Colorado Water Resources Research Institute
Annual Technical Report
FY 2001

Introduction

Drought and wildfire conditions in the Spring of 2002 have overshadowed other water management concerns in the State of Colorado, and in some other Western states as well. On April 22, 2002 Colorado Governor Bill Owens requested an emergency drought disaster designation by the Agriculture Secretary for the entire State of Colorado. On the same day, Governor Owens requested activation of the Drought Mitigation and Response Plan. On May 31 Colorado and ten other western states were declared a federal agricultural disaster area because of the worst drought in decades.

The Colorado State Engineers Water Supply Conditions Update for June, 2002 shows all basins, with the exception of the South Platte, in severe drought conditions. The update shows the South Platte Basin in the moderate drought range. Reservoir storage, the major component in evaluating South Platte Basin conditions, was 73 percent of normal at the end of May.

The Colorado Water Resources Research Institute has, during its 37-year history, produced drought information that it has made available on its website. One publication in particular, Water in the Balance No. 9, describes new techniques for drought monitoring that have been developed in Colorado and presents results of drought studies that have been supported by the Colorado Office of Emergency Management, the Colorado Water Resources Research Institute, and the Colorado Agricultural Experiment Station. The publication, titled A History of Drought in Colorado: Lessons Learned and What Lies Ahead, was developed jointly by the Colorado Climate Center and CWRRI with collaboration from the Colorado Water Conservation Board. The report summarizes more than 20 years of research findings related to drought in Colorado. It was prepared for the Governors Flood and Drought Conference in 1999 to explain the nature of Colorados aridity and the implications for humans living in the states various river basins.

On the CWRRI website, at http://www.cwrri.colostate.edu, is a button to access Drought- Related Publications and Links.

FY 2001 CWRRI RESEARCH PROGRAM

At the annual October 15, 2000, meeting of CWRRIs Advisory Committee for Water Research Policy (ACWRP) in Denver, faculty in charge of the four FY2000 CWRRI projects and graduate students presented updates on the progress of their research. The presenters and topics were:

1. Lee MacDonald Forest/Water Management Interface 2. Jim Loftis and Justin Twenter Source Water Monitoring 3. Tim Gates Arkansas Valley Salinity 4. Kurt Fausch and Julie Scheurer Brassy Minnow Life Cycle

The first two projects began on March 1, 2000, and were of one-year duration. The last two projects were in the second year of projected three-year durations. The ACWRP reviewed progress on the two multi-year projects and decided to fund them for a second year. The projects were:

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, and Israel Broner, Department of Chemical Engineering, Colorado State University. (James C. Valliant, Extension Irrigation Specialist, Cooperative Extension, Colorado State University was originally listed as a co-investigator. He retired in April, 2002.) 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.

The committee then voted to devote remaining research funds to two research thrusts, mapping in the South Platte and nutrients in reservoirs, equally. Four proposals were identified as fitting these priorities and received the remaining CWRRI FY 2001 research funding:

Enhancements to the South Platte Mapping and Analysis Program (SPMAP) The Principal Investigator is Luis Garcia, Department of Civil Engineering, Colorado State University. (CWRRI funds were supplemented with funds from the Northern Colorado Water Conservancy District, the Lower South Platte River Group, and the Central Colorado Water Conservancy District.

Managed Ground Water Recharge for Habitat Restoration: The Development of an Expert System for a Biological Component to the South Platte Mapping and Analysis Program (SPMAP) The Principal Investigator is Luis Garcia, Department of Civil Engineering, Colorado State University.

Eutrophication of Reservoirs on the Colorado Front Range The Principal Investigator is Jim Loftis, Department of Civil Engineering, Colorado State University. Co-Investigators are Brett Johnson, Department of Fishery & Wildlife Biology, Colorado State University; and Laurel Saito, Department of Civil Engineering, Colorado State University. (CWRRI funds were supplemented with funds from the cities of Denver, Fort Collins and Westminster.)

Applicability of Various Trophic Status Indicators for Colorado Front Range and Plains Reservoirs. The Principal Investigator is John Stednick. Department of Earth Resources, Colorado State University.

FY2001 USGS National Competitive Grants Program -- Professors Eileen Poeter, John McCray, and Geoffrey Thyne of the Colorado School of Mines were recipients of one of nine awards made in the FY2001 U.S. Geological Survey National Competitive Grants Program. The award for the project, Use of Low-Cost Data to Simulate Fractured-Aquifer Watersheds for Management of Water Quality and Quantity,was made through the Colorado Water Resources Research Institute in April, 2002. There is no progress to report on this project at this date. The project was initiated in late May after completing the contract award, the subcontract with the Colorado School of Mines, and the establishment of accounts to allow spending on the project.

CWRRI Activities and Accomplishments

Water Archive Established at Colorado State University -- Colorado State Universitys rich and longstanding tradition of water research, education and service is now complemented by the creation of a new Water Resources Archive. Located in new archive facilities in the remodeled Morgan Library, the Water Resources Archive will preserve, protect and promote the history of Colorado water through the papers, maps, and records of significant figures such as Ival G. Goslin, Whitney Borland, Robert Glover, J.R. Barkley and James L. Ogilvie, whose collections inaugurate the Archive.

The collection includes the papers of: J.R. Bob Barkley, outlining his participation in the National Water Reclamation Association from 1934-1969 (the National Water Resources Association today); the Rocky Mountain Hydraulics Research Station near Allenspark, Colorado; and the Colorado Water Resources Research Institute. The Archive also houses the Ival Goslin Collection, which consists of a complete set of the technical data and reports generated by the Colorado Water Resources and Power Development Authority during the 1980s. The Goslin Collection documents Colorado's continued water project planning despite President Carters late 1970s removal of the Federal government from such planning. The papers of Whitney Borland, Robert Glover and James L. Ogilvie describe the careers of prominent water engineers involved in a number of Bureau of Reclamation projects and other water developments from the 1930s until the 1980s.

The Archive represents a partnership of the Colorado Water Resources Research Institute (CWRRI), the Colorado Agriculture Archive, and CSU Libraries to sustain important collections that document individual and organizational efforts that have influenced the availability of todays water resources. Professor John Newman, Colorado State University Archivist, is directing the creation and operation of the new water archive. As collections are received, CSU staff organize the materials, properly store them, and develop guides to collections. The University Archives staff provides a world class-service to archive users so this rich history can be tapped in an environment that respects the historical importance of the materials. The Water Archive now includes the following papers:

UYWCD Water Scholarship -- The Upper Yampa Water Conservancy District (UYWCD) is funding a new $2500 scholarship at Colorado State University for the next school year. The one-year scholarship, administered by CWRRI and the CSU Water Center, was established to provide financial assistance to committed and talented juniors who are pursuing a water-related career in any major at CSU. Joshua Duncan was the recipient of the 2001/2002 UYWCD Scholarship. Joshua is a junior in Civil Engineering, and plans a career in hydraulic engineering and water resources. He will seek a Masters degree upon completion of his BS degree in May 2002, and then work toward obtaining his professional engineering license.

3-F Scholarship -- Tracy Phelps, graduate student in the Department of Earth Resources specializing in surface-water hydrology, is the recipient of the CWRRI/CSU Water Centers 3-F Graduate Fellowship for the 2001-2002 school year. Tracy is working with her adviser, Ellen Wohl, on the North Fork of the Cache la Poudre River investigating 3-dimensional velocity characteristics in a six-meter riffle section of the river. Tracy hopes to find correlations between velocity characteristics and site-specific variables, and to investigate temporal characteristics as well.

National Science Foundation Grant - An NSF grant awarded to Jorge Ramirez, Department of Civil Engineering, through the CSU Water Center, has given a unique opportunity for 15 undergraduate students from four-year colleges and universities to conduct independent research in Water Science and Engineering during and 8-week summer session. Students worked in teams that included faculty, graduate students, and staff to gain hands-on experience in laboratory and field research methods. Students were under the guidance of faculty from the departments of Civil Engineering, Earth Resources, Soil and Crop Science, Chemical Engineering, Fishery and Wildlife Biology, and Rangeland Ecosystem Science.

Annual Water Resources Seminar -- 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, 2001 seminar focused on the History, Current Use and Future of the Prior Appropriation Doctrine. The speakers examined issues surrounding use of the Prior Appropriation Doctrine to allocate water in Colorado during rapidly changing times.

Additional CWRRI Activities Involving Local, State and Federal Agencies and Other Organizations -- The CWRRI/CSU Water Center Director and Water Resources Specialist have contributed to the following activities involving water in Colorado:

As president-elect of the National Institutes for Water Resources (NIWR), Robert Ward took the lead in organizing the 2001 annual meeting,

Assisted the National Association of State Universities and Land Grant Colleges (NASULGC) Water Committee, the Universities Council on Water Resources (UCOWR) and the National Institutes for Water Resources (NIWR) in developing a response/initiative to the NRC report on the water research agenda for the 21st century. At present NIWR is hoping to have several institute directors appointed to the new NRC committee on coordination of, and investment in, federally funded water research.

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

Serves as peer reviewer for two NRC council reports (TMDLs and NAWQA design enhancements);

Working with the Colorado Water Conservation Board to establish a student intern program whereby diverse students are brought into the organization for summer jobs;

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

Served as peer reviewer for two NRC council reports (TMDLs and NAWQA design enhancements);

and is a member of the following organizations: the National Water Quality Monitoring Council, the Colorado Water Quality Monitoring Council (CWRRI played a major role in establishing the Council), the Bureau of Reclamations Research Steering Committee, the Poudre Heritage Alliance (Commissioner designate), the GreenCO Water Task Force, Fort Collins Water Board, and the Larimer-Weld Water Issues Group.

Note: Membership of the CWRRI Advisory Committee on Water Research Planning is provided for in CWRRIs by-laws. The ACWRP is comprised of: the Chair of the Colorado Senate Committee on Agriculture, Natural Resources and Energy, the Chair of the Colorado House Committee on Agriculture, Livestock and Natural Resources, the Executive Director of the Colorado Department of Natural Resources, the Executive Director of the Colorado Department of Public Health and Environment, the Commissioner of the Colorado Department of Agriculture; and six members of the general public selected based on their participation in setting Colorado water policy in the legislative process and involvement in obtaining funding for such policy. The ACWRPs 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. See Attachment A for a list of members of the CWRRI Advisory Council on Water Research Policy.

Reagan Waskom, Water Resources Specialist for the Colorado Water Resources Research Institute, is principal or co-principal investigator on the following research/education projects: an investigation of selenium on Colorados West Slope and an agricultural education project funded by the U.S. Department of Agriculture, a project related to phosphorus runoff funded by the U.S. Department of Agriculture and the Environmental Protection Agency, and a project on ground water education funded by the Colorado Department of Agriculture.

Research Program

Meeting Time-Dependent Instream Flow Requirements in a Fully Appropriated Multi-State River

Basic Information

Title:	Meeting Time-Dependent Instream Flow Requirements in a Fully Appropriated Multi-State River
Project Number:	1998CO0017G
Start Date:	9/1/1998
End Date:	8/31/2000
Funding Source:	104B
Congressional District:	4th
Research Category:	Not Applicable
Focus Category:	Economics, Law, Institutions, and Policy, Management and Planning
Descriptors:	Institutional adjustments, economics, multiple-objective planning, decision models
Principal Investigators:	W. Marshall Frasier

Publication

1. The principal investigator has completed the publication and pending the return of reviewer comments it will be published by CWRRI. Publication should be within the next two months.

Managed Groundwater Recharge for Habitat Restoration: The Development of a Biological Component to the South Platte Mapping and Analysis Program (SPMAP)

Basic Information

Title:	Managed Groundwater Recharge for Habitat Restoration: The Development of a Biological Component to the South Platte Mapping and Analysis Program (SPMAP)
Project Number:	2001CO821B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Ground-water Flow and Transport
Focus Category:	Ecology, Groundwater, Hydrology
Descriptors:	Stream depletion factor, Augmentation, GIS, State-listed Aquatic Species,Habitat restoration
Principal Investigators:	Luis Garcia , Luis Garcia

Publication

1. Shrier, Catherine, The Development of an Expert System for Habitat Restoration Through Managed Groundwater Recharge, in Proceedings of the Fifth Annual Colorado State University Student Water Symposium, p. 14, published on-line at the Student Water Symposium website http://watersym.colostate.edu/
2. Garcia, Luis and Catherine Shrier, Managed Ground Water Recharge for Habitat Restoration: The Development of a Biological Component to the South Platte Mapping and Analysis Program (SPMAP), Progress Report presented at the CWRRI Advisory Council on Water Research Policy (ACWRP) annual meeting, November 5, 2001, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO.

SYNOPSIS

Project Number: 2001CO821B **Start:** 3/01
End: 2/02

Title: Managed Ground Water Recharge for Habitat Restoration: The Development of a Biological Component to the South Platte Mapping and Analysis Program (SPMAP)

Investigators: Luis Garcia

Congressional District: 4th

Focus Categories: GW, MOD, WL, WQN

Descriptors: Decision Models
Ecosystems
Geographic Information Systems
Surface-Groundwater Relationships
Wildlife Management

Problem and research objectives: The South Platte Lower River Group (SPLRG) was organized to address critical water management problems in the lower portion of the South Platte basin. SPLRG'S focus is the creation and enhancement of (1) groundwater well augmentation, (2) in-stream flows for which Colorado receives credit in a Platte Basin Endangered Species Program or ESRP, and (3) wetlands and wetland habitat for aquatic wildlife species of concern, waterfowl and other wildlife species. Under the *Tamarack Plan*, SPLRG is overseeing the development of a series of managed groundwater recharge projects to re-time river flows in order to assist with in-state water management and to provide Colorado's water contributions to the Platte River ESRP. In pilot recharge projects developed at the Tamarack Ranch State Wildlife Area, SPLRG, the Colorado Division of Wildlife (CDOW), and Ducks Unlimited (DU) have integrated habitat components into recharge facility designs, including the use of multiple recharge ponds to control temperature of return flows, the development of a live stream fed by ponds, and the development of a wetland area fed by recharge return flows (see Figure 1).

There is strong interest among private land owners in the region in developing additional recharge facilities for the *Tamarack Plan* to meet interstate water obligations, and in designing these recharge facilities both for wildlife habitat and for recharge credits for in-state water use. There is also strong interest from CDOW in continuing to restore wildlife habitat at the new recharge facilities. In 2001, the CDOW received a directive from Colorado Department of Natural Resources Director Greg Walcher to work towards the prevention of further federal threatened and endangered species listings in Colorado, and to attempt to recover currently listed species to the point where they can be de-listed. Several partnership programs with state and federal agencies and private wildlife organizations are available that can provide financial and technical assistance to private landowners who develop habitat on their property. The partnership programs include the U.S. Fish and Wildlife's Partners for Fish and Wildlife and the Natural Resources Conservation Service's Wildlife Habitat Incentive Program (WHIP) and Wetlands

Reserve Program (WRP). These partnership programs can fund 75% to 100% of the costs for construction of the recharge facilities and also provide technical expertise in the design of the facilities to maximize the potential habitat benefits. Joining private landowners with habitat partnership programs also helps the mainly agricultural users to meet the costs of developing recharge facilities for well augmentation and for the Three States Agreement.

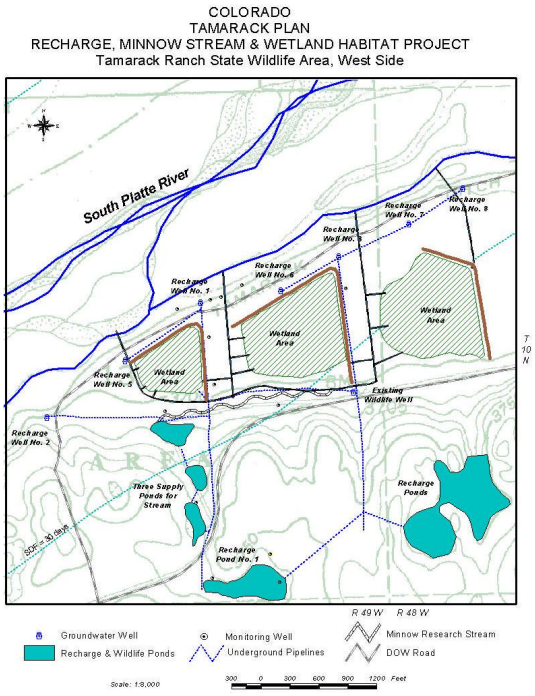


Figure 1. Tamarack Plan Recharge, Minnow Stream & Wetland Habitat Project

The goal of this research project is to develop tools that will help increase the amount of wetlands and wetlands habitat for aquatic wildlife species of concern, waterfowl, and other wildlife species in the lower South Platte River by linking recharge facility development with habitat development partnership programs. This will be accomplished primarily by:

1) developing a screening tool to identify locations for recharge facility development;
2) collecting and providing to partnership programs that develop habitat information on existing habitat development activities, species sampling activities, and CDOW wildlife management activities at State Wildlife Areas, CDOW data on riparian vegetation, and water user organization information on the location and availability of water storage and delivery facilities; and
3) facilitating a more formal relationship between habitat development partnership programs and the water user organizations by providing educational materials on habitat development on private lands targeted to the lower South Platte River of Colorado, so that the development of habitat on private lands and distribution of funds to private landowners can occur in a more coordinated manner.

A GIS-based tool is being developed to support a coordinated approach among partnership programs, CDOW, and water user organizations to the development of habitat at new managed

groundwater recharge facilities, particularly on private lands. The suitability of individual recharge sites has not been extensively modeled, but a knowledge base will be developed that will represent the expertise of engineers with experience in the development of recharge facilities. The knowledge base will be linked to user inputs and to GIS-based data that is either already available or that will be developed through this research. This tool is being developed as a biological module to the South Platte Mapping and Analysis Program (SPMAP), with 2001-2002 funding support from the Colorado Water Resources Research Institute (CWRRI) and CDOW. SPMAP is a program that is already used by water user organizations and CDOW for management and planning of well augmentation requirements in the lower South Platte.

Methodology

In developing a decision support tool that will increase habitat enhancement activities in association with managed groundwater recharge facilities in the lower South Platte, the researchers took the following steps during the 2001-2002 year of the project:

Task 1 Determine what habitat development activities can be performed in conjunction with the development of managed groundwater recharge facilities, and what steps would be required to evaluate a site for potential recharge facility and habitat development.

Several meetings were held with Colorado Division of Wildlife and Ducks Unlimited personnel, who designed the recharge and habitat demonstration project (Figure 1). Discussions concerned how those habitat components were designed and what site characteristics were necessary to support the development of those habitat components, which included: fish ponds, temperature control ponds, a live fish stream, restored sloughs, and wetland cells for waterfowl. Literature on habitat development methods was reviewed, particularly for waterfowl and fishponds. Ducks Unlimited personnel were consulted regarding their approaches to development of waterfowl habitats on private and public lands.

Northern Colorado Water Conservancy District Water Resources Engineer Jon Altenhofen was interviewed concerning parameters necessary for recharge pond development.

Task 2 Determine what partnership programs would be available for private land sites and what habitat development would be necessary for use of public wildlife lands for recharge facility development.

Several people were consulted regarding their funding programs and eligibility requirements (CDOW, USFWS, several NRCS District Managers and a couple of Ducks Unlimited South Platte Coordinators). NRCS checklists and technical reports were reviewed to ascertain management practices used by NRCS for partnership program eligibility determination.

To better understand the legal issues surrounding the development of recharge ponds on private lands, meetings were attended which addressed the legal constraints surrounding the use of State Wildlife Areas, which were purchased with federal funding support on the condition that the lands be used for wildlife-related purposes. Separate meetings were held with CDOW personnel

to discuss the constraints on uses of State Wildlife Areas and to review the CDOW draft Master Management Plan for the Tamarack Ranch State Wildlife Area.

Task 3 Identify the potential users and determine what user-inputs can be expected.

Potential uses for a computer-based tool that would be used to screen individual sites for recharge or habitat development feasibility or to support watershed-level planning for the development of multiple recharge or habitat sites were discussed in meetings with representatives from water user organizations and partnership programs. Individual landowners were contacted to determine their level of interest in partnership programs for habitat development on private lands. The amount of time and type of data that could reasonably be expected for user inputs was also assessed in the meetings with landowners.

Task 4 Identify and acquire available GIS themes containing data needed for evaluation of potential recharge and habitat development sites, and analyze GIS themes to determine whether they have appropriate scale, resolution, and accuracy for use in site or watershed scale analysis.

Available fish sampling data for the lower South Platte River was reviewed with CDOW Fish Biologist Jay Stafford. GIS themes showing locations of sampling sites with links to sampling data and photographs of sampling sites were created in cooperation with IDS GIS Specialist Dave Patterson. Meetings were held with CDOW Aquatic Section GIS Specialists to acquire data on fish sampling in the lower South Platte.

Monthly meetings of the CDOW Integrated Management Process (IMP) workgroup for the lower South Platte/Area 3 prototype were attended. The IMP workgroup had been tasked with developing "a support system to landscape management decisions and plan development by others … intended to provide a means of categorizing data and conditions and applying Geographic Information Systems to manage the data in ways that are useful to and support analysis of specific landscape conditions, support management decision making, integration of decision impacts and monitoring of selected conditions." Separate meetings were also held with members of the IMP workgroup and members of the CDOW GIS Group. Wildlife –related GIS themes were acquired with the help of the IMP workgroup.

Data and metadata from the web-based Natural Diversity Information Source (NDIS) on species and habitat in the lower South Platte were reviewed and downloaded, including data from the Colorado Riparian Mapping Project, Regional Gap Analysis Project, and Basinwide Mapping Project.

GIS themes that had been acquired were analyzed to determine whether the scale and resolution was suitable for site-specific or watershed scale analysis and whether the attribute tables associated with shapefiles contained appropriate data.

Task 5 Review alternative approaches to knowledge-base development, in order to be able to use a knowledge-based approach to link knowledge about the development of recharge facilities and habitat development with GIS-based data and site-specific user inputs.

The U.S. Forest Service's Ecosystem Management Decision Support (EMDS) system, a "knowledge-based decision support for ecological assessment" based in ArcView, was acquired and reviewed using the NetWeaver knowledge base development system. Excel-based decision support systems created by CSU Professor Darrell Fontane also were reviewed. The option of purchasing software for developing knowledge bases and inference engines versus programming simple decision support systems using Excel with Visual Basic was investigated.

Task 6 Develop prototype knowledge base for assessment of potential recharge pond sites.

A rule base for the assessment of potential recharge pond sites entered the initial stage of development. The rule base was founded upon interviews with Northern Colorado Water Conservancy District Water Resources Engineer Jon Altenhofen. The rules were evaluated to determine which parameters could be based upon GIS data or calculations in ArcView or Excel and which would require user inputs.

Principal findings and significance

Task 1 Determine what habitat development activities can be performed in conjunction with the development of managed groundwater recharge facilities, and what steps would be required to evaluate a site for potential recharge facility and habitat development.

In conjunction with DOW employees, it was determined that greater control could be exerted over the design of the pond site itself and of any habitat components to which water from the ponds would be diverted (e.g. wetland cells) than over the impacts of the return flows from the recharge ponds on the main stem of the river. The habitat potential analysis should be focused on off-stream activities rather than on impacts to the river.

Parameters necessary to evaluate sites for recharge pond development were identified. The principal parameters necessary for evaluation of potential recharge pond sites include:

> water availability; pond size, depth, and quantity and timing of water available for pond; market for recharge credits; landowner membership in water user organization; surface soils; presence of an alluvial aquifer; saturated thickness of the aquifer; depth to groundwater at the pond site; stream-depletion factor at the pond site; and whether the property is riparian or there are other landowners between the recharge pond site and the river.

Several of the necessary parameters to evaluate sites for habitat development for some types of habitat were identified. The principal parameters necessary for evaluation of habitat development include:

> surface soils; proximity to other areas managed for wildlife, including State Wildlife Areas and privately managed wildlife areas; proximity to other ponds; vegetative cover; proximity to dwellings and roads; proximity to known species populations; prior land use; use of pesticides at or near the site; landowner willingness to develop recharge facility; landowner willingness to work with

partnership programs; landowner willingness to retire land for specified period of time (e.g. 30 years), or permanently.

Task 2 Determine what partnership programs would be available for private land sites and what habitat development would be necessary for use of public wildlife lands for recharge facility development.

Several habitat partnership programs for which private lands, and particularly riparian irrigated lands, could be eligible were identified. Partnership programs identified include:

NRCS Wildlife Habitat Initiative Program (WHIP)
NRCS Wetlands Reserve Program (WRP)
NRCS Environmental Quality Improvement Program (EQIP)
USFWS Partners for Fish and Wildlife Program
Ducks Unlimited-North American Wetlands Conservation Act (NAWCA) Grant for the Lower South Platte River Wetland and Riparian Restoration Project, Phase I

It was determined that available partnership programs may change with passage of the 2002 Farm Bill. The USDA Conservation Reserve Enhancement Program (CREP) for irrigated farmlands was considered, but since the program is still under development for Colorado and is not yet available, it will not be included yet in this research effort.

Task 3 Identify the potential users and determine what user-inputs can be expected.

During meeting with Partners for Fish and Wildlife South Platte Coordinator, it was determined that the USFWS and NRCS programs work through the local Soil Conservation Districts to identify potential private landowner partners and to gain access to private lands to identify potential sites. The funding arrangements by partnership programs through soil conservation districts were discussed as well as the ways that partnership programs coordinate site visits and plan for distribution of habitat sites in conjunction with soil conservation districts. The possibility of developing a similar arrangement with the water conservation districts was explored. Types of computer-based information that would be useful to Partners for Fish and Wildlife in their planning and coordination efforts were discussed.

Several landowners who have been involved in habitat development partnerships were interviewed. They answered questions concerning incentives for participating in partnership programs, types of information that could be readily provided by landowners, and level of interest in use of computer-based tools and educational information.

The Ducks Unlimited Great Plains Regional Office was consulted to learn about information needed for strategic planning of waterfowl habitat development in the South Platte. Ducks Unlimited made it clear that they need to know legal and other constraints under which habit development will occur. Ducks Unlimited is looking for documentation of SPLRG activities and driving forces on private lands in the region.

Task 4 Identify and acquire available GIS themes containing data needed for evaluation of potential recharge and habitat development sites, and analyze GIS themes to determine whether they have appropriate scale, resolution, and accuracy.

Field records with current fish sampling data was acquired. A GIS-based tool was developed that shows the location of each sampling site with links to sampling data (species collected, number of each, sampling date, etc.) and links to photographs of the sampling site (Figure 2). CDOW fish sampling data from Aquatic Section GIS Specialists was acquired. CDOW GIS data was correlated with the current fish sampling data.

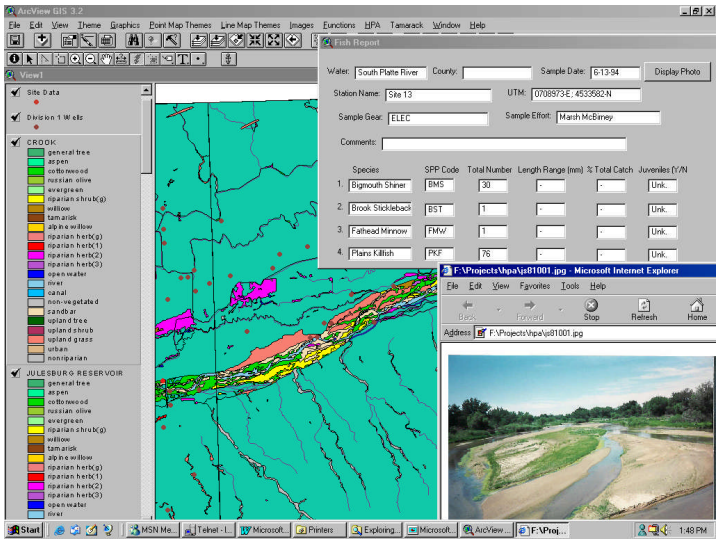


Figure 2. Habitat Potential Assessment Tool GIS themes:
South Platte hydrography, fish sampling data, riparian vegetation, photo link of sampling site

In cooperation with CDOW Integrated Management Planning Workgroup and CDOW GIS personnel, GIS data on riparian vegetation map and Natural Diversity Information Source (NDIS) maps using Basinwide Mapping vegetation data (hard copies of maps only, GIS-based data not provided by CDOW) were obtained. Meetings were held with Colorado Natural Heritage Program and CDOW personnel to determine data sources, scales, and accuracy estimates. It was determined that the Riparian Maps have the highest resolution and the highest level of accuracy but that the Riparian Mapping Program and Basinwide Mapping Program use different classification schemes to identify vegetative land cover. Also, it was ascertained that the NDIS species-vegetation affinity determinations were made using a different classification system from either the Riparian Mapping Program or the Basinwide Mapping Program. (Figure 3).

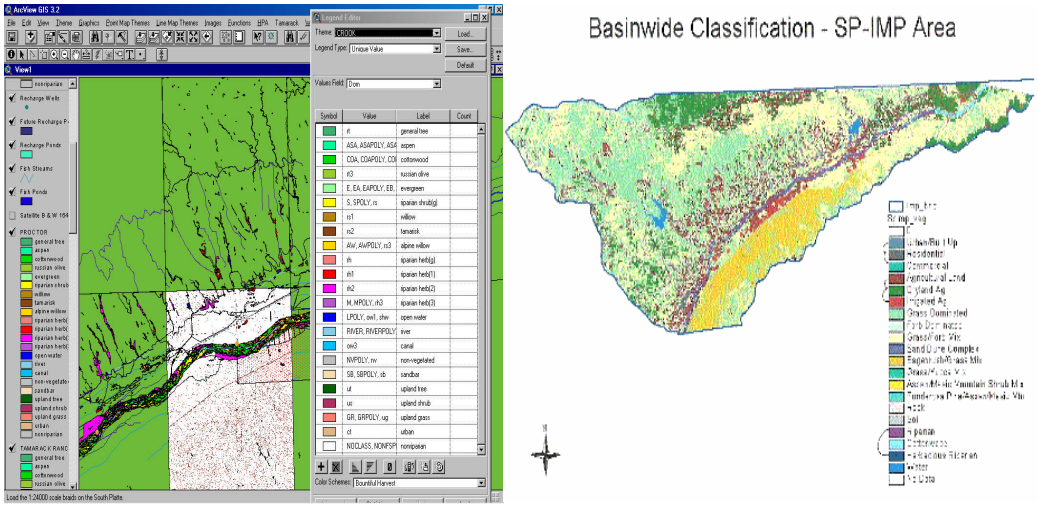


Figure 3. Images of the Riparian Mapping Program GIS-based data showing the vegetation classification scheme (left) and the Basinwide Classification map showing the Classification Scheme for the lower South Platte (SP-IMP Area) (right).

The availability of soil survey data in GIS format was investigated. Detailed soil survey data (approximately 1:24,000 scale) was discovered for Morgan County. The data was developed by a consultant for the County, was complete in the early 1990s, but was not certified by the National Rescues Conservation Service. Data for the remainder of northeastern Colorado was found only in "STATSGO" format, which are 1:250,000 scale soil survey maps, intended for state, regional, or multi-state scale analysis, with data tables from the 1980s. Hard copies of SCS/NRCS Soil Surveys and USGS Hydrologic Maps for Morgan, Logan, Sedgwick, and Washington Counties were acquired. The alternative of contracting CSU Pedology and Soils Lab to digitize Sedgwick County soils using paper soil surveys was explored. A meeting with State Soil Scientist Cameron Loerch revealed that 1:24,000 scale "SSURGO" maps are being digitized during the 2002 fiscal year for Logan, Sedgwick, and Phillips Counties.

A list of Area 3 (lower South Platte) State Wildlife Areas and a GIS-based shapefile of State Wildlife Area maps was acquired. Attribute tables for State Wildlife Areas showing the management and protected species present at each State Wildlife Area , as determined from review of MMPs and CDOW summaries of SWAs were created (Figure 4).

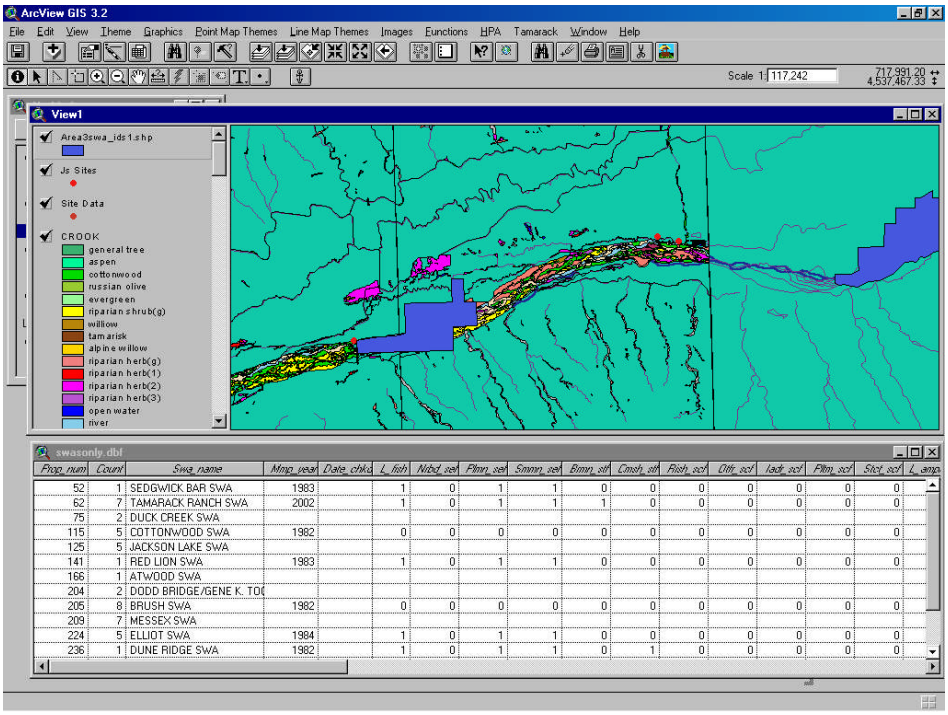


Figure 4. HPAT with GIS maps showing State Wildlife Areas and attribute table of game species and listed species, and dates of Master Management Plan

Task 5 Review alternative approaches to knowledge-base development, in order to be able to use a knowledge-based approach to link knowledge about the development of recharge facilities and habitat development with GIS-based data and site-specific user inputs.

Telephone and email interviews were conducted with the developers of EMDS and regarding the applicability of EMDS for our purposes (Figure 5). Matt Turner at the US Forest Service's Institute for Monitoring and Inventory in Fort Collins was also consulted regarding their use of NetWeaver for GIS-based data analysis. It was determined that, while EMDS can be used for fuzzy logic analysis of GIS-based data, there is limited flexibility in the output and presentation of findings of analysis if EMDS is used. Therefore, the use of an Excel-based knowledge base with links to GIS for inputs and outputs will provide greater flexibility in the development of a recharge potential assessment tool. An Excel-based knowledge-based system (KBS) shell developed by CSU Professor Darrell Fontane was evaluated, and programming of Excel-based KBS for recharge feasibility assessment began.

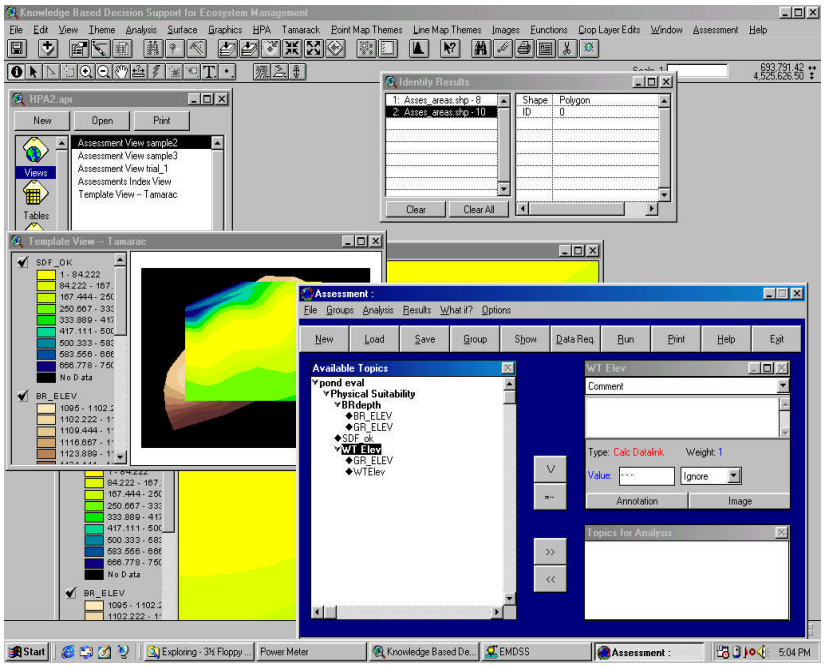


Figure 5. Sample EMDS Assessment for recharge

It was determined that the data and level of knowledge available for recharge facility development exceeds the data and level of knowledge available for habitat potential assessment. Also, investigation revealed that habitat potential assessment needs lie more in the area of watershed scale planning and improved understanding of the constraints of the various programs involved in habitat and recharge facility development.

Task 6 Develop prototype knowledge base for assessment of potential recharge pond sites.

The programming of the rule base in Excel and development of GIS themes to be linked to rule base was initiated, based on interview with Northern Colorado Water Conservancy District Water Resources Engineer Jon Altenhofen (Figure 6).

Microsoft Excel - CatSampleRule_Demo(2).xls

	A	B	C	D	E	F	G	H	I	J	K
1	Rule Based Solution Using EXCEL by Cat Shrier										
2	Based on a worksheet developed by D.G. Fontane, Oct. 2001										
3							Input Lists				
4	Input	SDF	Depth to WT	Sat Thick	Soil Type	Pond Depth	SDF	Depth to WT	Sat Thick	Soil Type	Pond De
5	Data	>=150 d	>=15 ft	>= 30 ft	Clay	0-2 ft	No Data	No Data	No Data	No Data	No Dat
6							>=150 d	>=15 ft	>= 30 ft	Sand	0-2 ft
7	Conclusions	Rules	Habitat	Recharge			150 d >x>=50 d	15 ft > x >= 5 ft	< 30 ft	Clay	>2 ft
8		1					<50 d	< 5 ft			
9		2									
10		3	Wetland	Poor							
11											
12											
13											
14											

Figure 6. Programming of the rule base

Enhancements to the South Platte Mapping and Analysis Program (SPMAP)

Basic Information

Title:	Enhancements to the South Platte Mapping and Analysis Program (SPMAP)
Project Number:	2001CO822B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Engineering
Focus Category:	Agriculture, Groundwater, Water Use
Descriptors:	Conjunctive use of groundwater/surface water, Augmentation, Geographic information system,Agricultural consumptive use
Principal Investigators:	Luis Garcia , Luis Garcia

Publication

1. Garcia, Luis; 2001, South Platte Mapping and Analysis Project, in Wassup in the South Platte Basin, Proceedings of the 12th Annual South Platte Forum, October 24-25, 2001, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, p. 33.
2. Garcia, Luis, 2001, Enhancements to the South Platte Mapping and Analysis Program (SPMAP), Progress Report presented at the CWRRI Advisory Council on Water Research Policy (ACWRP) annual meeting, November 5, 2001, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO.
3. Garcia, L.A. South Platte Mapping and Analysis Program, presented at the 21st Annual Hydrology Days, April 2-5, 2001, Ft. Collins, CO Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO.
4. Garcia, L.A., 2001, South Platte Mapping and Analysis Program, presented at the 2001 GIS of the Rockies Conference, September 20th, Denver, CO.

SYNOPSIS

Project Number: 2001CO822B

Start: 3/01
End: 2/02

Title: Enhancements of the South Platte Mapping and Analysis Program (SPMAP)

Investigators: Luis Garcia, Colorado State University, Fort Collins, CO

Congressional District: 4th

Focus Categories: AG, GW, WU

Descriptors: Conjunctive use, Groundwater-surface water, Augmentation, Geographic information system, Agricultural consumptive use

The Issue

Water managers in Colorado are faced with balancing many competing demands for water. Water is needed for crop irrigation, for domestic use, for mimicking natural flow rhythms to protect aquatic habitat, and for recreation. In order to meet the challenge of allocating a finite amount of water amongst an increasing number of users, water managers need sophisticated tools. The South Platte Mapping and Analysis Program (SPMAP) provides water managers with a common set of computer tools and data that can be used to accurately estimate augmentation requirements and model the area for future changes.

History of the Project

In the 1970s and 1980s, CWRRI funded research to develop mathematical models describing interactions between surface and groundwater in alluvium aquifers along the South Platte River. The utility of these early models was limited by the available technology. At that time, it was difficult to integrate data systems into the models, and user interfaces were daunting rather than friendly. In the ensuing years, microcomputers and satellite technology have improved dramatically allowing for the creation of SPMAP.

The SPMAP project began in 1995 when the IDS Group, directed by Dr. Luis Garcia at Colorado State University, started to work with a number of local and regional water management organizations along the South Platte River. As a consequence of the combined support of the CWRRI at CSU and the water management organizations SPMAP has become a benchmark of applied research resulting from collaboration and communication with end users.

SPMAP is a set of computer tools constructed to enhance water management by carefully matching data acquisition system design, modeling, and user interfaces to meet the needs of decision makers in the Lower South Platte River Basin. SPMAP is a data centered, modular set of tools. This means that the data are generic and tools are developed in such a way that all the modeling efforts can use the same data. Individual models are developed as part of a larger

framework but can be easily added or subtracted from the system in response to the needs of the user.

Water managers and the IDS Group initially identified two pressing needs for the South Platte River Basin. The area needed an accurate spatial database and a set of analytical tools for computing farm water budgets and consumptive use (CU) of groundwater in order to help quantify the impact of groundwater well pumping on the flows of the South Platte River.

During 1995-96, project efforts focused on spatial data collection and evaluation. A Geographic Information System (GIS) module was developed as an extension to ArcView 3.0a. The GIS module allows the user to view point, line, polygon, and image coverages. The current system contains themes for irrigated lands, well locations, stream depletion factors, hydrography, weather stations, county boundaries, roads, cities, and more.

In 1997-1998, the project focused on developing a Consumptive Use (CU) Model and an interface for a Stream Depletion Factor (SDF) Model. Satellite images were purchased to determine irrigated land area. A Graphical User Interface (GUI) for the CU Model was constructed. The GIS module can be used to locate fields and the surface and/or groundwater sources that provide water to them. This information along with the crop types grown in each field and the weather station information can be stored in an ASCII file. The CU Model imports the ASCII file and uses it to create an input file that is used to calculate the CU and any pumping requirements.

During 1998-1999, SDFView and the Stream Depletion Factor (SDF) Model were released. SDFView can be used to estimate the lag time when irrigation well water is pumped from or water is recharged to an alluvial unconfined river aquifer and when a depletion or accretion happens in the river. Required input information for SDFView is irrigated consumptive use from well water or net recharge amounts and SDF values for irrigation wells or recharge basins. SDFView is a stand-alone interface for Windows 95/98/NT. SDF View was released as part of the Three State Agreement to the State of Nebraska to help them manage South Platte groundwater wells in Nebraska.

In 1999-2000 the project team concentrated on finishing SPMAP, SDFView and CU Model interfaces to the satisfaction of the cooperating water managers and the IDS Group. A stand-alone interface for the CU Model was developed. This interface makes the CU Model more flexible although coordination with SPMAP still makes data entry easier and more comprehensive.

Additional options were added to the CU Model in 2000-2001. Water managers requested that CU Model be able to retrieve data from HYDROBASE, a statewide model being developed by the state engineers office. A new version of the CU Model was introduced with this added capability.

Accomplishments for 2001-2002

Participating organizations recommended that the IDS Group should continue to enhance the SPMAP tools in 2001-2002. In response, the IDS Group upgraded the GIS data layers and added functionality to the SPGIS. All the GIS data layers were re-evaluated and a metadata file was created for each of them. The following coverages were upgraded or created this year:

- Roads
- Wells
- Cities
- Stream Depletion Factors (10-day)

The extension that has been created to allow users to export GIS information into the CU model can now be downloaded along with most of the GIS data layers from a webpage. The URL for the website is:

http://www.ids.colostate.edu/projects/spgis/index.html.

In a significant change to the SPGIS system, the process of creating input to the SPCU model has been streamlined. The SPCU model editor has now been linked to an icon in ArcView. To bring up the editor, the user clicks on the icon of the well shown next to the scissors in the Figure 1.

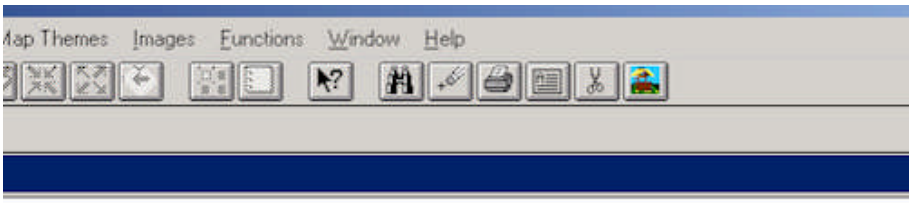


Figure 1: Well Icon in ArcView

A pop-up window is displayed (Figure 2).

This window contains tools for creating and editing the layers required by SPCU. This includes functions for creating new irrigated fields and assigning attributes to them such as crop type and field application efficiency. Fields are then assigned to farms, which can then be exported to serve as the basis for a new SPCU input dataset. This dialog has been significantly enhanced based on input from the water users.

Another function that has been added to SPGIS is the ability for the user to create a well theme from HYDROBASE based on the legal description. Also, the capability of SPGIS to generate well locations from legal descriptions has been improved by changing the procedure used to locate points in alliquate sections; the error in irregular sections is now moved to the northwest corner. The pop-up screen for allowing the user to generate legal description locations for points is shown in Figure 3.

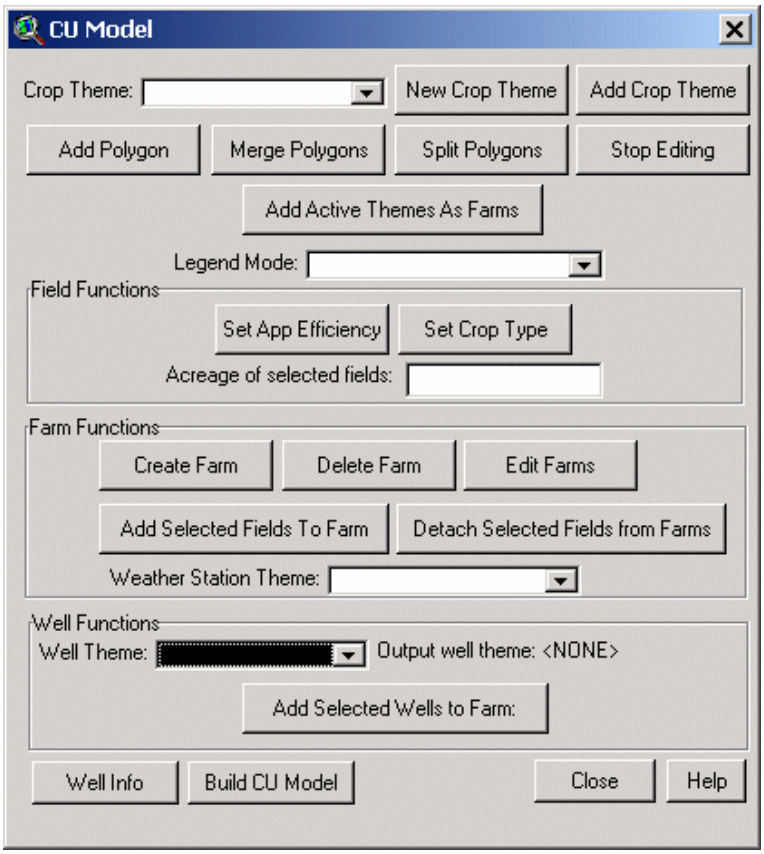


Figure 2: SPCU Input Editor

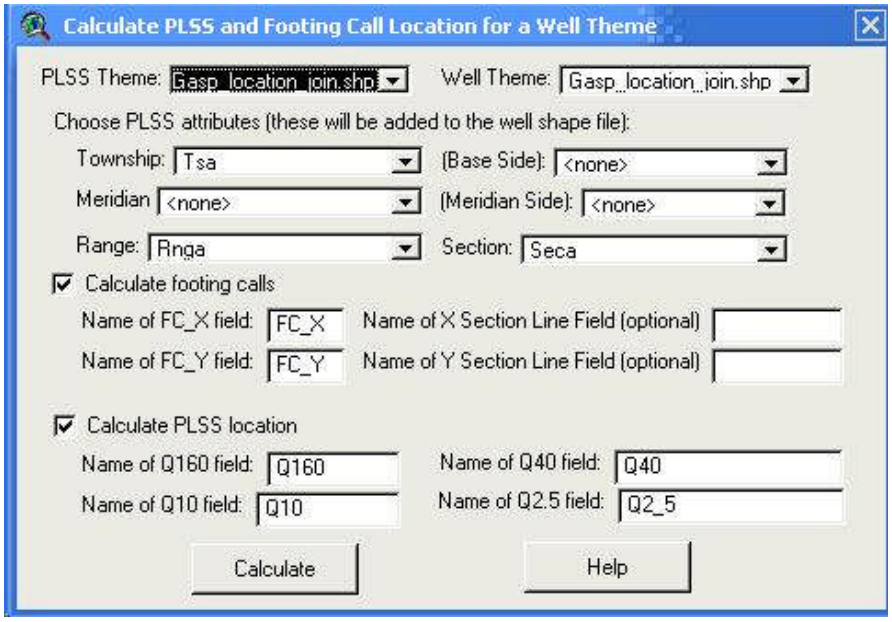


Figure 3: Generating Well Locations from Legal Descriptions

Output displays for the CU Model were expanded to include all year types (calendar, irrigation, and water).

To better analyze wells and recharge occurring close to the river, SDFDaily was created so that stream depletions and accretions could be computed and displayed on a daily basis. SDFDaily is based upon the Analytical Stream Depletion Model, a model created by the Office of the State Engineer-Division of Water Resources.

The Analytical Stream Depletion Model allows the user to assess the impacts of an alluvial groundwater well or a groundwater recharge facility on a nearby stream. The output of hydrographic data is displayed in user-specified time-steps and using different boundary conditions, important considerations when analyzing wells or recharge facilities within a mile of the stream channel. Depletion can be computed to a stream of infinite length or to a segment of the stream. Pumping can be input at a constant or variable rate. No-flow boundaries can be simulated parallel or perpendicular to the stream. Stream depletion factor is computed using equations described by Glover and others. The source code for the program is written in BASIC.

SDFDaily translates the Analytical Stream Depletion Model into the C^{++} programming language, adds graphic capabilities to the model, and gives the model a new, user-friendly interface. Users still specify yearly, monthly, weekly, or daily time-steps, but now with SDFDaily output data is displayed in graphs and tables. Figure 4 shows the input screen.

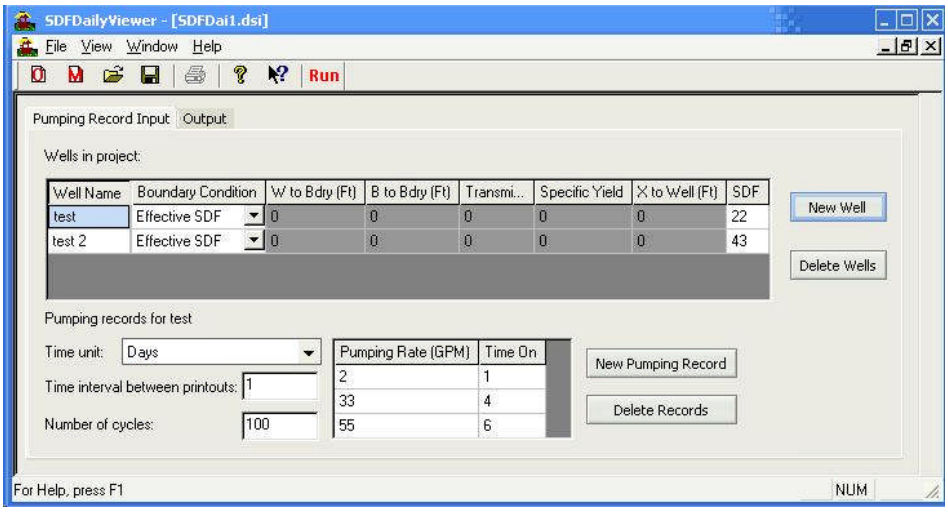


Figure 4: Input Screen for SDFDaily

Figure 5 shows SDFDaily output.

SDFDaily can also be operated in a modified mode (Figure 6), which is based upon the SDFView interface. It is anticipated that SDFDaily will eventually replace SDFView.

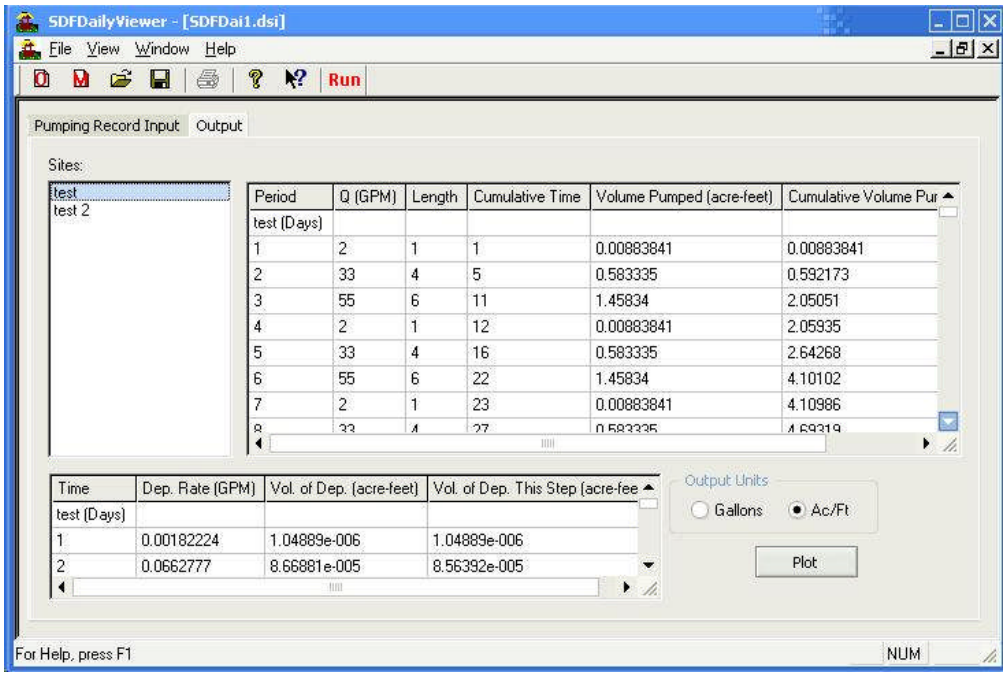


Figure 5: SDFDaily Output Screen

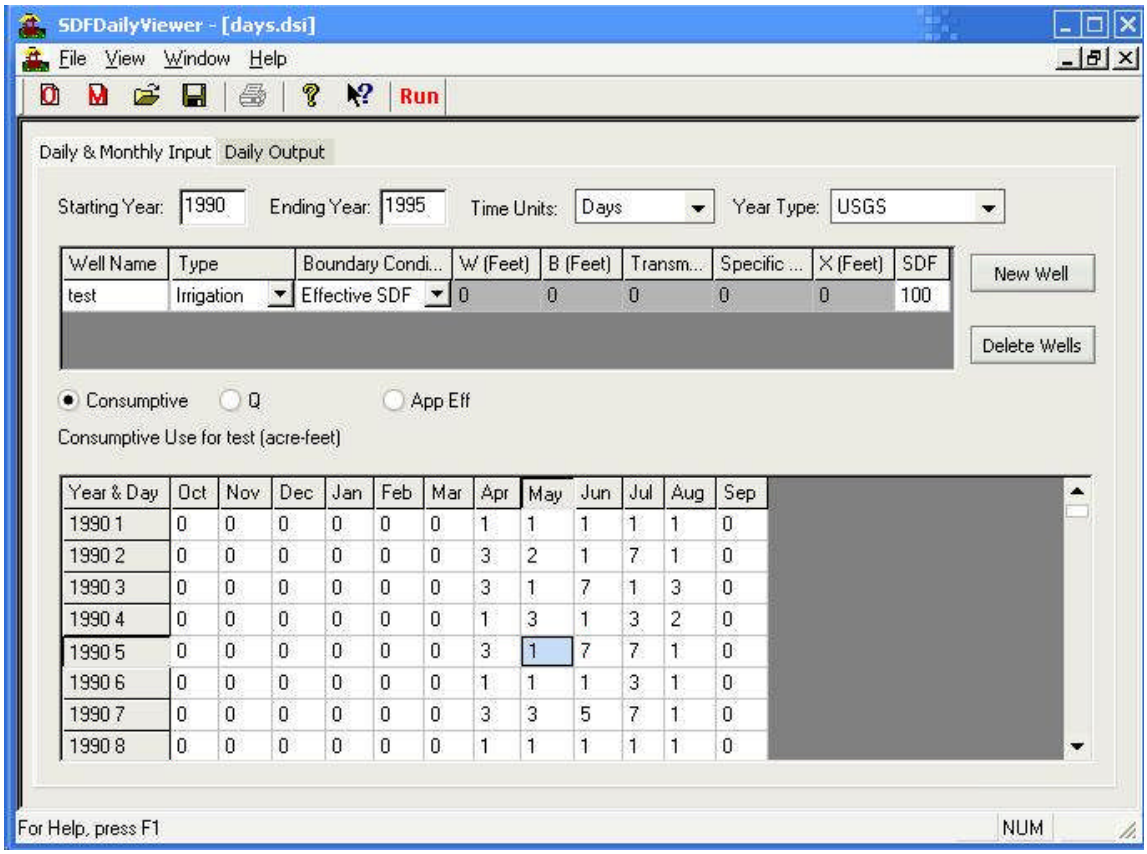


Figure 6: SDF Daily Input Screen with an Interface Based on SDFView

The SDFView model is used by a number of water users groups. It is used regularly by the Ground Water Appropriators of the South Platte and the Northern Colorado Water Conservancy District.

This year Central Colorado Water Conservancy District started to digitize all their fields and farms and the locations of their wells. They are planning to use all the tools developed as part of this process to help them develop their augmentation requirements. We worked closely with them in making enhancements tools to simplify the process. This process was very rewarding and productive for us. Next year they plan to expand their use of the tools and provide additional matching funds for development of additional capabilities to the system to allow them to import all their historical data and to create some additional capabilities for them.

Module upgrades can be accessed through the IDS website.

http://www.ids.colostate.edu/projects/splatte

The IDS Group at CSU continued to work closely with local water organizations. Ongoing efforts include developing a model to assist in assessing wildlife habitat in the South Platte, upgrading interfaces, and developing tools for accessing databases of the water user groups.

Team Participants

Luis Garcia, Colorado State University
Jon Altenhofen, Northern Colorado Water Conservancy District
James Hall, State Engineer's Office
Forrest Leaf, Central Colorado Water Conservancy District
Randy Ray, Central Colorado Water Conservancy District
Jack Odor, Groundwater Appropriators of the South Platte
Brent Nation, Groundwater Appropriators of the South Platte

Eutrophication of Reservoirs on the Colorado Front Range

Basic Information

Title:	Eutrophication of Reservoirs on the Colorado Front Range
Project Number:	2001CO861B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Biological Sciences
Focus Category:	Ecology, Nutrients, Water Quality
Descriptors:	Reservoirs, Eutrophication, Drinking water, Nutrients
Principal Investigators:	Jim C. Loftis , Brett Johnson , Laurel Saito

Publication

1. Saito, Laurel; Brett Johnson, John Bartholow, and Blair Hanna, 2001, Assessing Effects of Reservoir Operations on the Reservoir Ecosystem Using Food Web-Energy Transfer and Water Quality Models, presented at Hydrology Days, 2001, Department of Civil Engineering, Colorado State University, Fort Collins, CO.

SYNOPSIS

Project Number: 2001CO861B

Start: 3/01
End: 2/02

Title: Eutrophication of Reservoirs on the Colorado Front Range

Investigators: Jim Loftis, Colorado State University, Fort Collins, CO
Laurel Saito, Colorado State University, Fort Collis, CO
Brett Johnson, Colorado State University, Fort Collis, CO

Congressional District: 4th

Focus Categories: WQL

Descriptors: water quality, reservoirs, modeling, monitoring

Problem and research objectives

Eutrophication, or the aging of lakes and reservoirs due to nutrient inputs, has been observed in many, if not most, Colorado Front Range reservoirs. Notable examples include Standley Lake, Lake Loveland, and Horsetooth Reservoir. While eutrophication is a natural process, the rapid pace with which it is occurring in Front Range reservoirs is a cause for concern. For many reservoirs in the region, a shift in use is occurring rapidly as well, away from irrigation water storage and toward municipal water supply, with generally more stringent requirements for water quality. In several reservoirs water quality has already been impacted to the extent that treatability for municipal water supply is affected, and in some cases recreation and aesthetics have been impacted also. In addition to taste and odor concerns associated with excess algae production, elevated levels of total organic carbon (TOC) are an increasing concern because of the harmful and stringently regulated disinfection by-products that result from chlorinating waters high in TOC. Management intervention may be necessary across the region for protecting these beneficial uses over the long term. Certainly, public awareness must be raised on a state-wide level.

To date, Front Range Reservoirs have been studied individually, and management has been addressed on a case-by-case basis. This approach makes sense in that each system is unique limnologically, and the uses of the reservoir are often primarily local. The disadvantages of this approach are, however, that there are very likely common lessons that could be learned regarding causes, effects, and potential solutions to the eutrophication problem. A regional approach, rather than an individual approach, is necessary to explore these commonalities.

Primary 0bjectives of the project are to

1. Review and synthesize existing data and information on the water quality conditions and trends of Front Range water supply reservoirs, concentrating on trophic status.
2. Identify gaps in data needed for determining the causal mechanisms that control trophic status and water quality of these systems.

3. As existing data permit, identify similarities and differences among the reservoirs that would suggest opportunities or constraints for developing regional approaches to management.
4. Review existing reservoir quality models and determine how well the characteristics of the reservoirs in the study match the assumptions and key governing relationships of each model
5. Determine whether a regional approach to modeling makes sense, and if so, which of the available models is most appropriate.

Objectives #4 and #5 have evolved over the course of the study.

Methodology

The research methodology has two components, the first is to develop, implement, and evaluate the results of a survey of Front Range water suppliers. And the second is to review and evaluate existing reservoir water quality models.

The survey was developed from an initial meeting with Front Range water suppliers. The survey was implemented by meeting with each participant and then having them supply detailed information on study reservoir characteristics and water quality issues of importance to them. The results were complied in an Access database for analysis.

Reservoir water quality models were evaluated by matching the assumptions and governing equations of each model to study reservoir characteristics. For a few cases, the models were actually run and results evaluated. A review of commonly applied eutrophication models including those from Alex Horne, BATHTUB, Chapra and Canale, CE-QUAL-W2, DYRESM-CAEDYM, EUTROMOD, Molot et al., MINLAKE, and Vollenweider was conducted to evaluate the model characteristics and ease of calibration. Models for further testing were selected based on the ability to have a working model within the time constraints (2-3 months) and the ability to model dissolved oxygen and TP, which are the causes of water quality concerns that the operators and managers have. The selected models by Alex Horne, Chapra and Canale, and Vollenweider were then applied to three reservoirs, Aurora Reservoir, Horsetooth Reservoir, and Standley Lake, that had readily available monitoring data to evaluate the ability to adequately model the constituents of concern and the model's ease of use.

Principal findings and significance

The survey identified a fairly wide range of reservoir physical characteristics, including size, depth, residence time and age. All but one of the study reservoirs was primarily off-line storage, meaning that more than half of the inflow was from out-of-basin sources. The top 5 issues identified via the survey were, in decreasing order of importance

1. nonpoint pollution
2. nutrient loading
3. watershed protection
4. eutrophication/trophic status, and
5. algae blooms.

Virtually every water supplier on the Colorado Front Range that depends on reservoir storage is concerned about these issues. The State of Colorado will be attempting to set nutrient criteria for lakes and reservoirs in the near future. The levels of nutrients that are important for many of the

Front Range drinking water reservoirs are low, and difficult to measure (especially phosphorus). Different sampling and analytical methods or different laboratories can yield very different results. Yet there is no consensus on what monitoring and approaches and laboratory methods should be used to measure standards compliance, much less on what numerical limits would be appropriate.

Based on the model characteristics and results, Chapra and Canale's model incorporating sediment feedback appears most favorable for implementation for most of the reservoirs looking at low cost, low time requirement solutions. The Alex Horne model is limited in the fact that it does not model anoxia over winter and does not allow changes in reservoir management and both Alex Horne and Vollenweider models are limited in that they don't consider the impact sediments have in buffering the change in TP once loading is reduced. Of the more complex models, CE-QUAL-W2 was the only one implemented due to the excessive data input required for DYRESM-CAEDYM and the inability to obtain a working model of MINLAKE. In addition, a decision tree was developed to aid in determination if modeling is a feasible and, if so, it helps select appropriate models based on reservoir and model characteristics and availability of time and funding.

The overall conclusion of the study is that future collaboration on monitoring is absolutely essential for effective management of Front Range drinking water supply reservoirs, especially in a regulatory setting. Collaboration on modeling may prove helpful as well, though the varying characteristics of the reservoirs may make application of a single model rather difficult. For management, information exchange on the effectiveness of management alternatives is the logical first step. Entrenched local policies, on recreational use of reservoir in particular, may make a common approach to management difficult in the near term. The Colorado Lake and Reservoir Management Association, CLRMA, continues to be an effective forum for information exchange and is the likely forum for future collaboration on monitoring, management, and modeling.

Description and Interpretation of Salinization in the Lower Arkansas River Valley, Colorado

Basic Information

Title:	Description and Interpretation of Salinization in the Lower Arkansas River Valley, Colorado
Project Number:	2001CO881B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Water Quality
Focus Category:	Water Quality, Groundwater, Agriculture
Descriptors:	Salinity, Saline soils, Drainage, Water quality, Groundwater quality, Data analysis, Data storage
Principal Investigators:	Timothy K. Gates , John W. Labadie

Publication

1. Gates, T.lK., 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, in Journal of Irrigation and Drainage Engineering, ASCE, 128(2):87-99.
2. Valliant, Jim, 2001, An Overview of Water Outreach Activities in the Arkansas River Basin, in October 2001 Colorado Water, Newsletter of the Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, pp. 9-11.
3. Gates, Timothy, 2001, Evaluating Strategies to Mitigate Waterlogging and Salinization in Colorado's Lower Arkansas River Valley, Progress Report presented at the CWRRI Advisory Council on Water Research Policy (ACWRP) annual meeting, November 5, 2001, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO.

SYNOPSIS

Project Number: 02

Start: 3/01
End: 2/02

Title: Description and Interpretation of Salinization in the Lower Arkansas River Valley, Colorado

Investigators: Timothy K. Gates, Colorado State University, Fort Collins, CO
John W. Labadie, Colorado State University, Fort Collins, CO
Grant E. Cardon, Colorado State University, Fort Collins, CO

Congressional District: 4th

Focus Categories: WQL, GW, AG

Descriptors: Salinity, Drainage, Irrigation, Water Quality, Groundwater Quality, Saline Soils, Data Analysis, Data Storage

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, 2000, and 2001 under this and related projects. The data collection effort focuses on a representative subregion of the Valley that extends eastward about 62 km along the Arkansas River in Colorado, from the town of Manzanola in Otero County to Adobe Creek in western Bent County, encompassing about 26,400 hectares of irrigated land. 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 100 monitoring wells have been installed and are routinely measured in the study subregion. Preliminary results from the 2001 season indicate an average water table depth of about 2.7 m. The average measured salinity (as electrical conductivity, *EC*) of the water table in the study region was about 3.0 dS/m (2700 mg/l) in 2001. Average depths and salinities were 2.1 m and 3.5 dS/m in 1999, and 2.5 m and 3.2 dS/m in 2000, respectively. Surface-water salinity is routinely measured 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 about 1.03 dS/m (900 mg/l) in 2001, indicating low to moderate restriction in use for irrigation. This compares to averages of 0.93 dS/m (812 mg/l) in 1999 and 1.12 dS/m (978 mg/l) in 2000. Global positioning equipment has been used to accurately locate each of the ground-water and surface-water sampling sites for use in a geographic information system. About 15 deep exploratory boreholes were drilled to describe aquifer lithology and to locate the aquifer base. Analysis of 1999 data indicated that the seasonal average rate of groundwater return flow to the river (directly and through tributary drainages) was about $5.5 \cdot 10^6$ m^3/week, with an accompanying diffuse salt loading rate of $16.2 \cdot 10^6$ kg/week (about 740 kg/week per irrigated hectare).

Soil salinity (to a depth of about 1 m) was measured in early June and in mid August on 80 fields in 2001. On each field, soil salinity (as electrical conductivity of saturated extract, EC_e) was estimated using electromagnetic induction probes at an average of 62 locations (about 1 to 10 locations per acre) for each sampling. In addition, about 6000 soil samples have been collected for use in calibrating the electromagnetic probes over the period 1999-2001. Analysis has yielded preliminary relationships between electromagnetic inductance and EC_e for the soils in the Valley. The average soil salinities measured in 2001 were 2.8 dS/m in the early season and 2.5 dS/m in the late season. For the late-season readings in 2001, about 70% of the study subregion had soil salinities that exceeded 2 dS/m (threshold level above which crop yield reductions are expected for corn and alfalfa), indicating significant soil degradation and declining yield. Crop yield reduction due to salinization has been estimated to range between 0 and 75% on fields spread over the subregion, averaging about 10%. This indicates a total revenue averaging $70/ha - $100/ha over the subregion (1999 crop prices). Additional losses are likely occurring due to waterlogging.

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.

Steady-state modeling, to estimate long-term equilibrium conditions, indicates that increased pumping of existing well facilities 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. However, lowering the saline water table in the most severely-affected areas will require more than simply increasing irrigation efficiency or increasing pumping rates. Costlier strategies will need to be considered, such as canal lining, horizontal subsurface drainage, and lowering of the river level. Unsteady modeling of flow and salt transport under these strategies is currently underway. 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.

Distribution, Habitat, and Life History of Brassy Minnor (Hybognathus hankinsoni) in Eastern Colorado Streams

Basic Information

Title:	Distribution, Habitat, and Life History of Brassy Minnor (Hybognathus hankinsoni) in Eastern Colorado Streams
Project Number:	2001CO882B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Biological Sciences
Focus Category:	Conservation, Ecology, Hydrology
Descriptors:	Conservation, Ecohydrology, Plains fish ecology
Principal Investigators:	Kurt D. Fausch

Publication

1. Fausch, Kurt, Christian E. Torgersen, Colden V. Baxter, and Hiram W. Li, 2002, Landscapes to Riverscapes: Bridging the Gap Between Research and Conservation of Stream Fishes, in Bioscience, Vol. 52, No. 6, June 2002, pp. 1-16.
2. Scheurer, Julie A. and Kurt D. Fausch, June 2001, Habitat Requirements and Systematics of Brassy Minnow in Intermittent Plains Streams in Eastern Colorado, Project Annual Report to Colorado Water Resources Research Institute and Colorado Division of Wildlife, Aquatic Non-game and Endangered Wildlife Program, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, 84 pp.
3. Scheurer, Julie A. and Kurt D. Fausch, January 2002, Brassy Minnow in Colorado Plains Streams: Identification, Historical Distribution, and Habitat Requirements at Multiple Scales, Final Progress Report, Colorado Water Resources Research Institute and Colorado Division of Wildlife, Aquatic Non-game and Endangered Wildlife Program, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, 148 pp.

DISTRIBUTION, HABITAT, AND LIFE HISTORY OF BRASSY MINNOW (HYBOGNATHUS HANKINSONI) IN EASTERN COLORADO STREAMS

In Colorado, six of 38 native plains fish species are known to have been lost since the first fish collections were made in the late 1800s. An additional 13 species are listed by the state as endangered, threatened, or of special concern – therefore, half of the native fish have either declined or been lost. The brassy minnow (Hybognathus hankinsoni) is one of three plains fish species listed as threatened or endangered by the State of Colorado in 1998, due to an apparent decline in distribution and abundance in Colorado since the 1970s. To help fishery managers locate suitable habitat and potentially restore the species to more of its native range and preclude the need for further listing, this research project sought to determine the historic distribution and critical habitat requirements of the brassy minnow.

Understanding the native range of brassy minnow is complicated, because it is difficult to distinguish the brassy minnow (Hybognathus hankinsoni) from a closely related species that also occurs in the region, the plains minnow (H. placitus). In addition, both species were originally classified as a different species in the same genus (Mississippi silvery minnow, H. nuchalis) before they were first described in 1929 (brassy minnow) and l962 (plains minnow). As a result, many early collections from Colorado and adjacent counties in neighboring states were classified as Mississippi silvery minnow, even though this species does not occur in Colorado, and many later collections were misclassified as the wrong species due to their similarity. Research investigators developed a method to distinguish the species identity of collections from Colorado and adjacent counties using eye diameter, standard body length, and eye position. This method correctly predicted species identity for 98 percent of the individual fish and 100 percent of the museum collections.

In general, brassy minnow have larger eyes with centers even with the tip of the snout, whereas plains minnow have smaller eyes centered above the tip of the snout (Fig. 1). Reference collections of these species are housed at the CSU Larval Fish Laboratory.

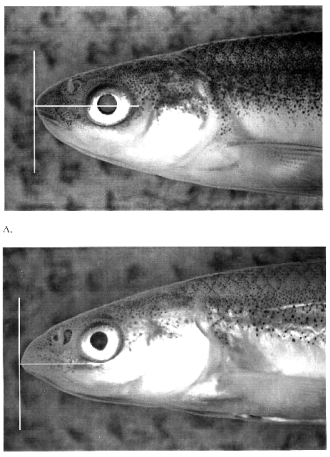


Fig. 1. Eye position characteristics for brassy minnow (top) and plains minnow (bottom). Photos by R.E. Zuellig.

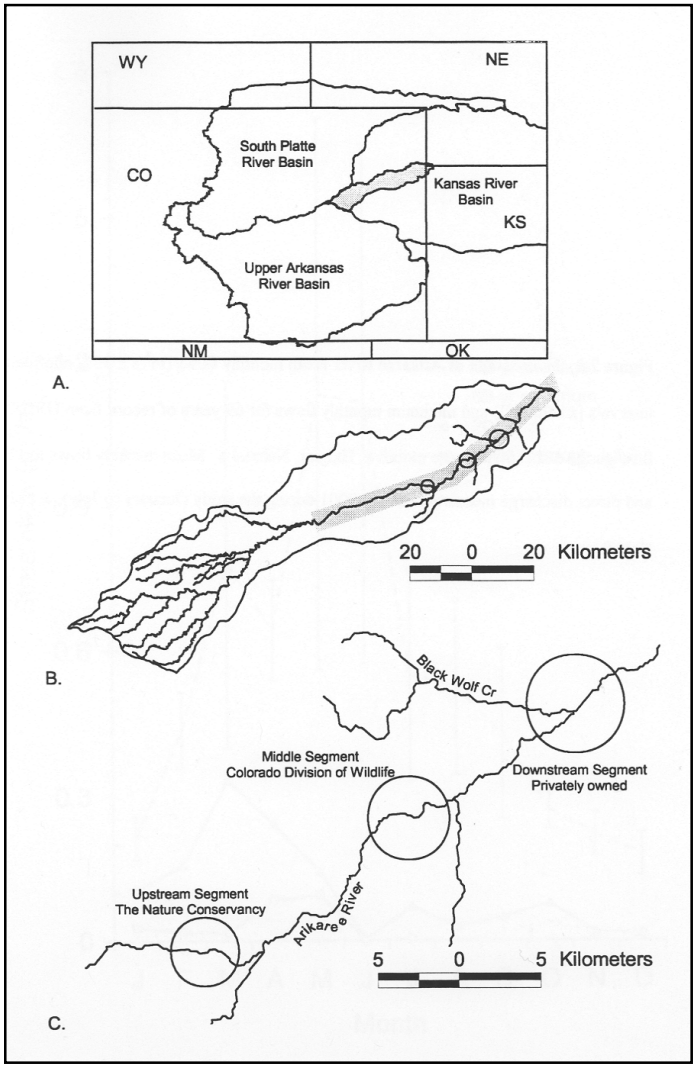
In 1999, the first year of this study, researchers sampled locations throughout eastern Colorado where brassy minnow had most recently been collected. The Arikaree River (Fig. 2) was selected to determine the ecological requirements of the brassy minnow, because it presented a unique opportunity to study population dynamics at three spatial scales (habitat unit, segment, basin) across a gradient of stream intermittency (i.e., drying). This allowed investigators to determine

the brassy minnow's thresholds of tolerance and assess how much perennial water is necessary to sustain populations.

Ninety-nine habitat units (pools, backwater pools, and runs) in three 4-mile segments ranging from perennial to seasonally dry were sampled during five surveys in 2000 and 2001, the two driest summers on record. For each survey, participants measured habitat variables in each unit, mapped flow connections between habitat units, and sampled each unit using two-pass depletion seining to determine the presence or absence of brassy minnow. Basin-scale flow connectivity was also mapped three times by aerial flights along the 66-mile mainstem of Colorado's Arikaree River.

At the basin scale, total habitat for brassy minnow was restricted to about 47 miles of the mainstem Arikaree River upstream from the confluence, but during early summer 2001 only a 16-mile stretch that contained the researchers' selected upstream segment had continuous flow. At the segment scale (upper, middle, downstream), drying occurred in all segments each summer, but was most pronounced in the downstream segment. The middle segment was intermediate in its degree of drying and the upstream segment had the most perennial habitat.

> The amount of available habitat, number of habitat units occupied by brassy minnow, persistence of brassy minnow through summer drying, and extent of recolonization after the channel rewetted were highest in the upstream segment and lowest in the downstream segment, corresponding to the gradient of flow intermittency.



Right: Fig. 2. Location of the basin and study segments

Of the 86 pools sampled across the three segments in 2000, brassy minnow were present in 65 during at least one survey. They persisted through summer 2000 in about half of the pools where they were present, were extirpated from 17 pools by stream drying, and emigrated to adjacent

habitat units or were not present in the 18 pools that remained wet. The researchers first identified factors that predicted brassy minnow persistence in pools that remained wet through the summer drought, and then predicted which pools would persist through summer drying.

Models of brassy minnow persistence through August 2000 were developed using variables measured at both the pool and segment scales. Then, because drying was the dominant mechanism affecting brassy minnow persistence, models of pool persistence through August 2000 were developed based on variables measured in June.

> Logistic regression showed that brassy minnow were more likely to persist through the summer in deeper pools connected to other habitats, and more likely to persist in pools in the upstream segment. The main cause of elimination was by pool drying, which logistic regression showed was more likely in pools with shallower June depths.

For example, a pool with a maximum depth in June of 0.5 meters would have only a 50 percent probability of persistence in the downstream segment, but a 77 percent probability of persistence in the middle segment and a 95 percent probability in the upstream segment. Thus, shallower pools were more likely to persist in the upstream segment and more likely to dry in the downstream and middle segments.

Because brassy minnow were tolerant of high water temperature (36C=97F) and low dissolved oxygen (as low as 0.01 mg/L), other factors, such as predation by terrestrial vertebrates and pool drying, likely had a greater effect on their persistence. Overall, the patterns of stream drying at the segment scale were more important predictors of brassy minnow population persistence than water chemistry or habitat features measured at the local or pool scale.

In addition to persistence of brassy minnow and their habitat, we compared several measures of brassy minnow population performance among segments, including survival, growth, and reproductive success.

> Brassy minnow survived to older ages and were larger at older ages in the most perennial segment compared to the others. However, despite poor adult survival in the drier segments, brassy minnow larvae were present in all three segments in both years, indicating that they are capable of reproduction and rapid recolonization when water is available.

Brassy minnow spawned from mid-April to mid-May and larvae appeared from mid-May through mid-June. The beginning of larval hatching coincided with the onset of pumping for irrigation and rapid dewatering of the driest segment, which killed most larvae.

For many fish populations living in “patchy” environments, such as streams that are seasonally intermittent, persistence at the regional scale depends on the balance between local extinction and colonization from adjacent patches that serve as refuges. Many seasonally intermittent steams are distinguished by marked wet and dry periods, so extinction and recolonization of fish

populations are common. Extinction occurs primarily as streams dry, whereas recolonization is prevalent during the wet season. Understanding the processes that drive populations in such habitats requires examining the distribution of fishes at both local and regional scales and during cycles of wetting and drying. Groups of subpopulations that persist in a network of patches despite local extinctions are termed 'metapopulations.'

Only a few studies have addressed whether stream fish populations are arranged as metapopulations, despite numerous studies of movement, extinction, and colonization patterns. However, several studies provide good evidence that metapopulation processes are at work in stream fish populations. Researchers have found that fish apparently move relatively long distances to recolonize pools where previously fish had been eliminated by drought or freezing.

If any stream fish are likely to show metapopulation processes, fishes of the Great Plains are good candidates. Plains streams are harsh environments that fluctuate drastically in both physical and chemical properties due to flash floods that rearrange habitat, seasonal drying, and winter freezing. The extreme conditions created by these natural processes are often exacerbated by land and water use practices. Understanding the role of metapopulation processes in sustaining rare and declining species is important for managers, because their goal is to achieve regional persistence of these species and their habitats.

Brassy minnow in the Arikaree River showed evidence of metapopulation dynamics because persistence was related to patch size (depth) and isolation, with extinctions more likely in shallow, disconnected pools. Moreover, some suitable habitats were empty, there were asynchronous local dynamics among pools, and the species persisted at the segment (regional) scale despite population turnover. The dynamic nature of plains streams, differences in flow regimes among segments, and the large scales over which brassy minnow fulfill their life history require management at the 'intermediate' segment scale for effective conservation.

This research showed that brassy minnow are very tolerant of harsh conditions, move relatively long distances to recolonize empty habitat, and produce offspring even during the driest years on record. This suggests that the declines observed from 2000 to 2001 could be offset by a series of wet years. However, a prolonged drought could extinguish brassy minnow from most of the basin, and recolonization could take many years once favorable conditions return.

RECOMMENDATIONS

The following measures are recommended to improve habitat conditions in the Arikaree River and enhance brassy minnow populations:

- Increase spring flows to prevent early drying of the downstream segment and improve survival of brassy minnow larvae.

- Maintain riparian and stream processes that create deep pools and provide critical refuges for brassy minnow during summer drying. Intact riparian vegetation binds stream banks and allows deep pools to be carved by periodic floods from summer thunderstorms. In addition, beaver dams often create deep pools that persist through summer.

- Maintain the native fish community and prevent invasion of exotic predators or competitors. Although most nonnative fishes apparently cannot withstand the harsh physicochemical conditions of plains streams, off-channel ponds supplied by groundwater can provide refuges that harbor nonnative predators like largemouth bass. These fishes can emigrate and decimate native fishes in adjacent stream habitats.

- Investigate the effects of irrigation on groundwater hydrology that maintains stream flow and permanent refuge pools. These pools and backwaters are critical for brassy minnow larval and adult survival during periods of summer drying and winter freezing. A better understanding of the linkages between land and water use and plains fish populations at segment scales will be needed for effective conservation of these fishes.

Applicability of Trophic Status Indicators to Colorado Plains Reservoirs

Basic Information

Title:	Applicability of Trophic Status Indicators to Colorado Plains Reservoirs
Project Number:	2001CO1761B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	4th
Research Category:	Biological Sciences
Focus Category:	Nutrients, Water Quality, Management and Planning
Descriptors:	Reservoirs, Eutrophication, Trophic status index
Principal Investigators:	John D. Stednick

Publication

1. Hall, Emile; 2001, Nitrogen Phosphorus Ratios in South Platte Basin Reservoirs: A Recipe for Eutrophication and Blue-Green Algae?, in Wassup in the South Platte Basin, Proceedings of the 12th Annual South Platte Forum, October 24-25, 2001, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, p.73.
2. Hall, Emile, Nutrients in Off-Channel Storage Reservoirs of the South Platte River, Colorado, MS Dissertation, Department of Earth Resources, College of Natural Resources, Colorado State University, Fort Collins, CO, 119 pp.
3. Hall, Emile; Nitrogen and Phosphorus in Reservoirs Along the South Platte River, in Proceedings of the Fifth Annual Colorado State University Student Water Symposium, p. 13, published on-line at the Student Water Symposium website http://watersym.colostate.edu/

SYNOPSIS

Project Number: 2001CO1761B Start: 3/01
End: 3/02

Title: Applicability of Trophic Status Indicators to Colorado Plains Reservoirs

Investigator: John D. Stednick, Colorado State University, Fort Collins

Problem and research objectives

Anecdotal evidence indicates that off-channel storage reservoirs on the eastern Colorado plains downstream of Denver, Colorado are experiencing symptoms of eutrophication. Measures of eutrophication include nutrient concentrations, chlorophyll-a measurements and water transparency. Algal growth promoted by high nutrient inputs may create costly maintenance problems in reservoirs and water distribution systems, ecological changes, low dissolved oxygen and fish kills.

To mitigate the potential impacts of high nutrient inputs and resulting algae growth, Trophic Status Indices (TSI) and linear models are often used in classification and management. Although currently in use, the applicability of the models, and other efforts to determine a trophic status of reservoirs in Colorado, has not been examined. The recent proposed change in the Cherry Creek Reservoir TMDL brought to light several issues about using a trophic status index (TSI) for water quality in Colorado reservoirs. Concerns range from applicability to interpretation.

The overriding objective of this study is to evaluate the applicability of various trophic status indices and models to Colorado reservoirs using existing and collected water quality data from several South Platte River reservoirs. Specific objectives of this research are to:

1. Compile existing nutrient, chlorophyll-a and secchi disk data for eastern Colorado reservoirs in the South Platte Basin.
2. Collect additional nutrient, chlorophyll-a and secchi disk data, where necessary.
3. Determine the applicability of various TSI (EPA 1974, Vollenweider 1976, Carlson 1977, OECD 1982) and linear phosphorous~chlorophyll-a models.
4. Evaluate TSI in relation to reservoir hydrology and management.

This analysis will aid reservoir operators and water managers in Colorado, as well as explain the chemical and biological processes that control eutrophication in Colorado reservoirs.

Methodology

Data from seven reservoirs were compiled and considered for use in TSI and model evaluation. Three reservoirs were selected for further data collection. The compiled and collected data were used in two Microsoft Excel ® spreadsheets developed to evaluate the TSI and nutrient~chlorophyll-a models.

The first spreadsheet compared reservoir classification determined by different TSI to evaluate their applicability to Eastern Colorado reservoirs in the South Platte Basin. The worksheet

allows the input of data and computes the resulting index and classification (oligotrophic, mesotrophic or eutrophic) based upon each parameter. The final results can then be compared.

In order to compare the effectiveness of common nutrient~chlorophyll-a models, the second spreadsheet was developed to compute five measures of precision between the computed and observed chlorophyll-a values (Canfield 1983, Brown 2000):

1. Pearson's correlation coefficients between measured and calculated chlorophyll -a
2. Pearson's correlation coefficients between the logarithm of the measured and calculated chlorophyll-a values
3. 95% confidence limits for calculated chlorophyll-a concentrations from the standard deviation of the mean difference of the logarithms of measured and calculated values. The user must input the appropriate z value based upon the number of samples. The confidence limits are computed as the standard deviation * z +/- the mean.
4. Average error is computed using untransformed values as the mean of the absolute value of the difference between measured and calculated values.
5. Percentage error is the mean of the same differences standardized by dividing by the measured value and multiplied by 100 to express the value as a percent.

Seasonal nutrient declines, ratios, and relationships determined from collected data were also utilized in determining TSI and model applicability to eastern off-channel storage reservoirs in the South Platte Basin.

Principal findings and significance

The first objective of this project, to compile existing reservoir nutrient, chlorophyll-a and secchi disk data was met with limited success as relatively little information capable of TSI evaluation exists. No alga studies on the reservoirs were found, and there is little information on algae in the plains region of the South Platte Basin (USGS 1995a). Two sources of water quality data for the reservoirs were found. The NAWQA Program of the USGS collected data on five off-channel reservoirs in 1995, however the study was limited to four sampling days, and only three days had chlorophyll-a information. In addition, secchi disk depth was not reported, but was assumed to be half of the sampling depth. Another source of nutrient data was added to the NAWQA data; water quality data collected on Milton and Barr Reservoirs by Dr. John Stednick. Again, little chlorophyll-a and secchi disk information was available making most TSI and models difficult to evaluate.

Given the lack of existing data the second objective, collection of additional data, became more important. Nutrient, chlorophyll-a and secchi disk depth data were collected at North Sterling, Prewitt and Jackson Reservoirs on ten days between March and October 2001. Colorado State Parks provided boats for sample collection.

The third objective of determining the applicability of TSI and linear models is described below.

TROPHIC STATUS INDICES

A spreadsheet was developed to determine the trophic state of a reservoir or lake using three of the common computational methods, Carlson's TSI (1977), OECD fixed boundary system

(OECD 1982) and EPA NES guidelines (USEPA 1974) . Vollenweider's plots (based upon phosphorous loading) and OECD Probability Plots were also included to assess the trophic state of the reservoirs (Vollenweider 1976, OECD 1982).

On two days, Jackson Reservoir was classified as mesotrophic based upon chlorophyll-a using the EPA method. On all other days, the reservoirs were classified in the highest category available in the EPA method, eutrophic. Based upon the OECD fixed boundary system all of the reservoirs were hypereutrophic for each parameter. The Carlson TSI reports the trophic state as a number from 0 to approximately 100 in an attempt to quantify trophic status and offer more than three descriptive categories for trophic state. Secchi disk depth was the least reliable with respect to the other measures, especially at Prewitt Reservoir, leading to the highest mean TSI . TP concentrations generally gave higher TSI than chlorophyll-a or Secchi disk depth in Jackson and Sterling Reservoirs. Chlorophyll-a gives the lowest TSI at all three reservoirs. Even though the TP concentrations were high, the primary production did not reach the same trophic classification levels. Most eutrophic lakes have TSI greater than 45 (Novotny and Olem 1994). The lowest value for any parameter and date was 50 indicating that by all measures the reservoirs are eutrophic based upon Carlson's TSI. Based upon an average of all the values, Prewitt showed the highest degree of eutrophication, followed by Jackson and Sterling Reservoirs, respectively.

Vollenweider plots use the total input of phosphorous per year per surface area. Based upon the calculated incoming load estimated from mean South Platte River TP concentrations at Weldona in 2001, annual inflow, hydraulic residence time and maximum reservoir depth, all three reservoirs would be classified as eutrophic. The mean TP concentration (374 μg/L) was calculated using 3 samples collected in 2001 at Weldona, which is located between the Jackson and North Sterling Reservoir inlet canals (Sprague 2002). Residence time, defined as initial reservoir volume/total yearly outflow, was 0.84 years for Sterling, 2.4 years for Prewitt and 1.2 years for Jackson. The yearly area loading of TP was determined by multiplying the total inflow by the concentration and dividing this number by the initial reservoir surface area giving Sterling (4.34 g TP/m^2/yr), Prewitt (2.78 g TP/m^2/yr) and Jackson (1.01 g TP/ m^2/ yr). The calculated values are used along with mean depth to determine the trophic state using the plot (Figure 3). Since the mean depth was not available, the maximum depth was used as a conservative measure. Using the maximum depth on the x-axis (depth / residence time) will produce a higher value for the horizontal axis, making the potential classification more likely lower on the trophic scale. Estimation based upon Vollenweider plots is approximate because the incoming TP was estimated from South Platte River mean concentrations, the surface area and depth are approximate and they fluctuate seasonally. The incoming phosphorous loads indicate that regardless of the depth or residence time, the reservoirs are classified as eutrophic.

Using the OECD probability plot, North Sterling, Prewitt and Jackson Reservoir concentrations were beyond the greatest value and are therefore considered hypereutrophic based upon TP concentrations. North Sterling had a 10% probability of being eutrophic and 90% probability of being hypereutrophic based upon mean chlorophyll-a. Jackson had a 5% probability of being eutrophic with a 95% probability of being hypereutrophic based upon chlorophyll-a concentrations. Prewitt reservoir chlorophyll-a concentrations were greater than the largest

value on the graph leading to a 100% probability of hypereutrophic conditions based upon chlorophyll-a.

MODELS

A spreadsheet with common nutrient~chlorophyll-a models was developed which allows input of observed values and reports five measures of precision for the input data. This spreadsheet was used to evaluate the models given the data from 8 sampling days at the reservoirs.

In evaluating the measures of precision at North Sterling Reservoir, an equation using both TN and total phosphorus had the best correlation coefficient between measured and predicted log chlorophyll-a values (0.82) and the lowest percent error (38.2%); (Smith 1982); (Table 13). A different equation, developed for nutrient balanced lakes, had the lowest average error (59.8) (Brezonik 1984). The correlation coefficient using untransformed values was also best for a TP and TN mixed model (Canfield Jr. 1983). The smallest 95% confidence interval was 28-120% based upon a TP model developed for Florida lakes (Baker et al. 1981).

In contrast with North Sterling Reservoir, the best models for Prewitt Reservoir, based upon correlation coefficients between measured and predicted chlorophyll, were models based upon TP alone (r=0.52). The smallest confidence interval was 33 - 71 % for the calculated chlorophyll. The smallest average error and percentage error was found using an equation developed by Brown (2000).

At Jackson Reservoir the highest correlation coefficient between predicted and measured log chlorophyll-a values was based upon TP (r=0.77). The untransformed values yielded the best correlation of r = 0.92 using TP models. The lowest average error was 35.30 based upon an equation for nitrogen limited lakes using TN (Brezonik 1984). The smallest percent (70.5%) error was found for Carlson's total phosphorus equation (Carlson, 1977), however it produced a large average error and 95% confidence interval. Similar to North Sterling Reservoir, the smallest 95% confidence interval was between 27-231 % using the model developed by Baker (Baker et al. 1981).

Several factors limit the use of TSI: nitrogen limitation, mean concentration utilization and limited classification categories. Nitrogen limitation hinders the utility of models based solely on TP. Although a nitrate decline was previously described, the EPA model does not account for that because it relies on mean nutrient concentrations. The use of the OECD fixed boundary system or the EPA fixed boundary system provided terminology to describe the trophic state of the reservoirs, but only offered between 3 and 5 options (ultraoligotrophic, oligotrophic, mesotrophic, eutrophic and hypereutrophic) for describing the reservoirs. In 2001, the reservoirs (excluding Jackson Reservoir chlorophyll-a for the first two sampling days) were generally in the highest classification based upon each parameter. The chlorophyll-a concentrations did not lead to a trophic classification as high as the other parameters. It is clear from the indices that the reservoirs are eutrophic or hypereutrophic, but little other information is provided from the indices. For example, the mean TP concentration at North Sterling Reservoir was 161 μg/L and the mean concentration at Prewitt Reservoir was 100 μg/L greater. Although this is a large difference in concentrations, both are classified as eutrophic, not reflecting the higher

phosphorous concentration at Prewitt Reservoir. The indices are useful only for minimal description of the reservoirs.

Similar to the EPA method at Jackson Reservoir, TP concentrations result in higher trophic classification by the Carlson method than does chlorophyll-a. One strength of the Carlson method is that it allows a gradient of numerical classifications so that information is retained, unlike the fixed boundary systems. The reservoirs are classified between approximately 0 and 100, with occasional classification greater than 100. Using this system it is possible to decide which parameter, chlorophyll-a, TP or Secchi disk depth, would be most appropriate for the system. For example, in the South Platte off channel storage reservoirs with high TP concentrations and high turbidity, primary production may be a better metric upon which to base trophic status indices.

Although the Carlson TSI offers the advantage of retaining information about the system, there are several reasons why it may not be appropriate for the reservoirs. First, this study has shown the importance of total and inorganic-N in contributing to primary production in South Platte Basin Reservoirs. Based upon linear regression with log TP alone, only 50 percent of the chlorophyll-a was described, but this value increased to between 60 and 80 percent by including nitrogen. The abilities of the Carlson TSI to describe the system are limited since it does not include nitrogen. The TP and chlorophyll-a equation was evaluated along with 23 other equations utilized in the model worksheet; it gave the smallest percentage error at Jackson Reservoir, but other equations provided a better determination of chlorophyll-a based upon phosphorous concentrations. Also, the use of Secchi depth in the reservoirs may not yield accurate values, depending upon the non-chlorophyll light attenuating substance in the water. Carlson advised that chlorophyll-a be used instead of Secchi depth whenever possible (Carlson, 1980).

The high nutrient concentrations and loads coming into the reservoirs result in a eutrophic classification using the Vollenweider plot. This plot is useful in that the proximity of the trophic state of the lake or reservoir can be seen in relation to the others plotted on the graph. In addition, Vollenweider developed a plot based upon incoming TP concentration rather than loads (Vollenweider 1976), which may be useful where annual loading information is not available.

The OECD probability plots, also developed by Vollenweider and others, are useful in that they recognize the uncertainty of the trophic designations and report the trophic state as a probability. However, these plots rely upon the average chlorophyll-a and TP concentrations. These measurements are not normally distributed and it may improve the plots to use the median value. In addition, these measures say nothing about the phosphorous, chlorophyll-a or transparency relationships within the reservoir.

Analysis of the TP models that predict chlorophyll-a was completed using several metrics (r^2 of log and untransformed values, 95% confidence interval for the calculated chlorophyll, percentage error and actual error). Different equations were best depending upon which metric was evaluated, but for Sterling and Prewitt Reservoirs, one model had the best fit with several different measurements. The North Sterling Reservoir correlation coefficient, percent error and average error were all best using the multivariate relationship. As a result, an equation using

nitrogen and phosphorous is recommended for North Sterling Reservoir predictions (Smith 1982). The lowest average error at Jackson Reservoir was derived from a nitrogen based equation (Brezonik 1984), but the correlation coefficient, confidence interval and percent error are best using TP alone. The equation with the highest log and untransformed correlation coefficients and the smallest confidence interval was developed for Florida Lakes (Baker et al. 1981). At Prewitt Reservoir, the equation with the lowest average and percentage error and the typical correlation coefficient (r=.52) was developed in 2000 using annual mean phosphorous and chlorophyll data for 274 lakes (Brown et al. 2000). Equations were also developed for nitrogen alone and nitrogen and phosphorous, but the TP equation gave the lowest values. Thus, different equations were determined at each reservoir to best represent the nutrient~chlorophyll-a relationship.

The final objective was to evaluate the TSI in relation to reservoir hydrology and management. As the reservoirs are primarily designated for agricultural storage, they are filled in the spring and decrease to between 10-30% of their initial volume by October. Since the TSI rely upon nutrient, chlorophyll-a and secchi depth information, their utility will relate to changes caused in those parameters by the decrease in reservoir volume. This must be evaluated on a case by case basis, since each reservoir has varying nutrient and chlorophyll-a concentrations, management and hydrology. In 2001, over the sampling period as reservoir volume decreased, the Carlson TSI based upon chlorophyll-a increased over the season. In general, the TSI based upon TP and Secchi disk depth also increased over the season. This increase is expected which indicates that any study should consider the time of year samples are collected and avoid using yearly or seasonal mean values in decision making as they will not represent the highest trophic state of the reservoir.

Principal findings and significance

This project relies upon nutrient, chlorophyll-a and secchi disk depth data. Little data containing all three elements is available. Thus, samples were collected to evaluate TSI and nutrient-chlorophyll-a models. The off-channel storage reservoirs in 1995 (five reservoirs) and 2001 (three reservoirs) exhibit a seasonal nitrate decline to below detection limits indicating potential nitrogen limitation. This nitrogen limitation, along with mean concentration utilization and limited classification categories, hinders TSI usage for off-channel storage reservoir evaluation. Typically total phosphorous gave a higher trophic status than chlorophyll-a indicating that another factor may be controlling primary production in the reservoirs. Different linear equations were determined to best represent each reservoir and equations using both nitrogen and phosphorous best characterized the system on several occasions. Thus, nitrogen may be a controlling factor at times in off-channel storage reservoirs and the lack of nitrogen use in TSI may hinder their applicability. Reservoir volume changes dramatically over the season and the month of sample collection with regard to trophic status determination should be considered.

References

Baker, L. A., P. Brezonik, and C. R. Kratzer. 1981. Nutrient loading - trophic state relationships in Florida Lakes. Publication 56, University of Florida Water Resources Research Center, Gainesville, Florida.

Brezonik, P. 1984. Trophic state indices: rationale for multivariate approaches. Pages 441-445 in 3rd annual conference of North Americal Lake management Society. U.S. Environmental Protection Agency, Knoxville, T.

Brown, C. D., M. V. Hoyer, R. W. Bachmann, and D. E. Canfield. 2000. Nutrient-chlorophyll relationships: an evaluation of empirical nutrient-chlorophyll models using Florida and North-temperate lake data. Canadian Journal of Fisheries and Aquatic Science 57:1574-1583.

Canfield Jr., D. E. 1983. Prediction of chlorophyll a concentrations in Florida lakes: the importance of phosphorous and nitrogen. Water Resources Bulletin 19:255-262.

Carlson, R. E. 1977. A trophic state index for lakes. Limnology and Oceanography 22:361-369.

EPA. 1974. An approach to a relative trophic index system for classifying lakes and reservoirs. Working paper no. 24 National Eutrophication Survey, Pacific Northwest Environmental Researach Laboratory, Corvallis, OR.

Novotny, V., and H. Olem. 1994. Water Quality: prevention, identification, and management of diffuse pollution. John Wiley & Sons, New York, NY.

OECD. 1982. Eutrophication of Waters: Monitoring, assessment and control. Organization for Economic and Co-operative Development, Paris, France.

Smith, V. H. 1982. The nitrogen and phosphorous dependence of algal biomass in lakes: An empirical and theoretical analysis. Limnology and Oceanography 27:1101-1112.

Sprague, L. 2002. 2001 South Platte River nutrient concentrations collected by the USGS. e-mail USGS, Denver, CO.

USEPA. 1974. An approach to a relative trophic index system for classifying lakes and reservoirs. Working paper no. 24 National Eutrophication Survey, Pacific Northwest Environmental Reserach Laboratory, Corvallis, OR.

USGS. 1995a. Inventory of biological investigations related to water quality in the South Platte River basin, Colorado, Nebraska, and Wyoming, 1891- 1994. Open File Report 95-379, U.S. Geological Survey, Denver, Colorado.

Vollenweider, R. A. 1976. Advances in defining critical loading levels for phosphorous in lake eutrophication. Memorie dell'Istituto Italiano di Idrobiologia 33:53-83.

Use of Low-Cost Data to Simulate Fractured-Aquifer Watersheds for Management of Water Quality and Quantity

Basic Information

Title:	Use of Low-Cost Data to Simulate Fractured-Aquifer Watersheds for Management of Water Quality and Quantity
Project Number:	2001CO261G
Start Date:	9/1/2001
End Date:	9/1/2003
Funding Source:	104G
Congressional District:	6th District
Research Category:	Water Quality
Focus Category:	Water Use, Geochemical Processes, Non Point Pollution
Descriptors:	Water quality, Water quantity, Fractured-aquifer watersheds
Principal Investigators:	Eileen Poeter

Publication

This project was begun in December-January because of the delay in processing the grant; therefore, no research results are yet available.

Information Transfer Program

Basic Information

Title:	Technology Transfer/Information Dissemination
Start Date:	3/1/2001
End Date:	2/28/2002
Descriptors:	Technology transfer, Information exchange
Principal Investigators:	Robert C. Ward

Publication

1. Brown, Jennifer, 2002, Wassup in the South Platte Basin, Proceedings of the 12th Annual South Platte Forum, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, 22 pp.
2. Epperson, Annie, 2001, Proceedings of the Fifth Annual Colorado State University Student Water Symposium, published on-line at the Student Water Symposium website http://watersym.colostate.edu/

INFORMATION TRANSFER ACTIVITIES

CWRRI provides the latest water information and research results to Colorado water users, managers and the public via an active technology transfer program. The CWRRI 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 CWRRI web site.

W E B S I T E S

CWRRI maintains the following web sites:

The CWRRI Homepage at http://cwrri.colostate.edu

Colorado Water Resources Research Institute

Creating and Transmitting New Water Knowledge

About CWRRI
- History and Mission
- Contact Us

Research Projects and Publications
- Water Research Projects
- Water in the Balance
- Report Series

Newsletter
- Index of Newsletters

Water Research Expertise
- Academic Faculty
- Federal Agency Contacts

Additional Resources
- Useful Water Links
- KIDS Zone
- Jobs in Water
- Colorado Water Concerns

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

Water Center

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 students can find the following information at the web site:

Professional Development Jobs in Water Resources Meetings/Seminars	Study Water at CSU – Undergraduate Undergraduate Water Minor Research Experiences for Undergraduates in Water
Educational Opportunities Water Related Courses at Colorado Universities Short Courses Scholarships	Study Water at CSU – Graduate Water Information for New CSU Graduate Students

The Colorado Water Knowledge web site 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/

Right: South Platte River near Greeley, Colorado.

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

Hydrology Days 2002

21st Annual
American Geophysical Union
HYDROLOGY DAYS
April 2-5, 2001

Cherokee Park Room
Lory Student Center
Colorado State University
Fort Collins, Colorado, USA

Sponsored by
Hydrology Section of the
American Geophysical Union

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

With funding provided by The National Science Foundation, the Water Center at Colorado State University provided a unique opportunity for undergraduate students from four-year colleges and universities to conduct independent research in Water Science and Engineering during 8 weeks in the summer under the guidance of faculty in the departments of Civil Engineering, Earth Resources, Soil and Crop Science, Chemical Engineering, Fishery and Wildlife Biology and Rangeland Ecosystem Science. Students work in teams including faculty, graduate students, and staff to conduct research and gain hands-on experience in laboratory and field research methods.

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.

  Water in the Balance No. 9, "A History of Drought in Colorado: Lessons Learned and What Lies Ahead," was published and printed in February, 2000 in collaboration with Colorado State's Department of Atmospheric Science. It has been reprinted several times, and with the current drought situation in Colorado, is still in demand.

- 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 making all its publications available on the World Wide Web.

M E E T I N G S AND C O N F E R E N C E S

Arkansas River Basin Water Forum
The Value of Water, The Value of Life
Lamar, Colorado -- March 22-23, 2001

CWRRI cosponsors this annual meeting that gathers together water interests in Colorado's Arkansas River valley. The 2001 meeting, held March 22-23, headlined "The Value of Water, The Value of Life." The forum featured sessions on Water Quality, The New Bush Administration and Water Policy Issues, Recreational Issues, Flow Management and Deliveries, The Rocky Ford Canal: Aurora's Perspective, and Saving Colorado's Water. Principal Investigators Luis Garcia and Tim Gates presented an update on their salinity study in the Arkansas Basin during the Water Quality session.

21st Annual Hydrology Days
Colorado State University -- April 2-5, 2001

The 21st Annual Hydrology Days was held April 2-5, 2001 on the campus of Colorado State University. The meeting was dedicated to Professor Emeritus Stanley Schumm of the Earth Resources Department at Colorado State. 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. The 2001 program included presentations by representatives of local, state and federal agencies and the private sector. Updates on hydrology concerns and research were presented by international representatives as well, who came from

Venezuela, Brazil, Albania, Colombia, Greece, Queensland, Italy, Uzbekistan and Iran to attend the meeting. CWRRI sponsors the annual meeting.

Colorado Streamgaging Symposium
Breckenridge, Colorado
May 3, 2001

In a cooperative effort, CWRRI, the U.S. Geological Survey, and the Colorado State Engineer's Office cosponsored a symposium to provide information about streamgaging programs in Colorado – the history; evolving uses and importance; current access to streamflow information; user perspectives on information uses, needs and priorities; and opportunities for improvement in gage network coverage and dissemination of streamflow information. Despite an early spring snowstorm, more than 80 people attended the symposium. The symposium included three panel discussions on two broad topics: perspectives on the use of stream flow data, and the need for improvement in gage network coverage and dissemination of stream flow data. The panels were moderated by Robert Ward, CWRRI; Bill Horak, U.S. Geological Survey, Denver; and Hal Simpson, Colorado State Engineer.

26th Annual Colorado Water Workshop
Who's in Charge
Western State College, Gunnison, Colorado – July 25-27, 2001

The 26th Annual Colorado Water Workshop's theme produced excellent presentations and generated spirited discussion around several key water issues¸ such as recreation flows, elections of conservancy district boards, and reserved water rights. More than 200 people attended the conference, including state legislators; county commissioners from both the West Slope and Front Range; and representatives from local, regional, state and federal agencies and the private-sector. University students attending the meeting had an excellent opportunity to meet key water leaders and learn first hand about the latest issues facing Colorado water managers and strategies being employed to address particular problems. CWRRI cosponsors the workshop.

Colorado Watershed Assembly
September 7-8, 2001
Frisco, Colorado

Representatives from Colorado watershed groups, along with nonprofits and governmental agencies, formed the Colorado Watershed Assembly to formally link together the growing number of people and entities committed to collaborative, watershed-based approaches to conserving Colorado's natural resources. The second annual conference of the Assembly featured workshops and a chance for watershed groups and agencies from across the state to network – something geographically diverse groups often don't get a chance to do. A panel discussed what local and regional watershed activities are occurring in Colorado. Most groups reported having coalesced around a local issue such as stream restoration, but each watershed group reportedly evolved in a different way and direction, according to local needs. Reagan Waskom, CWRRI's Water Resources Specialist, has been active in the assembly since its inception.

Wassup in the South Platte Basin
12th Annual South Platte Forum -- October 24-25, 2001

The 12th Annual South Platte Forum brought together more than 160 water users and managers, state and federal agency personnel, academics and students in water-related programs to hear views on "Wassup in the South Platte Basin." Ralph Morganweck, Regional Director, U.S. Fish and Wildlife Service and Russell George, Director of the Colorado Division of Wildlife, provided updates on the federal and state perspectives regarding the interface between water and wildlife issues. Panel discussions were held on the topics of Use Less Water, Reuse More, A Water Quality Update, Well Augmentation, Water Banking, Recreation Quantity Issues, and an Update on Recreation Quality and Opportunities. The annual South Platte Forum is jointly

sponsored by the Colorado Division of Wildlife, CSU Cooperative Extension, CWRRI, Denver Water, the Northern Colorado Water Conservancy District, the U.S. Bureau of Reclamation, the Environmental Protection Agency, the U.S. Fish and Wildlife, and the U.S. Geological Survey.

Planning for the Inevitable
5th Annual Student Water Symposium
Colorado State University -- November 7-9, 2001

The 2001 Colorado State University Student Water Symposium was held November 7-9 at the Lory Student Center on the CSU campus. The annual event was organized by graduate students focusing on a career in water. Invited speakers included Peter Gleick of the Pacific Institute for Studies in Development, Environment and Security, who touched on the social, political and ecological components of the changing world of water; and Professor Emeritus Gilbert White of the University of Colorado in Boulder, former director of the Natural Hazards Research and Applications Information Center. The symposium also included student speakers, who were given a chance to hone their presentation skills in an informal atmosphere. Certificates of achievement are given each year to exemplary student oral and poster presenters.

Economics of the Ogallala Aquifer
Ogallala Aquifer Symposium
Northeastern Junior College – Sterling, Colorado
February 21, 2002

This symposium gave attendees the "Big Picture" of the Ogallala Aquifer – current water use and management practices and food for thought on the issues at hand concerning the future and protection of this most valuable resource. The symposium is sponsored by Colorado State University Cooperative Extension and CWRRI.

STUDENT INTERN PROGRAM

The Institute continued its Student Intern Program in FY2001, 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 for the CWRRI newsletter, Colorado Water, and/or publications.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	8				8
Masters	2				2
Ph.D.	3				3
Post-Doc.					0
Total	13	0	0	0	13

Notable Awards and Achievements

Colorado State University's Civil Engineering Department has received the Sandor C. Csallany Institutional Award for Exemplary Contributions to Water Resources Management. Dr. Sandra Woods, Chair of the Civil Engineering Department, and Dr. Robert Ward, Director of the Colorado Water Resources Research Institute/CSU Water Center, accepted the award at the Annual Awards Luncheon of the American Water Resources Association. The luncheon was held November 14, 2001, in conjunction with AWRA's Annual Water Resources Conference in Albuquerque, New Mexico. Dr. John S. Grounds, III, AWRA President, said in presenting the award: "The CSU Civil Engineering Department has demonstrated its leadership in water resources management by achieviing an unmatched level of eminence in water education, research and service."

The following award winners have participated in many CWRRI water research projects funded through the State Water Institute Program since the program's inception in 1965.

The National Ground Water Association presented its M. King Hubbert Award 2001 to David McWhorter, Professor Emeritus of CSUs Agricultural and Chemical Engineering Department (now Chemical Engineering). The award is presented annually by NGWA to a person who has made a major science or engineering contribution to the knowledge of groundwater. McWhorter has been involved in contaminated site cleanups at some of the most critical sites in the country. He also worked internationally for the UN and FAO and for the governments of Kuwait and Brazil, advising them on problems of water supply and contamination.

Robert Longenbaugh received a National Ground Water Association Life Membership Award, which is presented to active members who have retired or are of retirement age and who have contributed special service in the furtherance of the ground water industry and/or to NGWA. Longenbaugh was a researcher and instructor at CSU, where he produced some of the very first digital ground water simulation models. After leaving CSU, he served as Colorados Assistant State Engineer, where he was responsible for administration of Colorados ground water resources and also had litigation and enforcement responsibilities.

The U.S. Committee on Irrigation and Drainage has recognized Maurice Albertson, CSU Professor of Civil Engineering, and Gordon Kruse, CSU Professor of Soil and Crop Sciences, for their outstanding contributions to USCID and to the profession. Albertson was awarded the USCID Service to the Profession Award in a ceremony that took place during the USCID Transbasin Water Transfers Conference in June 2001. He is known throughout the world for his contributions in the areas of water resources and irrigation engineering, hydropower engineering and constructed wetlands and, more recently, his work in sustainable village-based development. A feasibility study prepared by Albertson and colleagues at CSU led to the formation of the Peace Corps in the early 1960s.

Gordon Kruse received his award, the USCID Merriam Improved Irrigation Award, during a private ceremony in November 2001. He was honored for his innovative research in advancing the science of irrigation and drainage engineering with emphasis on irrigation water supply, control and distribution, and on improving irrigation water applications to increase efficiency and to reduce environmental problems.

Publications from Prior Projects

1. MacDonald, L.H., J.D. Stednick, E. Huffman and C.A. Troendle, 2001, Managing Colorado's Forests for Water Yield and Water Quality: Opportunities, Risks and Constraints, in Proceedings of the 21st Annual American Geophysical Union Hydrology Days, April 2-5, 2001, Civil Engineering Department, Colorado State University, Fort Collins, CO.
2. Twenter, Justin, 2001, Water Quality Monitoring System Effectiveness: Denver Water Case Study, in Proceedings of the 21st Annual American Geophysical Union Hydrology Days, April 2-5, 2001, Civil Engineering Department, Colorado State University, Fort Collins, CO.
3. Ward, Frank A., Robert Young, Ronald Lacewell, J. Philip King, Marshall Frasier, J. Thomas McGuckin, Charles DuMars, James Booker, John Ellis, and Raghavan Srinivasan; June 2001, Institutional Adjustments for Coping with Prolonged and Severe Drought in the Rio Grande Basin, Colorado Water, Newsletter of the Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO.
4. Hobbins, Michael T., Jorge A. Ramirez, and Thomas C. Brown, 2001, The Complementary Relationship in the Estimation of Regional Evapotranspiration: An Enhanced Advection-Aridity Model, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, Open File Report No. 13, 58 pp.
5. Green, Colleen H., 2001, The Solubility of Manganese and Coincident Release of Metals Based on the Reduction of Alamosa River Basin Soils, MS Dissertation, Morgan Library, Colorado State University, Fort Collins, CO, Call #TD878.3.C6 G74 2001, 135 pp.
6. Huffman, Edward Louis, 2001, Fire-Induced Soil Hydrophobicity Under Ponderosa and Lodgepole Pine, Colorado Front Range, M.S. Dissertation, Morgan Library, Colorado State University, Fort Collins, CO, Call #S593.H84 2001, 186 pp.
7. Cenderelli, Daniel A., 1998, Glacial-lake Outburst Floods in the Mount Everest Region of Nepal: Flow Processes, Flow Hydraulics, and Geomorphic Effects, Ph.D Dissertation, Morgan Library, Colorado State University, Fort Collins, CO, Call #QC571.C45 1998 c.2, 247 pp.
8. Monroe, Troy, 2000, Evaluation of the Hydrologic Component of EPA's basins Model Applied to the Big Thompson Watershed, Colorado, MS Dissertation, Morgan Library, Colorado State University, Fort Collins, CO, Call #GB656.2.H9 M65 2000, 99 pp.