado State University, June.

Problem and research objectives

There is growing evidence that the irrigated lands of the lower Arkansas River Valley in Colorado are suffering from severe waterlogging and salinization. Informal and anecdotal evidence abounds: salt crusting on soil surfaces, seepage and wet spots in selected fields, stunted growth of crops, and reduced crop yields. There is an acute need to place the diagnosis of salinity and waterlogging problems in the Arkansas Valley on a sound scientific footing. Over the last few years, we have initiated scientific investigations with the objectives of accurately diagnosing these problems.

Beyond the need to accurately describe the problems for farmers and for state and regional agencies, a reliable database is needed to aid in prescribing solutions. This project proposes to strengthen the data foundation needed to characterize salinization problems in the lower Arkansas River Valley and to guide the search for answers. The output of this project will be a report that assesses the scope and severity of the problems. The report will consider soil salinity, water table depth and salinity; river level, flow, and salinity; water levels, flows, and salinity in canals and drains; irrigation practices; hydraulic conductivity of surface soils; well pumping; and crop yields. Plausible causes and promising directions for addressing the problems also will be addressed. The report will be accompanied by a digital spatially-referenced (ArcView™ GIS format) database.

The results of the proposed project should prove a valuable resource in support of decision-making and intervention in the Valley. Without sound and timely intervention, it appears that the Valley will eventually succumb, at least in a large part, to the ill effects of salinization. Solutions based upon accurate knowledge of field conditions will be needed to insure sustainability of the Valley's productive agricultural base and preservation of its rural communities.

Methodology Synopsis

Project activities include compilation and evaluation of data from past studies, as well as collection of new field data. Data from past studies in the Valley are being pulled together, transformed into a compatible and accessible format, compared, and interpreted. Historic data considered include land topography and topology of hydraulic systems, field and crop layouts, general hydrology, subsurface geology and lithology, water table depth and salinity, groundwater well locations and pumping rates, river water levels and salinity, soil textures and classifications, irrigation practices, and county-wide crop yields. Extensive field data have been collected in 1999 and 2000 under this and related projects. The data collection effort focuses on a representative region of the Valley between Manzanola in Otero County to Las Animas in Bent County. Data have been collected and analyzed on water table depth and salinity; water levels and salinity in the river, irrigation canals, drains, and reservoirs; soil salinity; hydraulic conductivity of near-surface soils; land topography; and crop yields.

Principal findings and significance

More than 110 monitoring wells have now been installed and are routinely measured over a representative region of about 130,000 acres. Data collected in 1999 revealed an average water table depth of about 7 ft below ground surface, with a depth of less than 5 ft under 25% of the region. Data from the drier 2000 season indicates that the average water table depth increased to about 8.1 ft. The average measured salinity (as electrical conductivity, *EC*) of the water table in the study region was about 3.5 dS/m (3100 mg/l) in 1999 and 3.2 dS/m (2850 mg/l) in 2000. Surface-water salinity was measured weekly throughout most of the season at more than 170 locations, including points in the Arkansas River,

in six major canals, in twelve drainages, and in two reservoirs. The average salinity of the water in the irrigation canals was 0.93 dS/m (812 mg/l) in 1999 and 1.12 dS/m (978 mg/l) in 2000, indicating low to moderate restriction in use for irrigation. Global positioning equipment was used to accurately locate each of the ground-water and surface-water sampling sites for use in a geographic information system.

Soil salinity (to a depth of about 3.3 ft) was measured in early June and in mid August on 68 different fields in 1999 and on 77 fields in 2000. On each field, soil salinity (as electrical conductivity of saturated extract, EC_e) was estimated from measurements using electromagnetic induction probes at an average of 62 locations (about 1 to 10 locations per acre) for each sampling. In addition, more than 3500 soil samples were collected for use in calibrating the electromagnetic probes. Soil salinity measured in overlying fields varied from benign to extreme, tending to exceed threshold tolerances for crops when the depth to the saline water table was less than about 3 m. The overall average soil salinity was estimated as 2.8 dS/m (2470 mg/l) in 1999 and 2.0 dS/m (1730 mg/l) in 2000. For the late-season readings in 1999, about 70% of fields had at least 25% of measured points above the salinity threshold (level above which crop yield reductions are expected), indicating significant soil degradation and declining yield. Crop yield reduction due to salinization was estimated to range between 0 and 75% on fields spread over the subregion, averaging about 10%. This indicates a total revenue loss ranging \$0/ha - \$750/ha among the fields, and averaging \$70/ha - \$100/ha over the study subregion, based on 1999 crop prices. Additional losses are likely occurring due to waterlogging. Data collected in 2000 are currently under analysis. Data similar to those gathered in 1999 and 2000 will be collected at least through the 2001 season.

The developed database is being used in a related project to support a computational model of the study subregion. The model is being developed to help assess possible solution strategies. Preliminary modeling results indicate that increased pumping of existing well facilities (with excess pumped flows directed through open drains to the river) would result in only limited localized improvement. Reduced recharge through increased irrigation efficiency would provide more extensive benefits, especially in much of the area south of the river. Nevertheless, lowering the saline water table in the most severely affected areas will require more than simply increasing irrigation efficiency or increasing pumping rates. Costlier investments will need to be considered, such as canal lining, horizontal subsurface drainage, and lowering of the water level in the river. With guidance from Valley agencies and farmers, alternative solution strategies will be assessed by predicting how well they will control waterlogging and salinity, the impact they will have on time-varying return flows to the river, and their cost-effectiveness.

Basic Information

Title:	Distribution, Habitat, and Life History of Brassy Minnow (<i>Hybognathus hankinsoni</i>) in Eastern Colorado Streams
Project Number:	B-03
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Not Applicable
Focus Category:	Ecology, Hydrology, Conservation
Descriptors:	Plains fish ecology, Ecohydrology, Conservation
Lead Institute:	Colorado Water Resources Research Institute
Principal Investigators:	Kurt D. Fausch

Publication

1. Scheurer, J.A. and K.D. Fausch. 2001. Habitat requirements and systematics of brassy minnow in intermittent plains streams in eastern Colorado. Annual Progress Report to Colorado Water Resources Research Institute and Colorado Division of Wildlife, Fort Collins, Colo. 84 pp.
2. Presentations -- Posters presented at: 1. South Platte Forum, October 2000, Longmont, Colo. 2. Student Water Symposium, November 2000, Colorado State University, Fort Collins, Colo. Won Best Student Poster Award. 3. Oregon Chapter of the American Fisheries Society Annual Meeting, February 2001, Portland, OR.

Problem and research objectives

The brassy minnow (*Hybognathus hankinsoni*) has apparently declined in distribution and abundance in Colorado since the 1970s and was one of three plains fish species to be listed as threatened or endangered by the State of Colorado in 1998. The purpose of this research is to determine their historic distribution and critical habitat requirements. This information will aid fishery managers in efforts to locate suitable habitat and potentially restore the species to more of its native range, thereby precluding need for further listing. Understanding the native range of brassy minnow is complicated because it is difficult to distinguish from a closely related species, the plains minnow (*H. placitus*). Both species were originally classified as a different species in the same genus (Mississippi silvery minnow, *H. nuchalis*) before they were described in 1929 (brassy minnow) and 1962 (plains minnow).

Methodology, principal findings and significance

We obtained museum specimens of brassy minnow and plains minnow from locations where they occur alone (Michigan for brassy minnow, New Mexico for plains minnow) and could therefore be positively identified. We measured nine quantitative morphometric characters (e.g., standard length, eye diameter) and five qualitative characters (e.g., eye position, dorsal fin margin shape) thought to be useful for distinguishing the two species. Logistic regression was used to develop a model of species identity (brassy or plains minnow) as a function of sets of these characters. The model that fit the data the best correctly predicted the species identity of 96.2% of the 'known' museum specimens (n=81 brassy minnow, n=51 plains minnow). Analysis indicated that brassy minnow have a larger eye diameter than plains minnow at a given length, and that the center of the eye of brassy minnow was always even with the tip of the snout whereas the eye of plains minnow was generally centered above a line through the tip of snout.

We also obtained the 53 museum collections of *Hybognathus* known from Colorado and adjacent counties in Kansas, Nebraska, and Wyoming. These include original collections by David Starr Jordan (a famous early ichthyologist) in 1891 and Max Ellis in 1914, all of which were cataloged as *H. nuchalis*. The same 14 morphometric characters have been measured on more than 550 specimens from these collections. Our logistic regression model will be used to predict the identity of these specimens, after which their identity will also be verified by Dr. Kevin Bestgen of the Colorado State University Larval Fish Laboratory. A key will be developed based on the logistic regression model to aid biologists in separating the two species in the field or laboratory, and additional qualitative characters will be provided to improve accuracy of species identification.

The most common character listed in published dichotomous keys for separating the two species is the number of scale radii, which are grooves radiating from the center of scales presumed to allow the scale to flex. Brassy minnow are reported to have about 20 or more faint radii whereas plains minnow are listed as having 15 or fewer. We first developed an objective method for counting radii because none was described in the keys and radii vary greatly in length. Most brassy minnow were found to have fewer than 20 radii (mean 17, range 8-27, n=30), and the number of radii increased with standard length so that only the largest brassy minnow would be correctly classified by existing keys. Moreover, the number of radii varied among different scales from individual brassy minnow, so that in about a third of cases (n=11) the specimen would be classified as one species from one scale but the other species from a second scale. In contrast, most plains minnow had fewer than 15 radii (mean 10, range 4-20, n=30) and so fit the existing key better.

To determine habitat requirements for brassy minnow, especially as they relate to stream flow, we selected three segments of the Arikaree River in eastern Colorado that varied in degree of stream drying from perennial to seasonally intermittent. This stream was chosen based on a 1999 survey of 12 streams where brassy minnow were last recorded in Colorado, which showed that brassy minnow populations were abundant enough to study in only four streams. The Arikaree River was chosen because small streams were deemed more feasible for future management than larger rivers, and because of landowner cooperation.

We sought to determine attributes of critical habitat for brassy minnow survival, growth, and reproduction, and the timing of reproduction in relation to temperature and flow. Our two working hypotheses were that: 1) brassy minnow would persist in more locations, survive to older ages, grow larger, recruit more (i.e., produce more young that survived to enter the sampled population), and reach higher densities in habitats with perennial flow and more benign abiotic regimes than in those with intermittent flow and harsh abiotic regimes, and 2) brassy minnow would spawn during spring in temporary habitats with flooded vegetation and larvae would rear in these habitats before they dry up.

We selected three 4-mile (6.4 km) segments of the Arikaree River along a gradient of intermittency, divided them each into eight 0.5-mile (800 m) reaches, and randomly selected habitat units (pools, backwaters, runs, riffles) in each reach for measuring habitat and sampling fish. Habitat and presence/absence of fish species were determined for each of 99 habitat units in the three segments during June, July, August, and November 2000. In the downstream segment, which was the driest, most of the segment was dry by the June survey and only 10 habitat units were present. Of these, half dried up by August and did not reconnect by November. The middle segment flowed continuously in June, but became intermittent by August with portions of only three reaches remaining perennial. Flow remained intermittent through November. The upstream segment became intermittent in several reaches in July and August, but increased stream flow during fall reconnected the entire segment by November.

Persistence of brassy minnow in the three segments was strongly correlated with the extent of stream drying. The downstream segment dried the earliest and the most, and had the fewest brassy minnow and the lowest apparent survival and recruitment rate. In the middle segment, although brassy minnow were widely distributed in June, by late summer they were confined to a few reaches and scattered pools and backwaters in a few other reaches, and had not recolonized other locations by November. In the upstream segment brassy minnow were distributed throughout all reaches, and recolonized pools where they were extirpated or were never captured as flows increased in November. Measurements of the extremes of temperature and dissolved oxygen in individual pools during August showed that brassy minnow tolerated high late afternoon water temperatures and very low dissolved oxygen levels during early morning when it reaches a minimum. Means for late afternoon temperatures near the stream bed in pools ranged 26-32 C (79-90 F) for the three segments, and mean early morning dissolved oxygen ranged 1.32-1.84 ppm. Brassy minnow also disappeared from some pools that did not dry up, but in most cases it appeared that either the pool dried and refilled between surveys or that brassy minnow emigrated to adjacent pools with more favorable conditions as water levels declined.

Survival, growth, and recruitment of brassy minnow were also related to the extent of stream drying. Based on length-frequency histograms, brassy minnow survived to older ages in the middle and upstream segments than in the downstream segment. However, brassy minnow attained larger sizes (i.e., either lived longer, grew faster, or both) in the upstream segment than either of the other two segments, where growth was similar. Recruitment of age-0 brassy minnow into the sampled population failed in the downstream segment, where few fish of any ages survived to the end of the summer. In contrast,

recruitment of age-0 fish was successful in the other two segments, with many surviving through August to November. Larval brassy minnow were collected from nearly all reaches of the middle and upstream segments, and from three widely separated locations in the downstream reach, indicating that brassy minnow spawned even in the harshest segments. Of these spawning and larval rearing locations, about half dried up by August in the downstream and middle reaches whereas most remained wet in the upstream reach. Larvae were collected from all habitat types, including backwaters, pools, and runs. These data indicate that the brassy minnow population in the upstream segment would be best able to persist for long periods and recolonize reaches from which they were extirpated, by dispersal and reproduction.

Densities of brassy minnow, estimated by four-pass depletion seining, were similar among the three reaches (median 3.1 per m²), based on 8 pools where they occurred of 12 sampled. Brassy minnow were always detected on the first seining pass in pools where they occurred. Similarly, all other fish species were also detected on the first pass, except for a few rare species of which only a few individuals were ever captured. This indicates that our method of seining was very good for detecting presence and absence of brassy minnow, and all but the rarest other fish species.

Work during 2001 will focus on: 1) sampling larval fish and associated environmental features to further refine timing and habitat requirements for reproduction; 2) completion of two final surveys of the three segments during early and late summer to determine the extent of brassy minnow recolonization; and 3) analysis of data from the entire study to determine relationships among survival, movement, and abiotic and biotic factors at the habitat unit scale, and the landscape scale at which managers influence land use decisions.

Basic Information

Title:	Meeting Time-Dependent Instream Flow Requirements in a Fully Appropriated Multi-State River Basin
Project Number:	
Start Date:	3/1/2000
End Date:	2/1/2000
Research Category:	Not Applicable
Focus Category:	Water Quality, Water Quantity, Ecology
Descriptors:	Water quality, Water quantity, Land-water interactions, Watershed management
Lead Institute:	Colorado Water Resources Research Institute
Principal Investigators:	W. Marshall Frasier

Publication

1. Sperow, Mark. 1998. Three essays addressing production economics and irrigation: managing for drought and pests transported in irrigation water. Ph.D dissertation, Dept. of Agricultural and Resource Economics, Colorado State University. Morgan Library call # S618 .S54 1998.

Problem and research objectives

Water users in Colorado, Wyoming, and Nebraska have effectively fully appropriated the developed flows of the South Platte, North Platte, and Platte Rivers — primarily for irrigation uses. Water demand and the competition for existing supplies is growing throughout the basin and especially along the Front Range of the Rocky Mountains. At the same time, four species—the Whooping Crane, Piping Plover, Interior Least Tern, and Pallid Sturgeon—dependent on habitat associated with the Platte River in central Nebraska are listed under the federal Endangered Species Act (ESA) as either threatened or endangered. A three mile wide, 56 mile long section of the central Platte River in Nebraska has been designated as critical habitat for the Whooping Crane under the ESA. To comply with the ESA mandate for recovery of these species, the three states have agreed to increase stream flow through this reach by an average of 130,000 acre feet annually for the next 10 to 13 years. Approximately half of the water commitment is to come from specific water projects previously identified in the three states. However, the source of the remaining half of the committed water has yet to be identified and significantly more may be required in the future.

Altering existing Platte River water uses to make such a substantial amount of water available presents a major challenge. Throughout the West, state water laws establish priorities for intrastate water use, while interstate compacts (utilizing a broad range of formulas) provide rules for allocation between states. These rules have been established primarily to mediate water allocation among controlled diversions for out of stream uses. In contrast, institutions for satisfying emerging instream flow requirements are in their infancy. There is little actual experience in addressing needs for increased instream flows that are dependent on changes in management (e.g. reservoir operations), consumptive uses and legal institutions in multiple states. Further, the impacts and effectiveness of alternative approaches for meeting instream flow requirements are typically not well understood. Little is known about the required conditions and impacts of potential alternatives such as, interstate coordination, or use of market-type mechanisms, particularly in complex hydrologic systems with highly variable consumptive and nonconsumptive use demands.

The overriding objective of this study is to evaluate the feasibility, effectiveness and distribution of impacts and benefits of alternative institutional arrangements in delivering water for instream use in the lower reaches of the Platte River Basin. Specific objectives of this research are to:

- Identify a broad range of institutional, water management, and economic conceptual alternatives that may be used to satisfy instream flow quantity and timing requirements. The primary focus will be on alternatives that are consistent with existing interstate apportionments.
- Evaluate the institutional, legal, hydrologic and economic requirements of each of the conceptual alternatives and establish the necessary or prohibitive conditions for implementation. Explicit knowledge of the conditions necessary for alternatives will assist water resource managers and decision makers in developing effective programs.
- Identify economic costs and benefits to Platte River economic users impacted by the conceptual alternatives.
- Develop an integrated hydrologic, institutional, and economic river basin model that accounts for dominant sources and uses of water in the Platte River Basin under present water laws, policies and management institutions.

- Use the integrated model under baseline conditions to illustrate and evaluate the relative effectiveness in satisfying instream flow requirements and economic impacts of feasible selected alternatives.
- Conduct sensitivity analysis to explore the robustness and thresholds of feasible alternatives to variability in hydrologic and climatic conditions (e.g. streamflows and evapotranspiration requirements), and model assumptions (e.g. agricultural market conditions, characteristics of stream-aquifer interactions.)

Methodology

Identification and Evaluation of Institutional Alternatives

In a fully appropriated system such as the Platte, there are three general ways in which additional instream flows of water potentially can be made available: changing system water management, improving water use efficiency of existing uses, and transferring water.

We have arrayed the broad range of options for producing additional instream flows that might exist under each of these three general approaches. These options have been identified through a survey of the relevant literature, from the extensive knowledge and experience of the members of the research team, and from interviews with key water managers and water users in the basin. We have developed summary discussions that explain the identified options as a general matter and highlight general advantages and disadvantages, creating a broad menu of the possibilities that might be available for better meeting instream flow requirements in a western river basin. Requirements and opportunities specific to the Platte River Basin were developed simultaneously.

To narrow the set of potential alternatives, each was evaluated for feasibility according to a set of criteria that are determined as most important to those who rely upon the services of the river system. A set of feasibility criteria emerge naturally from the principles adopted to guide the project—legal, hydrologic, water potential, financial cost, third party impacts, and political. Legal feasibility evaluates the degree to which a given alternative can be implemented under existing state, interstate and federal laws and regulations. Hydrologic feasibility assesses the physical capability to generate stream flows in the critical reach during the necessary period of time for species protection. Water potential appraises the quantity of water that could potentially be made available and the reliability of that supply. Financial cost considers the likely annualized per-acre-foot financial cost of the alternative. Third party impacts identify the likelihood and magnitude of positive or negative effects to those not protected by water rights (includes changes in quantity, timing, quality or reliability of water resources). Political feasibility assesses the likely political and social acceptability of a given alternative, especially for issues of state sovereignty and the distribution of the burden allocated between and within states.

Identify Economic Impacts of Feasible Alternatives

Offstream and instream users of Platte River water will be impacted by alternatives which increase minimum instream flow levels in the critical reach. Because offstream water use is predominately agricultural, a major focus of our effort in this project is estimating economic impacts to agricultural uses in the three basin states. Some alternatives also impact municipal and industrial uses; economic impacts in these sectors are also being identified. Platte River water is also used instream for generation of hydropower and for recreation. (Offstream reservoirs are also important recreational resources.) We inventoried these uses and concluded that the magnitude of impacts was not comparable to identified offstream impacts in agricultural sectors, so no further analysis was conducted in this area.

The objective is to obtain the economic value and shadow price of water and the corresponding water usage from the various uses and benefits from the states and subregions within the Platte River Basin. The resulting economic benefit functions have been utilized in an integrated modeling framework to evaluate the impacts of the feasible alternatives.

Over 90 percent of the water in the Platte Basin is used by agriculture. Therefore when we look at opportunities to increase instream flows a primary focus is on agricultural use and impacts. Direct economic impact to agriculture is measured as the associated change in net income with a change in the timing and quantity of water use. Given the size and diversity of agricultural production, coupled with the hydrologic characteristics (timing and availability) over the broad region of the Platte River Basin, representative farm models have been constructed for identified sub-regions.

A single optimization framework has been adopted for representative farms in the Platte Basin, which can be customized to "regional" conditions of crop production, markets and water timings and availability. Discrete Sequential Stochastic Programming (DSSP) models have been formulated to accommodate the stochastic nature of water. We are particularly concerned with developing economic impact estimates across states (and regions within states, as necessary) which are comparable. We recognize that methodologies based on residual imputation (such as linear programming) can be particularly sensitive to assumptions such as cropping constraints, yields, and production costs. While these factors do vary across regions and hence lead to real differences between economic impacts of unit changes in water use across regions, it is important that valuation methodologies minimize the bias in estimates of these differences.

Integrated Framework for Evaluation of Selected Conceptual Alternatives

The conceptual alternatives identified above include approaches that reduce consumptive uses, change diversion levels, or alter the timing of deliveries. The spatial distribution and timing of such changes are a function of the conceptual alternative. Evaluating the effectiveness of the alternatives for achieving instream flow goals requires a framework for projecting economic and hydrologic impacts. Institutional alternatives may allocate water on the basis of hydrologic conditions (e.g. priority systems), economic values (e.g. water markets), or a combination of factors. A framework integrating institutions, hydrology, and economic value was developed to provide a basis for evaluating the effectiveness of institutional alternatives.

While currently pre-existing models are not be capable of addressing the effectiveness of our conceptual alternatives, they have played a critical role in providing data and calibration for our proposed Platte Basin model. The integrated framework provides a flexible environment for representing alternative institutions while accounting for a set of interactions between uses, storage (including groundwater), and flows (including diversions and return flows) in the Platte River Basin. The framework is spatially integrated to include major uses, storage, and flows in North, South, and central reaches of the Platte River. Because of the importance of interstate issues, including representation of relevant compacts and decrees, uses, storage, and flows are clearly identified by state (e.g. Colorado, Wyoming, or Nebraska).

Economic impacts can be both a consequence, and a determinant of the water allocations which are the solutions to models of the type discussed above. Because economic impacts of providing instream use are of central concern, it is appropriate to directly calculate such impacts within the model structure. In practice it is also necessary to make such calculations to determine allocations which maximize beneficial use. We will calculate and report such impacts by state, river reach, and sector (agriculture,

municipal, and industrial uses).

Because of the inherent variability in the hydrologic and economic parameters it is important to conduct extensive sensitivity and threshold analysis of the feasible alternatives. A primary purpose of the sensitivity and threshold analysis is to explore the robustness of feasible alternatives to variability in hydrologic and climatic conditions (e.g. streamflows and evapotranspiration requirements), and assumptions (e.g. agricultural market conditions, characteristics of stream-aquifer interactions.) For example, an alternative such as irrigation efficiency improvements may be effective in one region (e.g. just upstream of critical instream reaches), but may do little to increase instream flows if implemented far upstream of critical reaches. The effectiveness of a policy of subsidizing irrigation efficiency improvements would thus be highly sensitive to the financial benefits of adopting these technologies at different basin locations. The sensitivity analysis will help to identify the robustness of the alternative over a range of conditions.

Principal findings and significance

This research project is built upon a system of mathematical models that are currently being developed. Significant progress has been made in four general areas. 1) identifying and screening alternatives, 2) constructing the representative farm models, 3) developing and parameterizing basin hydrology model, 4) constructing the integrated basin model. However, few intermediate findings are available for disclosure at this time. The publications and papers that have come out of the project focus on institutional and methodological developments that have arisen in working on the specific objectives. While the work is largely completed, some effort is yet required to generate the final results. Preliminary analysis indicates significant sensitivity to some parameterizations. The final report detailing the findings of the study is forthcoming and will be published by the end of summer of 2001.

Basic Information

Title:	Data Analysis Support for Goal-Oriented Monitoring
Project Number:	HQ96Gr02660
Start Date:	3/1/1997
End Date:	2/28/2001
Research Category:	Not Applicable
Focus Category:	Water Quality, Methods, Management and Planning
Descriptors:	Water Quality, Water quality monitoring, Data analysis, Statistical analysis
Lead Institute:	Colorado Water Resources Research Institute
Principal Investigators:	Robert Carl Ward

Publication

1. Griffith, Lindsay Martin, Robert C. Ward, Graham B. McBride, and Jim C. Loftis. 2001. Data analysis considerations in producing 'comparable' information for water quality management purposes. NWQMC Technical Report 01-01, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colo.

Problem and Research Objectives

Water quality monitoring is being used in local, regional, and national scales to measure how water quality variables behave in the natural environment. A common problem, which arises from monitoring, is how to relate information contained in data to the information needed by water resource management for decision-making. This is generally attempted through statistical analysis of the monitoring data. However, how the selection of methods with which to routinely analyze the data impacts the quality and comparability of information produced is not as well understood as may first appear.

Measuring water quality conditions, as a means of defining water quality problems and developing solutions, has been a part of place-based water pollution control efforts since the mid-1900s. States established water pollution control policies and institutional arrangements to control water pollution as well as designed the means to measure the quality of the water to implement the policies. Passage of the Federal Water Quality Act of 1965 initiated legally defined requirements for states to ‘monitor’ water quality as part of an enhanced federal role in the nation’s water quality management efforts.

Before the federally required, state-based monitoring programs could mature, a major change in the United States’ approach to water quality management occurred with passage of the Federal Water Pollution Control Act Amendments of 1972 (commonly referred to as the Clean Water Act). While appearing to be an update of existing law, the 1972 Act revolutionized water quality management in the United States. Management of water quality now involved the issuing of discharge permits that, in cases of water-quality limited streams, required large volumes of information about water quality conditions in the impacted water body. Furthermore, lists of water bodies not meeting standards were required to be assembled (Section 303d) and periodic assessments of a state’s water quality conditions had to be prepared and submitted to the U.S. Environmental Protection Agency (Section 305b). At the same time, the new law required that discharge permits, where the receiving water was not water-quality limited, be ‘technology based’. Considerable effort, in the early years of implementing the new ‘Clean Water Act’, was consumed with controlling ‘point sources’ of pollution. It has only been in the last 10 years that attention has returned to the ‘water-quality’ limited water bodies in such a way as to highlight anew the need for extensive data and information about the nation’s water quality conditions and the impacts of ‘non-point sources’ of pollution.

Methodology

To help understand the connectivity between the selection of methods for routine data analysis and the information produced to support management, the following three tasks were performed.

An examination of the methods that are currently being used to analyze water quality monitoring data, including published criticisms of them.

An exploration of how the selection of methods to analyze water quality data can impact the comparability of information used for water quality management purposes.

Development of options by which data analysis methods employed in water quality management can be made more transparent and auditable.

These tasks were accomplished through a literature review of texts, guidance and journals related to water quality. Then, the common analysis methods found were applied to portions of a river water quality dataset from New Zealand. The purpose of this was to establish how information changes as analysis methods change, and to determine if the information produced from different analysis methods is comparable.

Principal findings and significance

For several years it has been known or suspected that current methods for producing information from water quality data are subject to misuse and inappropriate application. Lack of statistical knowledge has caused poorly planned method selection and results that are not always comparable. This project has documented the problems associated with data analysis method selection for water quality monitoring, in an effort to provide problem definition as the first step in creating a solution. The process of documenting these problems has led to the conclusions discussed below:

Reviewing literature on water quality monitoring reveals the frequent use of a common class of statistical procedures (i.e., hypothesis testing) to produce information about water quality from the raw data. The majority of reviewed analysis methods use the concept of “statistical significance” to validate the information produced, be it comparison of means/medians (e.g., upstream/downstream averages), evaluation of trends, or detection of extremes. It is with these methods that most of our knowledge about the water quality of our nation has been derived. From government monitoring projects to private monitoring studies, it appears from the literature review that, despite recent efforts to provide auditable information, data analysis procedures are often loosely planned and documented and statistical results rarely explained. Except for a few studies of water quality statistics (Harcum *et al.*, 1992; Hirsch, 1988; Montgomery & Reckhow, 1984, Montgomery & Loftis, 1987; Loftis *et al.*, 1989; McBride, 1998, 1999a), alternative analysis methods with which to compare results are never explored, their significance is rarely explained, and information, once produced, never questioned, just reported as is. Discussions that led up to publication, if they questioned the methods, are rarely shared with the reader.

Through EPA’s requirements for State 303(d) reports and 305(b) listing of impaired waters, it is apparent that the vision is being developed to create monitoring systems that will produce information that will answer basic questions about our nation’s water quality. But a review of state assessment methodologies and other water quality studies showed that the analysis procedures fall short of providing indisputable information due to the fact that the assessments are often based on subjective narrative criteria or relatively small monitoring data sets, and lack broadly peer-reviewed and agreed upon data analysis methods.

Although the methods selected to produce water quality information are generally being used correctly, they may not be universally accepted or appropriate for the type of information about the environment that is needed. The availability of numerous analysis procedures means that methods selected to produce the same type of information (i.e., trends) may be different, resulting in a non-comparable basis for the same management decisions.

Because hypothesis-testing methods have been available and widely accepted, their appropriateness has been rarely questioned in the field of water quality monitoring. An argument that is at the forefront of the medical sciences is whether to use hypothesis testing at all (Berger & Berry, 1988; Loftus, 1991; Chow & Liu, 1992; Royall, 1992; Royall 1997). The value of these discussions in medicine is that they illustrate to other scientific fields that there are concerns with creating valid information using hypothesis testing methods for data analysis (McBride *et al.*, 1993; McBride 1998, 1999a; Johnson, 1999).

The solution to producing more valid information for management decision-making depends on the appropriateness of the methods chosen for the type of questions being asked, and the comparability of these methods with other, similar assessments. Many supplemental and alternative methods to hypothesis testing could be utilized to aid in the interpretation of monitoring data, data which is influenced by so many unknown variables that interpretation is often difficult. The use of new methods that are more appropriate in creating scientifically defensible information is becoming more common in the medical

field (Chow & Liu, 1992). However, these methods have not managed to effectively infiltrate water quality monitoring. Medical and epidemiological studies have shown that the use of methods such as meta-analyses, Bayesian statistics, and equivalence testing can produce more objective and valid information from the data than standard hypothesis testing. These alternatives, as well as others, need to be explored for applicability to water quality data analysis, in an effort to produce more comparable information from monitoring.

Solutions to the problems documented in this research may not come through common analysis methods, but instead require a deeper understanding of statistical theory, closer connections to the use of the information (i.e., management input), as well as new thinking about data analysis procedures. These considerations in the development of 'standard' water quality data analysis protocols will help to ensure that the procedures are transparent and auditable, and that results are comparable.

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Information Transfer Program

Basic Information

Title:	Information Transfer
Start Date:	3/1/2000
End Date:	2/28/2001
Descriptors:	Information transfer, Technology transfer, Education
Lead Institute:	Colorado Water Resources Research Institute
Principal Investigators:	Robert Carl Ward

Publication

1. Keammerer, Warren R., Ed. Proceedings, High Altitude Revegetation Workshop No. 14. 2000. Information Series No. 91, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colo. 293 pp.
2. Brown, Jennifer, Ed. 2000. Money Flowing through the South Platte Basin: The Business of Water, Proceedings of the 11th Annual South Platte Forum. Information Series No. 92, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colo. 22 pp.
3. Garcia, Luis A., Dave Patterson, Robert W. Lange, in cooperation with Jon Altenhofen, James R. Hall, Forrest Leaf and Jack Odor. 2001. South Platte Mapping and Analysis Program (SPMAP): Decision Support Tools for the Lower South Platte. Completion Report No. 193, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colo. 30 pp.

CW RRI UPDATE



Left: The New Water Plaza at Colorado State University

(Photo courtesy of John Eisele, Photographic Services, CSU)

In August of 2000 CW RRI and the CSU Water Center moved to new offices in Room E102 Engineering Building just off the new Water Plaza, the physical representation of Colorado State University's water tradition. This central campus location provides better access to campus facilities as well as allowing better coordination with water faculty and students.

The plaza celebrates Colorado State University's past, present and future activities in water. The highest point of the fountain, which artist William Jackson Maxwell entitled the "water drum," serves as the water source for the fountain and thus represents the source for water, or the sky.

The artist intended for the drum sticks, another feature of the water drum, to represent the various departments engaged in water-related activities at CSU. One of the original architects for the Plaza also suggested that the drum is linked to the Native American tradition of the rain dance, reflecting aspects of Colorado's history and climate.

The concrete streambed is representative of the complex structures of water transportation around Colorado. This meandering concrete trough symbolizes Colorado's various ditch companies and major water projects, such as the Colorado-Big Thompson project. At the same time, it displays native cobbles found in local streams and rivers, a reminder of the importance of natural resources.

The stream leads to a metaphorical dam and storage element of the design. Here the flow is augmented by water bubbling up from the circular, stainless steel water basin at the end of the stream. The basin represents another source of water – the ground. The stored water exists through a Parshall Flume, or one of three 'weirs.' CSU Engineering Professor Ralph Parshall developed the Parshall Flume in 1925. Elwood Mead, for whom Lake Mead is named, established the nation's first program of study in irrigation engineering at CSU in 1884.

CONNECTIONS TO WATERUSERS/MANAGERS

CW RRI provides the latest water information and research results to Colorado water users, managers and the public via an active technology transfer program.

The CWRRRI newsletter, *COLORADO WATER*, is published six times a year, with approximately 30-40 pages of water information including research findings, lists of water faculty and water courses, upcoming water conferences, short courses and seminars, new water research projects, and water news summaries. The newsletter is distributed widely throughout Colorado, to state water institutes, selected federal agency personnel out-of-state, and others upon request. The newsletter can be found at the CWRRRI web site.

WEB SITES

CWRRRI maintains the following web sites:

The CWRRRI Homepage at <http://cwrri.colostate.edu>

Welcome to the Colorado Water Resources Research Institute Web Center	
History and Mission of CWRRRI	Upcoming Events NEW
Site Map and Jump Station	Jobs in Water Resources
Research Programs at CWRRRI	Faculty with Expertise in Water
The Ival V. Goslin Collection	Cooperative Extension Water Specialists
June 2001 Newsletter NEW	Water Courses at Colorado Universities
Newsletters	Publications
Water in the Balance No.9 – Drought NEW	Water In the Balance Archives
Useful Water Links	Contact CWRRRI
CWRRRI KidsZone!	About Colorado Water Concerns NEW
Draft FY 2002 CWRRRI Request for Proposals	



The Water Center web site at:
<http://watercenter.colostate.edu>

The Water Center brings together a rich history in water related education and research with diverse talent from 25 different departments at Colorado State University to form a group of educators and researchers interested in water resources. In addition, the following information can be found at the web site:

Professional Development

[Jobs in Water Resources](#) [Meetings/Seminars](#)

Educational Opportunities

[Water Related Courses at Colorado Universities](#)
[Short Courses](#) [Scholarships](#)

Study Water at CSU – Undergraduate

[Undergraduate Water Minor](#)
[Research Experiences for Undergraduates in Water](#)

Study Water at CSU – Graduate

[Water Information for New CSU Graduate Students](#)

COLORADO WATER KNOWLEDGE

The Colorado Water Knowledge web site at: <http://waterknowledge.colostate.edu>

● Colorado Water --

A huge list of water facts!

A description of stream processes and an overview of Colorado's geology, water history, and climate. Links to water related definitions are also provided.

A description of Colorado's major river basins and aquifers, how the water from these sources is used and managed, and methods for conserving Colorado's water.

A description of the fish and aquatic insects present in Colorado's waters, wetlands, water quality, and links to environmental laws.

A description of transmountain diversions, interstate compacts, Colorado water rights law, and federal, state, and local administrative agencies.

A list of frequently asked questions and answers about Colorado water.



The South Platte Forum web site at: <http://southplatteforum.colostate.edu>



**Money Flowing Through
the South Platte Basin:
The Business of Water**

***11TH ANNUAL
SOUTH PLATTE FORUM***

**October 24-25, 2000
Raintree Plaza Conference Center
Longmont, Colorado**

Above: South Platte River near Greeley



The Hydrology Days web site at: <http://HydrologyDays.colostate.edu>

Hydrology Days 2000		
REGISTER	20th Annual HYDROLOGY DAYS April 3-6, 2000 Lory Student Center, Colorado State University Fort Collins, Colorado Sponsored by: Hydrology Section of the American Geophysical Union	
SUBMIT PAPERS ONLINE		
PAPER GUIDELINES		



The Research Experiences for Undergraduates Program at: <http://waterreu.colostate.edu/>

**Research Experiences for Undergraduates
Program in Water Research at
Colorado State University**



Summer 2001

The National Science Foundation and the Water Center at Colorado State University offer a unique opportunity for 15 undergraduate students from four-year colleges and universities to conduct independent research in Water Science and Engineering during 8 weeks each summer under the guidance of faculty in the departments of Civil Engineering, Earth Resources, Soil and Crop Science, Chemical and Bioresource Engineering, Fishery and Wildlife Biology and Rangeland Ecosystem Science. The goal of the program is to provide a comprehensive research experience that will motivate students toward a research career in water. Students will work in teams including faculty, graduate students, and staff to conduct research and gain hands-on experience in laboratory and field research methods. Applications must be submitted by **March 30, 2001**.

P U B L I C A T I O N S

CWRRI publishes and distributes water research information via the following publications:

- *WATER IN THE BALANCE*, a user-friendly new publication series that provides a condensed version of research completion reports that gives water users a 16-24 page review and analysis of the results of research conducted under the auspices of the State Water Institute Program.
- **COMPLETION REPORTS**--Final reports on completed research containing details of procedure, analysis of data and conclusions reached.
- **TECHNICAL REPORTS**--Technical information of interest to water resource professionals.
- **INFORMATION SERIES**--Information of general public interest on water-related subjects.
- **OPEN-FILE REPORTS**--Complete reports of research that are provided at cost upon request. These reports consist primarily of theses and dissertations from CWRRI-funded research projects.

CWRRI is in the process of converting all of its publications for availability on the World Wide Web.

M E E T I N G S A N D C O N F E R E N C E S

**Arkansas River Basin Water Forum
Colorado Springs, Colorado**

CWRRI cosponsors this annual meeting that gathers together water interests in Colorado's Arkansas River Valley. The 2000 meeting, held March 16-17, headlined Colorado's Fountain Creek Watershed. The spring 1999 flooding that originated in the Fountain Creek basin highlighted in a dramatic way the

importance of this tributary. Also, the effects of water rights transfers for urban use and the effects of Colorado Springs' rapid growth are now being seen in the watershed. Streambank erosion, sediment, and higher peak flow rates are just a few of the issues the forum addressed.

**Hydrology Days
Colorado State University
April 3-6, 2000**

The **20th Annual Hydrology Days** was held April 3-6, 2000 on the campus of Colorado State University. The meeting was dedicated to Professor Hubert J. Morel-Seytoux, Professor Emeritus of Civil Engineering at Colorado State, who founded Hydrology Days in 1981. The meeting has been held each year since on the campus of Colorado State University. Hydrology Days provides an opportunity for students to present papers in a friendly, yet professional, atmosphere and have the opportunity to meet leading hydrologists and hydrology-related professionals. The four-day program includes contributed papers, student papers and a poster session. CWRRI sponsors the annual meeting.

United States participants came from Colorado State University, the University of Colorado, the Colorado School of Mines, the University of California-Davis, Arizona State University, the University of Oklahoma, the U.S. Department of Agriculture's Great Plains Research Unit and Natural Resources Conservation Service, the U.S. Bureau of Reclamation, the U.S. Geological Survey's Midcontinent Ecological Science Center, Applied Weather Associates, Johnson Controls Inc. of Fort Collins, Colorado, Pacific Northwest National Lab, and Coastal Consulting of Huntington Beach, California.

International participants came from Weldwood of Canada Ltd., Hinton Alberta, Canada; the University of Genoa, Genoa, Italy; the Universidade Federal de Ceara, Ceara, Brazil; the University of Bonn, Bonn, Germany; the University of Genova, Savona, Italy; the University of Western Australia; the University of Ljubljana, the Mohammadia School of Engineers, Agdal-Rabat, Morocco, and from Consulting Eng. Of Tehran Iran and PWITT, Tehran, Iran.

**25th Annual Colorado Water Workshop
Clean and Flowing Water
Western State College, Gunnison, Colorado
July 26-28, 2000**

The following question set the stage for the three-day Colorado Water Workshop: "The Colorado Constitution guarantees that the right to divert shall never be denied, but recent developments in water quality, instream uses and federal flow requirements are making new demands on our water resources. How do these demands fit into Colorado's prior appropriation system? Can Colorado water law protect historic uses and meet the water demands of the 21st century?"

More than 30 speakers addressed various components of the above questions. Ultimately, the overarching theme was a recognition of the more recently acknowledge beneficial uses of water and the challenge of addressing those while maintaining the tried-and-true tenets of Colorado's water law system.

**Money Flowing Through the South Platte Basin:
The Business of Water
11th Annual South Platte Forum
October 27-28, 1999**

The 11th Annual South Platte Forum brought together approximately 140 water users and managers, state and federal agency personnel, academics and students in water-related programs to hear views on **Money**

Flowing Through the South Platte Basin: The Business of Water. Keynote speakers were David Robbins of Hill and Robbins, Denver, and Colorado's former Governor Dick Lamm. The forum also included a poster session. Marshall Frasier, Department of Agricultural Economics, presented an economist's view of "*Water Wars of the West.*"

**Student Water Symposium
Colorado State University
November 8-10, 2000**

The 2000 Colorado State University Student Water Symposium was held November 8-10 at the Lory Student Center on the CSU campus. The fourth annual event featured over 40 water-related presentations, including both poster and oral, given by students representing about 10 different departments at Colorado State University. In addition to a full program of student presentations, the Water Symposium hosted 11 guest speakers in two individual keynote addresses:

People, Land and Water in the New West: A Look to the Future -- Dr. William Reibsame, Professor of Geography, University of Colorado, and editor of *Atlas of the New West: Portrait of a Changing Region*;

Challenges in Adaptive Management of Riparian Ecosystems – Mr. Josh Korman, Systems ecologist and modeler.

and two panel discussions:

Dam Removal: Toward an Ecological Engineering and Societal Balance; and
Influence of Water Policy Evolution on Challenges Faced and Solution Options in Water Resources.

S T U D E N T I N T E R N P R O G R A M

The Institute continued its Student Intern Program in FY2000, a program designed to increase student interest in water issues. Student interns worked on the following projects.

Children's Water Festivals--Children's Water Festivals are fun for both students and presenters. These festivals are an excellent way to educate Colorado's children about one of our most precious resources, WATER. CWRRI interns taught children about Careers in Water. The students dressed in attire for their profession and taught other members of their class about their Career in Water.

Student interns also helped maintain, improve and update the CWRRI World Wide Web Homepages, monitored press reports and prepared newsletter summaries of water issues in Colorado; and researched background material for unfolding water issues and developed in-depth articles and-or publications.

USGS Summer Intern Program

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	15	0	0	0	15
Masters	4	0	0	0	4
Ph.D.	1	2	0	0	3
Post-Doc.	0	0	0	0	0
Total	20	2	0	0	22

Notable Awards and Achievements

AWARDS AND ACHIEVEMENTS

The Four States Irrigation Council presented its 1999 Headgate Award to John Wilkins-Wells, Professor of Sociology at Colorado State University. The award is presented to a person who has been active and supportive of irrigation and water resource management in Colorado. John was recognized for his work with agricultural water supply organizations over the past four years. He currently is principal investigator for a Bureau of Reclamation-sponsored study of five western states' irrigation districts and mutual irrigation companies. John was co-investigator of a USGS/CWRRI-sponsored project dealing with mutual irrigation company monitoring of main canal nitrogen levels.

On April 27, 2000, CSU Provost Loren Crabtree presented Robert Ward with the first Provost's Award for Interdisciplinary Environmental Achievement for his work as director of the CSU Water Center and CWRRI. The award ceremony took place during the First Annual Lecture Series, which highlighted a presentation by Patricia Nelson Limerick, leading historian of the American West.

The National Science Teachers Association has selected the COLORADO WATER KNOWLEDGE web site to include in its database of materials. The site was selected by a NSTA team of teachers. When a reader of a sciLINKed textbook comes across a sciLINKS icon in their textbook, they know that the content on that page has been enhanced with online content specifically connected to a single concept. The reader goes to the free sciLINKS WEB SITE, type in a code found on the pages of that text, and the sciLINKS search engine reports the pages the teachers selected. The main sciLINKS page is located at <http://www.scilinks.org/>

Publications from Prior Projects

1. Kenney, Douglas S. 2000. Laws Influencing Community-Based Conservation in Colorado and the American West: A Primer. Completion Report 192, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colo. 51 pp. Available from the Natural Resources Law Center, University of Colorado, Boulder, Colo.
2. Martin, Lindsay Melissa. 2000. The Role of Data Analysis Methods Selection and Documentation in Producing Comparable Information to Support Water Quality Management. M.S. Thesis, Dept. of Chemical and Bioresource Engr., Colorado State University. Call # TD367

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