Colorado Water Resources Research Institute
Annual Technical Report
FY 2004

Introduction

Colorado is a headwaters state, so Colorado water managers and users must base choices and usage on unpredictable supplies, the needs of thirsty states downstream, and the needs of various sectors of Colorados economy and environment. The allocation of limited water requires sound science to assist water managers in resolving conflicts within the state and meeting agreements with downstream states.

Colorado Water Resources Research Institute (CWRRI) facilitates the transfer of new water knowledge to water managers -- present and future. Working with the Colorado State University Water Center, the CWRRI establishes research priorities, publishes research results in a variety of formats (see Technology Transfer section), encourages the discussion of water topics and problems in a variety of meetings around the state, and fosters interactions between current and future water mangers and policy makers by facilitating seminars on campus where professionals and students can meet and discuss the issues.

With the assistance of the Advisory Committee on Water Research policy, the institute establishes statewide research priorities each year, and encourages research on those topics. The key themes for the 2003-2004 research cycle are:

- conjunctive management of ground and surface water
- salinity
- recycled wastewater as irrigation for urban landscapes
- better estimates of long-term water yield economic impacts of changing water use
- assessment of impacts of individual on-site wastewater disposal systems

In the past, CWRRI has seeded research by funding preliminary investigations which provided the information needed in applications for funding of larger projects. Budget constraints forced us to shift the way we fund state supported research, and that shift was implemented this fiscal year. Instead of a state research competition for academic principal investigators, we established a research fellowship for graduate students, forcing changes in the time line for procedures, approvals, and fund disbursement. By establishing the fellowship, our goal is to maintain the seed project notion, and enhance our focus on the future by encouraging graduate student research on topics of interest to our state water managers and users.

Advisory Committee On Water Research Policy

The mandate of the Advisory Committee on Water Research Policy (ACWRP), the governing committee for the Colorado Water Resources Research Institute (CWRRI), is two-fold: advise CWRRI regarding research imperatives for each year and to seek and procure state and local water research funding to match the federal funding which supports the research program.

Membership is established in the CWRRI by-laws. Designed to engage a cross-section of water professionals and policy-makers, the membership includes the chairs of key Colorado State Legislative committees as well as directors or commissioners of pertinent State of Colorado departments. The membership is rounded out by the appointment of six members of the general public selected by CWRRIs director based on their participation in setting Colorado water policy and obtaining funding for such policy.

Membership of the ACWRP as of November 2004 is: **Appointed by Position:**

- Chair, Senate Agriculture, Natural Resources and Energy Committee, Senator Jim Isgar
- Chair, House Agriculture, Livestock and Natural Resources Committee, Representative Kathleen Curry
- Executive Director, Department of Natural Resources, Russell George
- Executive Director, Department of Public Health and Environment, Mark Pifher (represents Doug Benevento)
- Commissioner, Department of Agriculture, Don Ament
- Fred Anderson, Former President of Colorado Senate
- Sara Duncan, Public Relations, Denver Water
- Eric Kuhn, Manager (David Merritt), Colorado River Water Conservation District
- John Porter, Manager, Dolores Water Conservancy District
- David Robbins, Hill and Robbins
- Ralph Curtis, Manager, Rio Grande Water Conservation District
- Lee Sommers, Director, Agricultural Experiment Station
- Bill Wilcox, Interim Director, Colorado State Forest Service
- Milan Rewerts, Director, Cooperative Extension

Water Center Board of Directors

Water Center Board of Directors

CWRRI receives on-campus guidance from the Colorado State University Water Center Board of Directors. Members are:

- Tony Frank, Provost
- Marc Johnson, Dean, College of Agricultural Sciences and Cooperative Extension
- Steve Abt, Dean, College of Engineering
- Joyce Berry, Dean, College of Natural Resources
- Lee Sommers, Director, Agricultural Experiment Station
- Milan Rewerts, Director, Cooperative Extension
- Lyn Kathlene, Director, Colorado Institute of Public Policy

Research Program

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:	2002CO2B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	4th
Research Category:	None
Focus Category:	Agriculture, Groundwater, Water Use
Descriptors:	None
Principal Investigators:	Luis Garcia

Publication

1. Garcia, L.A., 2004, "User centered approach to develop decision support systems - estimating pumping and augmentation flow needs in the South Platte Basin in Colorado," presented and published in the proceedings of the USCID Conference on Water Rights and Related Water Supply Issues October 13-16, Salt Lake City, Utah.
2. Garcia, L.A., and D. Patterson, 2005, "South Platte Mapping and Analysis Program", Colorado Water, April 2005, Colorado Water Resources Research Institute, Ft. Collins, CO.
3. Garcia, L.A., 2004, "Employing 'sound science' to conjunctively manage surface and ground water", Colorado Water, April 2004, Colorado Water Resources Research Institute, Ft. Collins, CO.
4. Shigidi A. and L.A. Garcia, 2003, "Parameter estimation in groundwater hydrology using ANN", Journal of Computing in Civil Engineering Vol. 17(4):281-289.
5. Eldaw, A., J.D. Salas, and L.A. Garcia, 2003, "Long range forecasting of the Nile River flows using climatic forcing", Journal of Applied Meterology, Vol 42: 890-904.
6. Labadie, J. and L. Garcia, 2003, "Has modeling of water resources on the basis of climate and dyrology reached its full potential?", Chapter 8, Water and Climate in the Western United States, William M. Lewis (editor), University Press of Colorado, Boulder, CO.
7. Elgaali, E. and L.A. Garcia, 2004, "Neural network modeling of climate change impacts on irrigation water supplies in Arkansas River Basin", presented at and published in the Proceedings, 24th Annual Hydrology Days, Fort Collins, CO, March 10-12.
8. Elgaali, E. and L.A. Garcia, 2004, "Quantification of climate change impacts on irrigation water demand in the Arkansas River Basin - spatial approach" presented at the 24th Annual Hydrology

Days, Fort Collins, CO, March 10-12.

9. Garcia, L.A., 2004, "Update on South Platte Map and its use in implementing Senate Bill 73", presented at the Colorado Water Congress, Denver, CO, January 29.
10. Garcia, L.A., 2003, "User centered decision support tools for computing augmentation requirements in the South Platte River", presented at the Groundwater Workshop sponsored by the Colorado Water Congress, Denver, CO, November 14th.
11. Garcia, L.A., 2003, "Development of tools for estimating pumping and augmentation flow needs in the South Platte using a user centered approach", Soil and Crop Sciences Fall 2003 Seminar Series, Colorado State University, Fort Collins, CO, September 18.
12. Garcia, L.A., D. Patterson, 2003, "South Platte Mapping And Analysis Program (SPMAP) water management tools for the Lower South Platte Basin", poster, In Service Training, Colorado State University Cooperative Extension, Fort Collins, CO, Feb 26.
13. Hanna, B., L.A. Garcia, and J. Loftis, 2003, "Modeling selenium loading throughout the Uncompahgre Basin", poster, In Service Training, Colorado State University Cooperative Extension, Fort Collins, CO, Feb 26th.
14. Garcia, L.A., 2003, "Improving estimates of augmentation flow needs through information technology", presented at the Colorado Water Congress, Denver, CO, January 23.
15. Garcia, L.A., B. Hanna and J. Loftis, 2003, "Managing selenium in the Upper Colorado River Basin", poster presented at the USDA-CSREES National Water Quality Coordinators' Conference, Tucson, Arizona, January 12-15.
16. Garcia, L.A., 2004, Decision Support System, invited speaker to NATO-Russian Advanced Research Workshop on "Flood Satellite Forecasting and Flood Risk Asessment", Khanty-Mansiisk, Siberia, May 28-29.
17. Garcia, L.A., 2003, "How the system works - where the water comes from and where it goes", presented at the Lower South Platte River Symposium, Sterling, CO, February 13.

Problem and research objectives:

Sustaining irrigated food production, providing high quality water to growing populations and establishing flow conditions to protect habitats for threatened and endangered species are some of the demands for water in the South Platte Basin. Legally, water managers must account for groundwater and surface water. In order to meet the water supply challenges, local water management organizations use computer-based tools tailored to provide a model of this unique area. SPMAP is a collection of computer tools allowing successful management of data to manage conjunctive use of ground and surface water and to determine augmentation requirements in the South Platte basin.

Principal findings and significance:

The South Platte Mapping and Analysis Program (SPMAP) is a user-centered decision support system which has been developed in close collaboration with a number of local and regional water management organizations along the Lower South Platte River. As part of this project four different components have been developed which are distributed via the web at www.ids.colostate.edu/projects/splatte. The components are:

(1) IDS PLSS Locator – a standalone tool that allows users to locate structures by generating UTM coordinates based on legal descriptions or convert GPS coordinates to legal descriptions;
(2) SPGIS – An ArcView extension which allows users to display different GIS layers and export GIS data into the IDSCU model developed as part of this project.
(3) IDSCU (IDS Consumptive Use Model) is a data driven computer model which can be applied anywhere. It allows users to compute consumptive use estimates for different crops using a number of ET methods including the Blaney Criddle, Pochop, and Hargraves methods for monthly time steps and Penman Monteith, Kimberly Penman and the new ASCE combination equation for daily time steps.
(4) IDS AWAS (Alluvial Water Accounting System) is a computer model that calculates stream depletions for different boundary conditions such as: infinite aquifer, no flow boundary and an alluvial aquifer using daily, monthly, or annual time steps. Additions to AWAS this year allow modelers to import well parameters from a database, set the ending year past the period of record to evaluate the effect of no pumping, temporarily set pumping to zero after a given year, ignore selected wells when calculating output, and handle of non-calendar year formats.

To respond to the increase in users of IDS CU, two software training sessions were held in May of 2004 and another will be held in May of 2005. The 2004 sessions filled up quickly and attracted users from around the state.

The SPMAP computer models are used in the South Platte to determine augmentation requirements for over 80% of the basin or more than 3,500 wells. The consumptive use model is now also being applied to the Middle Rio Grande Conservancy District in New Mexico.

Evaluating Strategies to Mitigate Waterlogging and Salinization in Colorado's Lower Arkansas River Valley, Phase 3

Basic Information

Title:	Evaluating Strategies to Mitigate Waterlogging and Salinization in Colorado's Lower Arkansas River Valley, Phase 3
Project Number:	2002CO6B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	4th
Research Category:	None
Focus Category:	Water Quality, Groundwater, Agriculture
Descriptors:	None
Principal Investigators:	Timothy Gates, John W. Labadie, Grant E. Cardon, W. Marshall Frasier

Publication

1. Burkhalter, J.P., and T.K. Gates, 2005, "Evaluating regional solutions to salinization and waterlogging in an irrigated river valley," Journal of Irrigation and Drainage Engineering, ASCE, 131: In press.
2. Burkhalter, J.P., and T.K. Gates, 2005, "Agroecological impacts from salinization and waterlogging in an irrigated river valley," Journal of Irrigation and Drainage Engineering, ASCE, 131 (2): In press.
3. Chiang, P., and T.K. Gates, 2004, "Strategic river water quality planning using calibrated stochastic simulation," Journal of Water Resources Planning and Management, ASCE, 130(3), 215-231.

Problem and research objectives:

For more than a hundred years, vast canal systems made up of more than 1000 miles of channels, have diverted and distributed the waters of the Arkansas River to thirsty, yet fertile alluvial soils in southeastern Colorado. Irrigation has made possible productive agricultural economies and scenic rural landscapes in the valley, but not without exacting a cost. Over the years, while the benefits of an impressive irrigation infrastructure were obvious, an insidious side effect was slow taking form. The groundwater table has been rising and growing more saline due to excessive irrigation, seepage from earthen canals, and inadequate drainage facilities.

Anecdotal evidence of irrigation-related problems in the Arkansas River Valley has been ample. Only recently, however, have researchers focused on accurately diagnosing these problems and systematically searching for viable solutions.

Development and evaluation of management strategies to reduce waterlogging and salinization problems in the Lower Arkansas Valley is the goal of this project. Strategies to be considered alone and in combinations include:

- Increased irrigation efficiency
- Reduced seepage from irrigation canals
- Increased pumping rates from existing pumping wells with excess flows (above legal permit) routed through drains to the river
- Installation of horizontal subsurface drains
- Lowering of water surface elevation along the river
- Conversion to more salt-tolerant crop varieties

Methodology:

Utilizing data from on-going projects, input from stakeholders, and extant field-scale models, various strategies will be modeled to determine viable solutions which address all aspects of the nature and variability of the Arkansas River and its tributaries, the reservoirs, and the groundwater aquifer within the lower river valley as well as information on the soils, crops, and irrigation and drainage system serving the valley.

Since 1999, a data set has been gathered in a region selected to be representative of hydrogeologic and agronomic conditions upstream of John Martin Reservoir (see figure 1). Within the study region, there are six major irrigation canals, numerous smaller irrigation and drainage ditches, eight tributary drainages, three main reservoirs, and over 280 active pumping wells. Major irrigation canals are allocated water based on prior-appropriation water rights. Cultivated crops include alfalfa, corn, grass, wheat, sorghum, cantaloupe, watermelon, and onions. The most common irrigation methods in the area are furrow irrigation and border irrigation using open ditches with siphon tubes or, in some cases, gated pipe. Less than five percent of the region is irrigated with sprinkler and drip irrigation systems.

Investigations in this study region include ground water monitoring, well installation and observation, surface water salinity measurements, intensive soil salinity monitoring, topographic and hydrographic surveying using differential global positioning systems (GPS), measurement of soil and aquifer properties, measurement of seepage from irrigation canals, measurement of irrigation applications and runoff, measurements of crop yield, and other related activities.

Principal findings and significance:

MODSIMQ has been augmented with the data collected to produce regional, basin, and field-scale models, which allow analysis of various strategies for dealing with the water salinity issues. Preliminary calculations predict that revenue lost to waterlogging and salinity in the Upstream study region is approximately $94/acre over April 1999 to October 2001. The model systems will be further calibrated and enhanced and then used to test various scenarios for managing the water quality issues in the area.

Urban Landscape Irrigation with Reclaimed Wastewater, Phase 2: Current Knowledge and Community Experience

Basic Information

Title:	Urban Landscape Irrigation with Reclaimed Wastewater, Phase 2: Current Knowledge and Community Experience
Project Number:	2003CO71B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	
Research Category:	None
Focus Category:	Irrigation, Water Quality, Water Supply
Descriptors:	None
Principal Investigators:	Yaling Qian, Yaling Qian

Publication

1. Alshammary, S., Y.L. Qian, and S.J. Wallner, 2004, "Water relationship of cold and warm season turfgrasses under saline water irrigation," Aust. J. of Agricultural Research, in press.
2. Alshammary, S., Y.L. Qian, and S.J. Wallner, 2004, "Growth response of four turfgrasses to salinity," Agricultural Water Management 66:97-111.
3. Qian, Y.L., R.F. Follet, S. Wilhelm, A.J. Koski, and M.A. Shahba, 2004, "Carbon isotope discrimination of three Kentycky bluegrass cultivars with contrasting salinity tolerance," Agron. J. 96:571-575.
4. Qian, Y.L., 2003, "Salt tolerance should be considered when choosing Kentucky bluegrass varieties," Turfgrass Trends, 12(6):62-64.
5. Qian, Y.L., 2003, "Can turfgrass sequester atmospheric carbon? Assessment using longterm soil testing data," Turf News: March/April 2003, p. 23-6.

Problem and research objectives:

Growing concerns of our future water supply and more stringent wastewater discharge standards to surface water bodies have contributed to increasing interest in using recycled wastewater for urban landscape irrigation. Like many other places in the world, cities along the Front Range of Colorado plan to expand wastewater reuse systems. Therefore, increasing numbers of landscape facilities and development areas have planned or have switched to recycled wastewater (RWW) for irrigation. To provide relevant information, the objectives of this project are:

1) To conduct a literature review and synthesize current knowledge to provide information on: a) guidance in monitoring water quality and soil and plant health; and b) best management practices for urban landscapes under recycled wastewater irrigation.
2) To evaluate landscape plants and soils along the Front Range of Colorado that are currently under recycled wastewater irrigation in comparison with plants and soils with conventional water source irrigation.

Methodology and progress:

To access current knowledge concerning the effects of irrigating with RWW on landscape plant performance and soil characteristics, we have collected and reviewed literature to assess trends of changes in key soil properties such as, salinity, sodicity, infiltration rate, hydraulic conductivity, heavy metals elements, etc. We found that soil salinity increments under wastewater irrigation are a function of water quality, soil texture, drainage effectiveness, topography, climatic, and management practices. Sodium adsorption ratio, total suspended solid, C:N ratio, and bicarbonate content of RWW directly affect water infiltration and percolation. To predict the resistance of targeted landscape plants to long-term RWW irrigation, literatures on the relative salinity tolerance of landscape plants were reviewed. A list of landscape plants [different turfgrasses, bedding plants, evergreen woody plants, and deciduous woody plants] and their general rankings of the salinity tolerance of individual plants were summarized. Currently, we are conducting further research to generate best management practices for urban landscapes under RWW irrigation

To evaluate landscape plants and soils along the Front Range of Colorado that are currently under recycled wastewater irrigation in comparison with plants and soils with conventional water source irrigation, we selected 12 urban landscape sites with 6 sites that have been irrigated with RWW exclusively for 5-34 years and the 6 other sites that have been irrigated with surface or municipal water as controls. From each site, soil, irrigation water, and plant samples were collected and analyzed for salinity, sodicity, and other ion content. In addition, on two landscape sites, soil samples were collected prior to and 4 or 5 years after the commencement of recycled wastewater for irrigation. Those soil samples were analyzed for salinity, sodicity, pH, and other ion content.

Principal findings and significance:

1. Recycled wastewater samples collected from the 6 reuse sites exhibited average EC value of 0.84 dS/m. The chemical constituent of recycled wastewater is dominated by sulfate, bicarbonate, chloride, and sodium. Adjusted sodium absorption ratio (SAR) of recycled wastewater from reuse sites ranged from 1.6 to 8.3. Based on the interactive effect of salinity and sodicity on soil infiltration and percolation, 90% of the water samples collected showed slight to moderate effects on soil infiltration and permeability. The average sodium and chloride concentrations of 37 water samples collected were 99 mg/L and 95 mg/L, respectively. Most of the surface water used on the control sites came from melting snow of the Rocky Mountains and exhibits good quality with average EC, SAR, sodium and Chloride content of 0.23 dS/m, 0.9, 15 mg/L, and 8 mg/L, respectively.

2. Our results indicate a substantial impact of recycled wastewater on soil properties. Soil samples in the 0-11.4 cm depth from reuse sites exhibited 0.3 units of higher pH and 200%, 40%, and 30% higher concentrations of extractable Na, B, and P then the control sites, respectively. Compared to sites irrigated with surface water, sites irrigated with RWW exhibited 187% higher EC and 481% higher sodium adsorption ratio (SAR) of saturated paste extract. However, extractable Mg was reduced 15% ($P < 0.005$). Comparison of soil chemical properties before and 4 or 5 years after RWW irrigation on two golf courses also revealed the following findings:
   a) 89-95% increase in Na content;
   b) 28-50% increase in B content; and
   c) 89 - 117% increase in P content at the surface depth.

   Regular monitoring of site-specific water and soil and appropriate management are needed to mitigate the negative impacts of sodium and salts accumulations.

3. Although greater variations in the incidence of needle burn or dieback existed, ponderosa pines grown on sites irrigated with RWW exhibited 10 times higher needle burn symptoms than those on sites irrigated with surface water (33% vs. 3%). The needle burn symptoms included the development of needle tip necrosis, resin-infiltrated bands, and necrosis of distal regions of needles. As the symptoms developed further, leaf falling or thins could occur. Tissue chemical analysis indicated a much higher sodium concentration in the affected trees. Ponderosa pine needles collected from reuse sites exhibited 11 times higher Na content, 2 times higher Cl, and 50% higher B content than samples collected from the control sites. Stepwise regression analysis revealed that the level of needle burn was largely influenced by leaf tissue Na content. Additionally, increasing Cl, B, Ni and Cu also exhibited positive relations with increasing levels of needle burn. Tissue Ca level and K/Na ratio were negatively associated with needle burn, suggesting calcium amendment and K addition may help mitigate the needle burn syndrome in ponderosa caused by high Na in the tissue.

4. Turfgrass grown under RWW exhibited acceptable quality and turf quality was not significantly different from turf receiving surface water for irrigation. However,

clippings collected from sites with RWW for irrigation exhibited 6.4 times higher Na content and 1.3 times higher B content than sites irrigated with surface water, reaching 3315 and 448 mg kg^{-1}, respectively.

From our initial study we found that both problems and opportunities exist in using RWW for landscape irrigation. Recycled wastewater irrigation in urban landscapes is a powerful means of water conservation and nutrient recycling, thereby reducing the demands of freshwater and mitigating pollution of surface and ground water. However, potential problems associated with recycled wastewater irrigation do exist. These problems include salinity build up and relatively high Na accumulation in the soil and plants. Salt leaching would become less effective when soil hydraulic conductivity and infiltration rate were reduced. These chemical changes may in part contribute to the stress symptoms and die off observed in some ornamental trees and, to a lesser degree, in Kentucky bluegrass/perennial ryegrass turf. As more landscape facilities and development areas switch to recycled wastewater for irrigation, landscape managers must be prepared to face new challenges associated with the use of recycled wastewater. Persistent management practices, such as applications of soil amendments that provide Ca to replace Na; periodic leaching to reduce salt accumulation; frequent aerifications to maintain infiltration, percolation, and drainage; regular soil and plant monitoring, and selection and use salt-tolerant turfgrass and landscape plants will be helpful in mitigating the negative impact and insuring continued success in using RWW for landscape irrigation.

Salt Chemistry Effects on Indirect Field Salinity Assessment in the Arkansas River Valley, Colorado

Basic Information

Title:	Salt Chemistry Effects on Indirect Field Salinity Assessment in the Arkansas River Valley, Colorado
Project Number:	2004CO99B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	4th
Research Category:	None
Focus Category:	Irrigation, Hydrogeochemistry, Water Quality
Descriptors:	None
Principal Investigators:	Grant E. Cardon, Grant E. Cardon

Publication

1. Cooper, C.A., G.E. Cardon and J.M. Wittler, 2005, "Influence of salt chemistry on direct and indirect salinity measurement in the Arkansas River Basin, Colorado," presented at International Salinity Forum, Riverside, California, 25-27 April 2005.
2. Wittler, J.M., G.E. Cardon, T.K. Gates, C.A. Cooper, and P.L. Sutherland, 2005, "Calibration of electromagnetic sensors for regional salinity assessment in an irrigated river valley," poster presented at International Salinity Forum, Riverside, California, 25-27 April 2005.
3. Wittler, J.M., G.E. Cardon, and C.A. Cooper, 2005, "Regional calibration of the EM-38 for salinity assessment," poster presentation at American Acadamy for the Advancement of Science Annual Meeting, Feb 17-22, 2005. Washington, DC.
4. Cooper, C.A., G.E. Cardon and J.M. Wittler, 2004, "Salinity chemistry in high plains irrigated agriculture, Arkansas River Valley, Colorado, " poster presentation at Soil Science Society of America, 68th Annual Meeting. Seattle, WA, 31 October to 4 November 2004.
5. Wittler, J.M., G.E. Cardon and C.A. Cooper, 2004, "Regional calibration of the EM-38 for salinity assessment in the Arkansas Valley," presentation at Soil Science Society of America 68th Anual Meeting, Seattle, WA, 31 October to 4 November 2004.

Problem and research objectives:

Salinity in the Arkansas River Basin is causing decreased productivity; with potential salinity sources being, geologic, waterlogging, urban and agricultural return flows. However, there was little chemical soil data to describe accurately and specifically, the type of salinity. Field observation suggested that the primary soil salinity is calcium-based (gypsum or calcite), and this type of salinity may be a factor in the difficulty of calibrating electromagnetic induction probes for in-field salinity assessment.

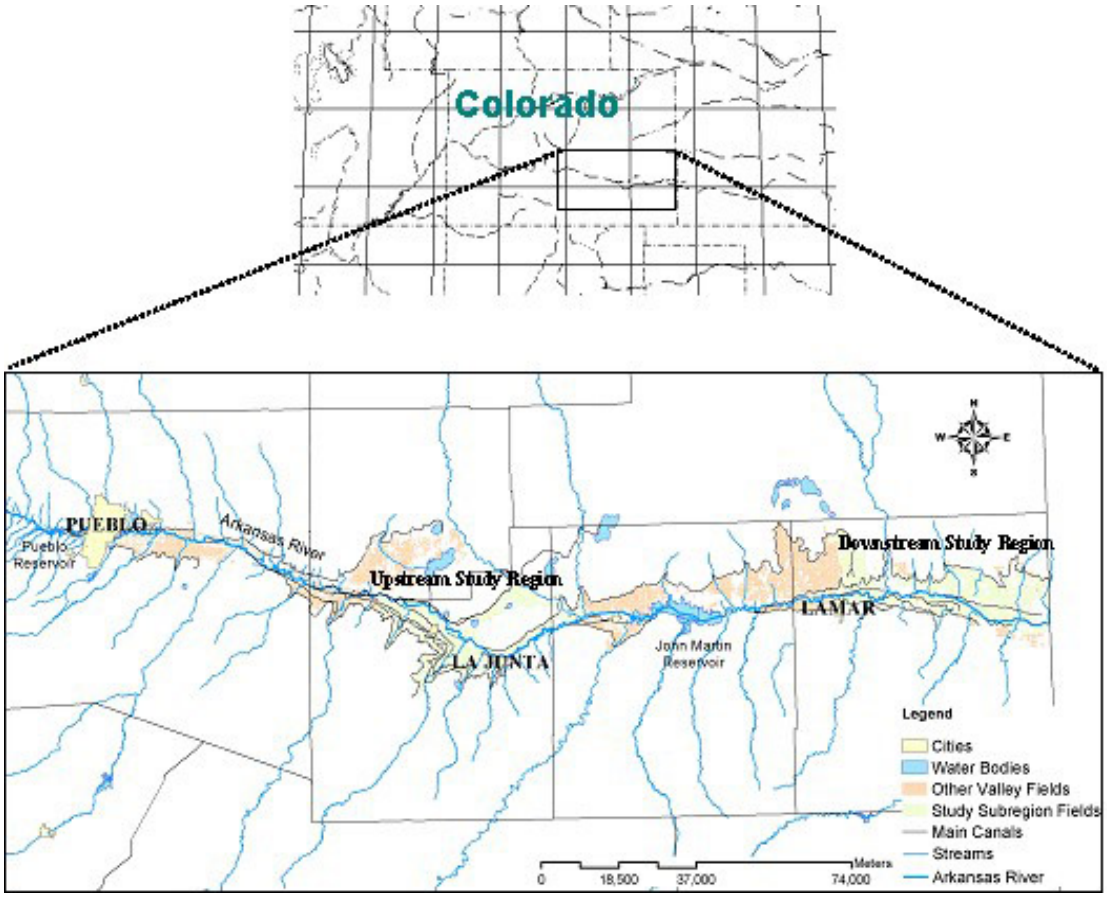


Figure 1. Upstream and Downstream Study Sub-regions on the Lower Arkansas River

Methodology:

Project goals to collect baseline soil chemical data have been completed. Field sampling in the Arkansas River Valley was completed in the summer of 2004. Overall, 24 fields were sampled in the upstream region and 27 fields in the downstream region. Samples were typically collected to a depth of 1.2 meters, spanning a range of salinities. Samples were then processed for saturated paste extracts with the extract waters being tested at the Soil, Water and Plant Testing Lab on the Colorado State University Campus. Additionally, chemical analysis was run on pore water extract waters and for a multiple extract testing. Method tests are also being conducted for in-laboratory procedures and the effects on the electrical conductivities.

Principal Findings and significances:

Data for the baseline chemistry are currently being analyzed, but preliminary results reveal that there are relationships between extract water electrical conductivity (EC) and the sodium concentrations (Figure 2), which is also true for the magnesium, and sulfate concentrations. This relationship is not found in the calcium concentrations in the extract waters. It is surmised that this is because $CaSO_4$ (typically as gypsum) and $CaCO_3$ (typically as calcite) are slightly to limited in their solubilities in near neutral pH conditions (Figure 2). However, some soils also appear to have a reserve of calcium attached either to colloids or in the soil solution that influences the EC/calcium relationship above an EC of approximately 3.0 dS m^{-1}.

The chloride relationship to EC is also unclear, presumably due to the different hydrological regimes on how the soils were "salted up." In fields in which the salt source is from the top down it is expected that chloride, which typically behaves as a conservative chemical species, should be leached to the deeper samples or to below the rootzone. However, in waterlogged fields it is expected that with an upwelling gradient for groundwater flow that the chloride will become concentrated near the soil surface due to evapotranspiration. Statistical analysis of these hydrologic regimes is planned for the summer of 2005.
Pore water extract waters were sampled from the Research Station in Rocky Ford, CO. Irrigation was applied on Day 0, and with *in-situ* extractions occurring on Days 1 – 4. Pore waters were sampled through multiple tubes each with a ceramic cup at either 1, 2, 3, and 4 foot depths using suction induced with a pump. Sample waters were not available at the 3 and 4 foot depths on Day 1. In Figure 3. the irrigation water sodium concentration and the saturated paste extract concentrations are presented as reference points. A combination of leaching, dilution of the pore waters and the movement of the wetting front through the soil profile are shown in Figure 3. These data are also paired with EM-38 measurements which suggest that there is a change in the overall bulk conductivity as the wetting front expands through the soil profile.

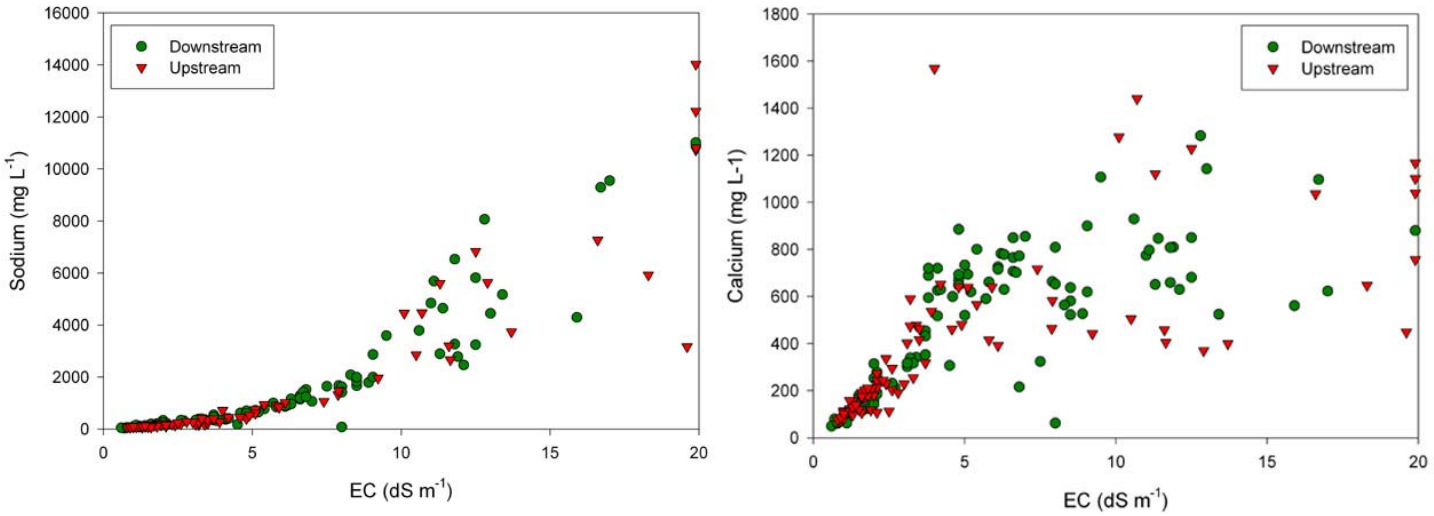


Figure 2. Sodium and Calcium extract concentrations (mg/L)

Multiple extracts of a single soil sample were completed in January 2005. This sample was repeatedly processed in a manner equivalent to all the other soil samples for saturated paste extracts. The chemical results of the repeated testing are in Figure 4. From these results the initial flush of sodium from the soil and

a subsequent decrease in the EC of the extract waters are apparent in the first six extractions. This result suggests that the EC is strongly influenced by sodium, which is highly soluble. As the multiple extracts proceeded, minor decreases in the magnesium concentrations occurred, but the calcium concentrations are essentially the same between the first extract and the 14th extract, which suggests that the soils and EC are "buffered" by gypsum and calcite mineral precipitates that cannot be readily leached from agricultural fields. Fourteen extractions were not sufficient to decrease the extract EC significantly below 4 dS m^{-1}. Implications of this research support leaching studies of soil cores by David Huber and Dr. Greg Butters. The data have not yet been completely examined for management recommendations of calcium-salt affected fields.

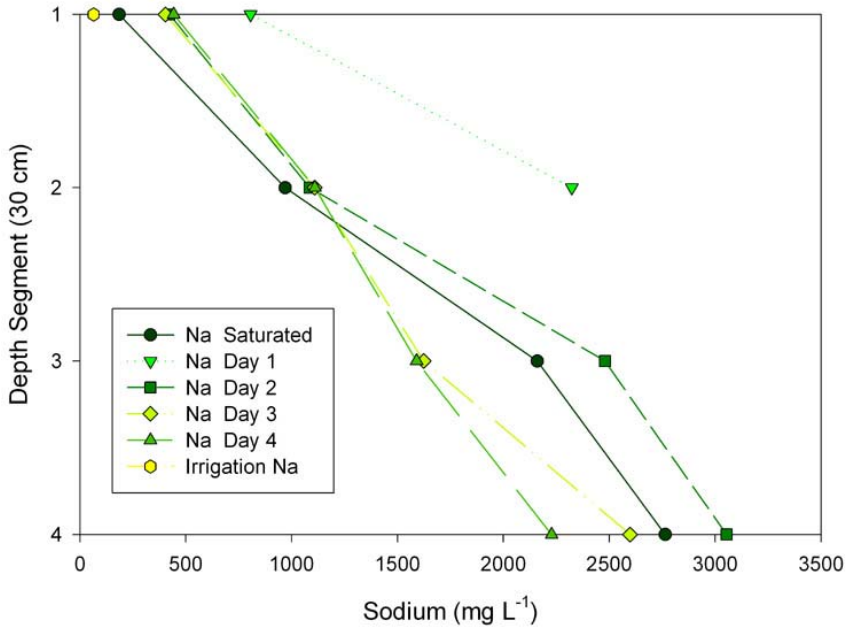


Figure 3. Sodium Concentrations in Pore Water Extracts

Testing of the EC laboratory methods is on-going. Since there are manipulations to collected soil samples as part of developing saturated paste extracts, such as drying, grinding and mixing of soils and pastes, there is a potential to influence the EC measurements. Grinding of nodules of calcium sulfate, calcium carbonate minerals/precipitates and of soil aggregates can increase the surface area available for dissolution and thereby change the overall EC measurement by making more salts available for dissolution than are available *in-situ* under typically irrigation processes. Preliminary data suggests that extract waters taken from soil samples retaining their aggregates, and not stirred during the saturation process, have a lower EC than those samples that are manipulated. The use of surrogate irrigation water in creating the saturated paste has preliminary results suggesting that the EC between the soils and the water is not additive. It is expected that the additional tests may offer clues/answers as to the why and how the two EC's become intermixed.

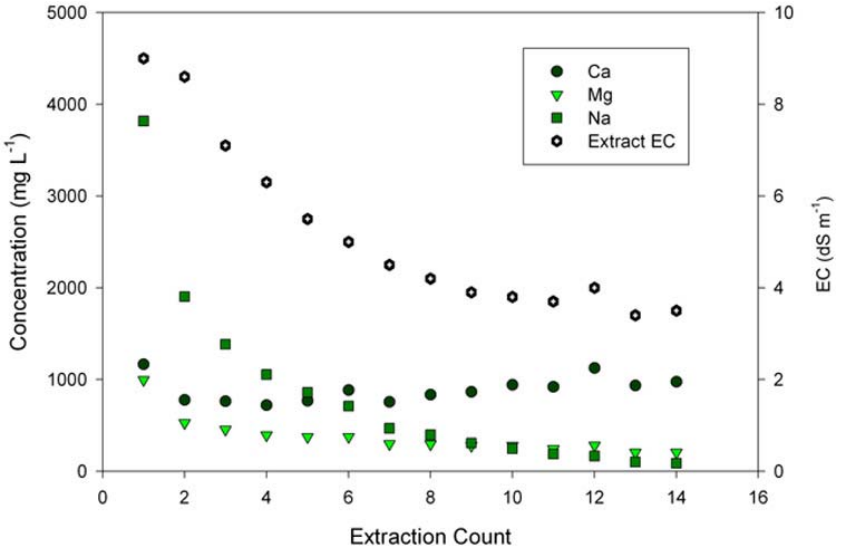


Figure 4. Multiple Extraction Results

Planned analysis for Summer 2005, include, but are not limited to:

1) Beta testing of an updated WATSUIT model by Dr. Jim Oster, Emeritus Soil and Water Specialist, University of California, Riverside.
2) Refining the calibration equations to the EM-38 electromagnetic sensor by utilizing chemical data. Equations were created by James Wittler as part of an ongoing Masters research at Colorado State University.
3) Continue working with other researchers on efforts related to salinity in the Arkansas River Basin. Data has already been used to direct monitoring and modeling efforts of Yaun-Win Lin and Roberto Arranz (graduate students of Dr. Garcia). The implication of the calcium chemistry/mineralogy in the soils has impacted assumptions of chemical transport and removal mechanisms.
4) Spatial statistically analysis of the chemical data regionally and between regions to determine locations with greater concentrations of salts, being sodium, calcium, magnesium, etc.
5) Normal versus inverted soil salinity profiles to determine the effects of waterlogging.
6) Variability in the chemical constituent concentrations as a function of EC groupings.
7) Chemical data is providing clues as to why current EC-Crop guidance manuals are not accurate for these saline systems and research/analysis will following up on this information.
8) Examination of available models, including Hydrus 1D 3.0 (with Unsatchem), and continuing use of Visual Minteq to help model chemical changes with the removal of pure water through evapotranspiration.

Assistance in this research came from five undergraduates working in the Irrigation Laboratory in Plant Sciences Building on the Colorado State University Campus. Additional assistance was provided by Dr. Tim Gates in Civil Engineering, Dr. Luis Garcia, Eric Morway and others involved directly with the Arkansas River Valley Project examining salinity and waterlogging. In particular, much of this current work is only possible because of the work done by James Wittler in examining and calibrating the EM-38 sensor and developing the pore water study.

Salary for Curtis Cooper was provided by the USDA, in the form of a three year National Needs Fellowship. The Colorado Water Resources Research Institute provided funding for the presentation of abbreviated forms of this research at the Soil Science Society of America, 68th Annual Meeting, Seattle, WA (November 2004) and at International Salinity Forum, Riverside, CA (April 2005). In April 2005, Curtis Cooper was offered a position in the 2005 Summer Doctoral Fellows Program at Washington State University, Pullman WA, in part due to his research of salinity.

Funding for the research was supplied by the Colorado Water Resources Research Institute and Agricultural Experiment Station.

Determination of Ecosystem Response Thresholds to Nutrient of Flowing Waters in Montane Colorado

Basic Information

Title:	Determination of Ecosystem Response Thresholds to Nutrient of Flowing Waters in Montane Colorado
Project Number:	2004CO105B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	2nd
Research Category:	None
Focus Category:	Water Quality, Nutrients, None
Descriptors:	None
Principal Investigators:	William M. Lewis, William M. Lewis

Publication

1. Lewis, William M. Jr., 2005, "Determination of ecosystem response thresholds to nutrient enrichment of flowing waters in montane Colorado," Completion Report 201, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, 12 p.

Problem and research objectives:

The purpose of this project was to collect field data on streams in the foothills and montane parts of Colorado in support of the State of Colorado's attempt to develop nutrient criteria in preparation for producing nutrient standards for Colorado waters. The state has identified high elevations as the highest priority, which explains the focus on streams of the mountains and foothills. The study was instituted to provide sufficient data on nutrients and potential ecological indicators of nutrient enrichment to establish thresholds of ecological change associated with nutrient enrichment. On this basis, thresholds for enrichments relevant to Colorado waters could be established for the state.

Methodology:

Nutrients of interest for this study include nitrogen and phosphorus, which are considered by the U.S. Environmental Protection Agency, the State of Colorado, and the research community to be the factors most likely to limit potential growth of autotrophs (algae and aquatic vascular plants" in aquatic ecosystems. Total phosphorus was analyzed, as were phosphorus fractions (soluble reactive phosphorus, total soluble phosphorus, particulate phosphorus). Dissolved inorganic nitrogen (nitrate, ammonia) was analyzed, but total nitrogen, which is considered to contain large amounts of unavailable forms of nitrogen, was not analyzed.

Response variables for the current study included biomass of attached algae (periphyton) measured as chlorophyll *a* per unit area, which is a conventional method for evaluating biomass of algae on illuminated surfaces. In addition, community composition of attached algae was considered a potential response variable, as was composition of the benthic fauna (bottom fauna) living in the streams. Chlorophyll data is cataloged, but the counting and identification of organisms, necessary for the community composition studies of periphyton and benthos, are still in progress. Response variables were sampled once (in fall).

Collections of all organisms at each site were made by standard methods, which involve taking multiple samples over the stream cross-section in order to compensate for spatial irregularities in the distribution of organisms. Sites were chosen so as to represent a range of elevations, and also to be located where an historical record was available for nutrient concentrations. Thus, the study did no rely entirely on nutrient samples taken at the time of sampling, but rather on a longer-term record that reflects more accurately the nutrient history of growth of the organisms at a particular site.

Approximately 75 sites were sampled at locations for which multi-year records were available for concentrations of total phosphorus (Figure 1). Most of these sites lacked adequate information on phosphorus fractions and on nitrogen fractions. Therefore, a subset of the sites (approximately 20) was analyzed with respect to these nutrient fractions.

Principal findings and significances:

The premise at the beginning of the study was that growth of attached algae would depend in part on elevation. The sites were grouped for convenience into three elevation categories: high (greater than 2700 m), low (less than 2100 m), and intermediate (2100-2700 m).

Figure 2 shows the relationship between total phosphorus and chlorophyll *a* at the time of the fall sampling. Clearly, any sites from any elevation and for any annual mean phosphorus concentration can produce a high chlorophyll reading in fall. Sites with higher total P, however, show consistently high chlorophyll. Therefore, the main distinction between the sites is the range in chlorophyll concentrations that can be expected in fall: enriched sites (greater than 25µg/L total P) have consistently high chlorophyll, whereas unenriched sites or minimally enriched sites (below 25 µg/L) show a range of chlorophyll concentrations, including some very low amounts and some high amounts.

The relationship between chlorophyll *a* in the fall and the nitrogen and phosphorus fractions is shown in Figure 3. The general pattern is very similar to the pattern for total P. Basically, total P and the nutrient fractions give redundant information with respect to the response of biomass as represented by fall sampling. Therefore, total P can be used as the key nutrient factor.

The information on total phosphorus and chlorophyll suggest a threshold at about 25 µg/L total P separating a wide range of chlorophyll concentrations (below the threshold) from consistently very high concentrations above the threshold. This threshold could be used as the basis for nutrient criteria in Colorado. In terms of SRP (the soluble inorganic portion of phosphorus) the threshold falls at about 15 mg/L.

Additional sampling is underway through EPA support that will build on the observations made in this study. In addition, the studies of community composition may show that the threshold is verified or superceded by thresholds represented through community composition.

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:	1/31/2004
Funding Source:	104G
Congressional District:	6th District
Research Category:	Water Quality
Focus Category:	Water Quality, Geochemical Processes, Non Point Pollution
Descriptors:	Water quality, Water quantity, Fractured-aquifer watersheds
Principal Investigators:	Eileen Poeter

Publication

1. Wellman, Tristan, and Eileen Poeter, 2005, "Estimating spatially variable representative elementary scales in fractured architecture using hydraulic head observations," Water Resources Research, Vol. 41, No. 3.
2. Thyne, Geoff, Cuneyt Guler, and Eileen Poeter, 2004, "Sequential analysis of hydrochemical data for watershed characterization," Ground Water, v. 42, no. 5, pp 711-723.
3. VanderBeek, Greg, 2003, Masters Thesis: "Estimating recharge and storage coefficient in a fractured rock aquifer, Turkey Creek Basin, Jefferson County, Colorado," Colorado School of Mines, Department of Geology and Geological Engineering, Masters Thesis.
4. Vanderbeek, Greg, Eileen Poeter, Geoff Thyne, and John McCray, 2003, "Ground-water availability in Turkey Creek Basin, Colorado," Geol. Soc. Amer., Abstracts with Programs, 35 (5).

Problem and research objectives:

Mountain watersheds are primary water resources in the western United States, but we lack a scientific basis for making credible decisions regarding mountain land use. The rapid growth of population and development in mountain watersheds caused Jefferson County of Colorado to begin collecting data in a pilot study of ground-water resources in the Turkey Creek Watershed, a fractured-crystalline rock aquifer, typical of those that support individual domestic wells and sewage disposal systems for residents of the county and similar areas throughout Rocky Mountains, United States, and the world. A number of agencies funded data collection in the watershed, but the data are in different forms at many locations and have not been integrated into a model for a management tool. Although a ground-water model of the watershed is not expected to predict conditions in a particular well, it can provide information about future conditions in specific areas of the watershed. The proposed research utilizes a rare database from the watershed to complement and extend the work of the USGS by integrating data from many sources and developing models to: 1) better understand the flow system, 2) determine which low-cost data are instrumental in describing the system and which data reduce uncertainty, and 3) simulate the impacts of alternative development scenarios on ground-water levels, quality, and its to the total maximum daily load in streams. The value of the low-cost data will be confirmed using the more unusual data. The methods developed in this research will be useful for assessing the effects of population growth and development in other fractured-aquifer watersheds. The most difficult portion of this task is evaluating the fracture character of the aquifer. At this time, society cannot afford to characterize every detail of the subsurface water-bearing fractures to manage ground water. This project will use an elaborate database to determine the value of low-cost, holistic measures for evaluating the character of three-dimensional fracture flow and the scale at which equivalent porous media models can be used to predict impacts of management scenarios. Before collecting additional field data, modeling studies can glean information from existing data and determine which data will decrease uncertainty.

Methodology:

Task 1) compile and organize available data in a manner that will facilitate its dissemination;
Task 2) evaluate the data by viewing their distribution from a variety of perspectives;
Task 3) utilize the data to develop representative synthetic equivalent-porous-media and fracture flow models, with characteristics similar to that of Turkey Creek Watershed, to evaluate attributes generally believed to differentiate porous media and fracture flow systems and compare the character of hydraulic head and water quality observed in Turkey Creek Watershed to synthetic model behavior to estimate the scale at which Turkey Creek Watershed can be represented as equivalent porous media;
Task 4) use results of task 3 to generate models of Turkey Creek Watershed applicable to the management scale, calibrate the models using multiple regression techniques, and identify the data that are instrumental in describing the flow system, as well as, the type and location of new data that will improve the calibration or confirm the value of the low-cost data
Task 5) collect data identified in task 4 and incorporate the data into the model calibration to modify and improve the representative models;

Task 6) use the representative models to predict the impact, and associated uncertainty, of increased development on the quantity and quality of water resources;
Task 7) identify the data that are instrumental in making accurate predictions and evaluate the type and location of new data that would reduce prediction uncertainty or confirm the value of the low cost data;
Task 8) prepare a report and provide project findings to the public; and
Task 9) train future geological engineers while accomplishing the previous objectives.

Research Results:

Evaluation of front-range aquifers is only beginning and this project will continue to refine conceptual models and limit the possible range of interpretation through data mining, data collection, and analysis. Current analysis of the available data reveals:

- Water bearing fracture frequency is fairly uniform among rock types (~0.01 water-bearing fractures per foot) but fault zones and coarse granitic rocks have higher yields per fracture, thus are likely to have larger apertures and/or better connectivity.
- Fracture frequency (and yield) is uniform between 100 and 700 feet below ground surface.
- Well yields are higher in the fault zones and coarse granite, which occupy limited area in the upper portion of the basin.
- Depth to water averages less than 100 feet (30m).
- Water levels in wells mimic the topography, with coincident surface and ground-water divides.
- Water levels are responsive to spring recharge and generally exhibit a recession each water year.
- Precipitation is on the order of 20 in/yr (508 mm/yr) while evapotranspiration is on the order of 18 in/yr (457 mm/yr). Both are variable and known from a short period of limited spatial distribution, and thus introduce much uncertainty in the water budget.
- Water levels are declining.
- Storage in the basin is poorly characterized.
- Volume of annual recharge is uncertain but is currently estimated on the order of an inch per year, with 75% pumped, but only 7% consumed because of ISDS recharge.
- Estimates of recharge are uncertain due to the short period of record and limited spatial distribution, consequently the estimate may be somewhat more or substantially less.
- The uncertainty associated with the water budget renders assessment of the sustainable population difficult.
- Surface water chemistry appears to have been adversely impacted by population growth during and after the 1970s.
- Ground-water chemistry has been impacted by anthropogenic effects that include high nitrate and chloride and lower pH, primarily in areas of high population density.
- Limited duration and spatial distribution of data prevents determination of whether the system has reached equilibrium concentrations.
- Ongoing studies will reduce current uncertainties.

- Hydrochemical data, water levels, and response of wells to recharge suggest an equivalent porous medium can represent the watershed for large-scale evaluations.
- Equivalent porous media models can be used to integrate the data, design further data collection and provide predictions of the hydrologic response to further development with ever decreasing uncertainty as additional data are accumulated.

Uncertainty associated with the Turkey Creek Basin water budget is large, making it difficult to determine the population that can be reasonably supported in the basin. Short-term records can be misleading, and must be used with caution. Water quality has been impacted by development, but the limited period of record prevents us from knowing whether concentrations have reached a steady condition or are reflecting only the beginning of a long-term increase. Continued collection of hydrologic records and assessment modeling is necessary to reduce uncertainty.

Low-cost data are useful for characterizing the spatial distribution and magnitude of recharge, hydraulic conductivity, storage, and water consumption, in support of sustainability evaluation. For a system to be sustainable, long term recharge to the system must exceed long term consumption, and storage volume must be sufficient and its rate of decline slow enough to provide water during times of drought when use exceeds recharge.

In TCB, water use and return flow fractions are uncertain yielding a broad range of possible consumption on the order of 113,000 to 670,000 m^3/yr, with a likely value on the order of 340,000 m^3/yr (~90, 275, and 550 AFY for low, intermediate and high consumption rates). Recharge varies with location with a long-term spatially average rate between 0.3 in/yr and 2+ in/yr (750 to 5664 AFY), but is likely less than 1 in/yr and closer to the lower value. Hydraulic conductivity in TCB is low, ranging from 0.0001 to 0.003 ft/day. Consequently, drainage from the basin will be relatively slow, which should enhance sustainability through droughts. This is confirmed by the slow decline of water levels during the drought of 2001. Although different approaches to estimating specific yield produce wide variation, overall system behavior, given aquifer tests and water level declines during drought, suggest a specific yield is on the order of 0.6%. However this may reflect shallow conditions and specific yield may decrease with depth, which may cause the level of sustainability during droughts to decrease if averages use increases and lowers regional water levels.

Water use ranges from 100 to 200 AFY, assuming a 90% return, or from 300 AFY to 600 AFY for a 70% return. The long-term average recharge rate in the Turkey Creek Basin is expected to exceed 0.3 in/yr (~750 AFY), thus current water use in TCB appears to be sustainable on average. However, if the high estimate of use is more representative of current use, then sustainability of further growth is questionable. Additional monitoring of pumpage and return flow is warranted to obtain a better representation of consumptive water use.

Given that the current use is likely near the low estimate of the possible range of recharge to TCB, the long-term water level declines likely reflect a transition to a new equilibrium condition. In a fractured environment this may result in individual wells going dry (well yield below sustainable use), but deepening or relocating wells should yield a sufficient supply once a well-connected fracture is tapped by the well**.** Given that 1) the long-term average recharge is likely greater than average water consumption in TCB, and 2) available storage relatively high and

declines slowly (for a fractured rock aquifer), the current population of TCB is expected to be sustainable. However, specific yield is likely to decrease as water levels decline, and the maximum estimated current water use exceeds the minimum estimated recharge, thus continued refinement of these estimates is prudent.

Theoretical development of a method for estimating spatially variable representative elementary scale (RES) from low-cost data for the purpose of estimating the potential minimum scale of water resource management in a fractured aquifer led us to the following conclusions:

1. Porous media theory requires that the minimum scale of RES is constant in geometry and magnitude throughout a model domain. In naturally fractured media there is wide variation of connectivity, which we argue must lead to spatially variable RES. We have developed the HYRES approach to estimate spatially variable RES using readily-available low-cost field data.
2. Requiring absolute scale invariance of a parameter to define RES likely is not reasonable and arguably impossible for many fractured aquifers. We use scale derivatives of effective hydraulic head to estimate an appropriate tolerance, which we determine by dividing the global head gradient by the model area. Other tolerances may be appropriate and can be evaluated by plotting scale derivatives as a function of sampling area, in the manner described above. In practice an appropriate tolerance should be determined for each fractured aquifer.
3. We demonstrate the utility of estimating spatially variable RES using hydraulic head observations. HYRES is consistent with hydraulic head contours and fracture structure. Rather than analyzing structural behavior as a function of sampling volume, HYRES measures the variability of volume-normalized fluid energy. We argue HYRES is a more direct measure of flow behavior.
4. RES estimated via porosity indicates major regions where fractures have become disconnected, but exhibits significant noise in regions which are relatively homogeneous, as indicated by head contours and fracture structure. While RES determined from porosity can sense the structure of a discontinuity it does not account for fluid diversion around impermeable or low conductivity regions.
5. There is strong agreement between RES predicted by hydraulic conductivity and HYRES. Difficulty with using effective hydraulic conductivity results from its scale dependency, spatial variability, and the difficulty of measuring hydraulic conductivity relative to measure hydraulic head. Our analysis cannot distinguish which predictor is more accurate.
6. HYRES distinguishes disconnected regions with improved accuracy for larger data sets.
7. HYRES distinguishes clustered regions via varying tolerances. Varying tolerances in an iterative manner can identify clustering and regions with similar permeability. Regardless of the tolerance used for evaluating clustering, an appropriate tolerance should be employed for the HYRES analysis.
8. Varying hydraulic gradient does not affect HYRES. RES in a fracture flow system is independent of the fluid energy gradient, but dependent on spatial variability of fluid energy.
9. Varying flow direction causes a significant difference in predicted RES. These results do not contradict porous media theory but highlight the fact that discretely fractured systems will

seldom, if ever, approach theoretical porous media behavior. Subsequently a structural measure of continuum for fractured aquifers may not be appropriate, at least with respect to a flow continuum.

10. Multiple realizations are conducted using different numbers of observations. Accuracy and consistency of RES estimations improve with increasing number of observations.

We cannot determine nor numerically honor the true fracture architecture over large scales. Therefore determining a direct relation between complex, spatially variable fracture structure and RES may not be possible. We hypothesize RES can be determined by examining fluid behavior in an unknown fracture network by spatially analyzing hydraulic head observations. Our analyses compare HYRES to structural indicators of RES, and HYRES behavior under varying boundary conditions and fracture architecture. Our results indicate HYRES is an appropriate fluid-based approach to estimate spatially variable RES.

HYRES is an estimation of RES for fluid flow and provides some indication of subsurface structure, which may not completely coincide with transport RES. HYRES maps indicate areas with low fracture connectivity, thereby delineating zones where flow is channeled. In these regions it is reasonable to expect that transport is also channeled, possibly with a stronger control by the fracture network geometry. Therefore, HYRES maps provide some understanding of subsurface structure which is most pertinent to flow continuum but may have some first order applicability for transport.

HYRES improves with increasing data observations, in accordance with most analyses involving spatial data. Hydraulic head measurements are optimal because they are readily available and relatively inexpensive to collect. HYRES accuracy is likely a function of the number of data observations, the distribution of these points, and fracture architecture. In systems that are essentially homogeneous few points may characterize continuum behavior, whereas in highly heterogeneous zones more points may be required to adequately constrain spatially variable RES.

We argue that because HYRES analyzes variability of fluid energy it is a direct measure of flow behavior. Analyses support our hypothesis, indicating HYRES may provide the best estimation of large-scale flow continuum in fracture aquifers.

We have published the HYRES methodology to estimate spatially variable RES in fractured architecture in Water Resources Research.

Occurrence and Fate of Emerging Organic Chemicals in Onsite Wastewater Systems and Implications on Water Quality Management in the Rocky Mountain Region

Basic Information

Title:	Occurrence and Fate of Emerging Organic Chemicals in Onsite Wastewater Systems and Implications on Water Quality Management in the Rocky Mountain Region
Project Number:	2002CO46G
Start Date:	9/1/2002
End Date:	5/31/2005
Funding Source:	104G
Congressional District:	6th
Research Category:	None
Focus Category:	Waste Water, Water Quality, Toxic Substances
Descriptors:	None
Principal Investigators:	Dr. Robert L. Siegrist, John E. McCray, Kathryn S. Lowe

Publication

1. DeJong, K., 2004, "Occurrence of emerging organic chemicals in wastewater system effluents," presented at the 4th International Conference on Pharmaceuticals and Endocrine Disrupting Compounds in Water, Minneapolis, MN.

Problem and research objectives:

The purpose of this project was to collect field data on streams in the foothills and montane parts of Colorado in support of the State of Colorado's attempt to develop nutrient criteria in preparation for producing nutrient standards for Colorado waters. The state has identified high elevations as the highest priority, which explains the focus on streams of the mountains and foothills. The study was instituted to provide sufficient data on nutrients and potential ecological indicators of nutrient enrichment to establish thresholds of ecological change associated with nutrient enrichment. On this basis, thresholds for enrichments relevant to Colorado waters could be established for the state.

Methodology:

Nutrients of interest for this study include nitrogen and phosphorus, which are considered by the U.S. Environmental Protection Agency, the State of Colorado, and the research community to be the factors most likely to limit potential growth of autotrophs (algae and aquatic vascular plants" in aquatic ecosystems. Total phosphorus was analyzed, as were phosphorus fractions (soluble reactive phosphorus, total soluble phosphorus, particulate phosphorus). Dissolved inorganic nitrogen (nitrate, ammonia) was analyzed, but total nitrogen, which is considered to contain large amounts of unavailable forms of nitrogen, was not analyzed.

Response variables for the current study included biomass of attached algae (periphyton) measured as chlorophyll *a* per unit area, which is a conventional method for evaluating biomass of algae on illuminated surfaces. In addition, community composition of attached algae was considered a potential response variable, as was composition of the benthic fauna (bottom fauna) living in the streams. Chlorophyll data is cataloged, but the counting and identification of organisms, necessary for the community composition studies of periphyton and benthos, are still in progress. Response variables were sampled once (in fall).

Collections of all organisms at each site were made by standard methods, which involve taking multiple samples over the stream cross-section in order to compensate for spatial irregularities in the distribution of organisms. Sites were chosen so as to represent a range of elevations, and also to be located where an historical record was available for nutrient concentrations. Thus, the study did no rely entirely on nutrient samples taken at the time of sampling, but rather on a longer-term record that reflects more accurately the nutrient history of growth of the organisms at a particular site.

Approximately 75 sites were sampled at locations for which multi-year records were available for concentrations of total phosphorus (Figure 1). Most of these sites lacked adequate information on phosphorus fractions and on nitrogen fractions. Therefore, a subset of the sites (approximately 20) was analyzed with respect to these nutrient fractions.

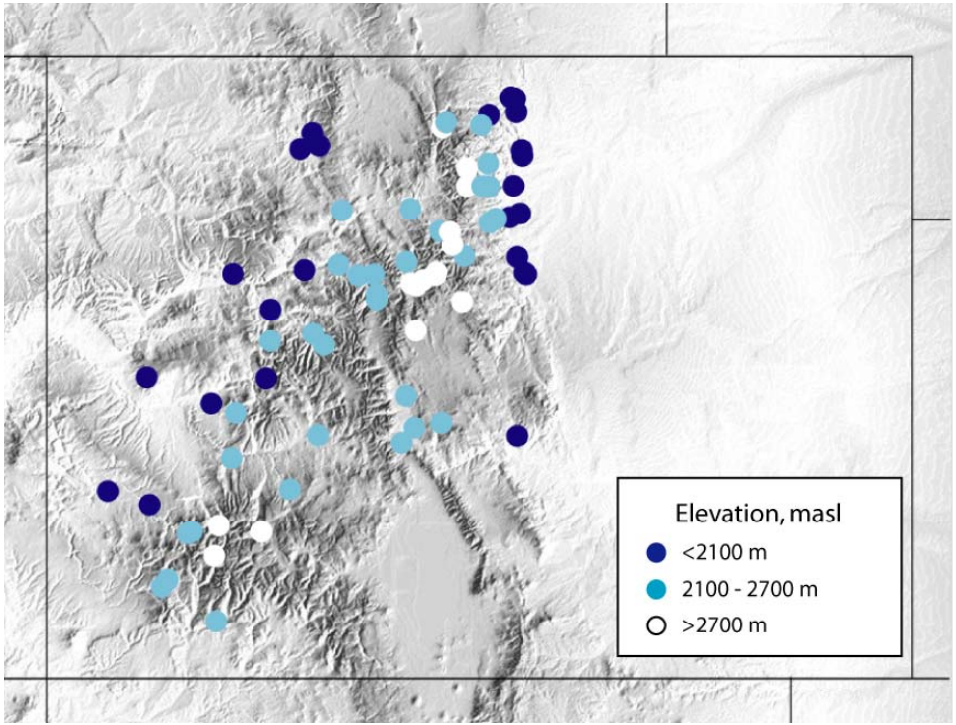


Figure 1. Map of sites sampled for this project.

Principal findings and significances

The premise at the beginning of the study was that growth of attached algae would depend in part on elevation. The sites were grouped for convenience into three elevation categories: high (greater than 2700 m), low (less than 2100 m), and intermediate (2100-2700 m).

Figure 2 shows the relationship between total phosphorus and chlorophyll *a* at the time of the fall sampling. Clearly, any sites from any elevation and for any annual mean phosphorus concentration can produce a high chlorophyll reading in fall. Sites with higher total P, however, show consistently high chlorophyll. Therefore, the main distinction between the sites is the range in chlorophyll concentrations that can be expected in fall: enriched sites (greater than 25µg/L total P) have consistently high chlorophyll, whereas unenriched sites or minimally enriched sites (below 25 µg/L) show a range of chlorophyll concentrations, including some very low amounts and some high amounts.

The relationship between chlorophyll *a* in the fall and the nitrogen and phosphorus fractions is shown in Figure 3. The general pattern is very similar to the pattern for total P. Basically, total P and the nutrient fractions give redundant information with respect to the response of biomass as represented by fall sampling. Therefore, total P can be used as the key nutrient factor.

The information on total phosphorus and chlorophyll suggest a threshold at about 25 µg/L total P separating a wide range of chlorophyll concentrations (below the threshold) from consistently very high concentrations above the threshold. This threshold could be used as the basis for nutrient criteria in Colorado. In terms of SRP (the soluble inorganic portion of phosphorus) the threshold falls at about 15 mg/L.

Additional sampling is underway through EPA support that will build on the observations made in this study. In addition, the studies of community composition may show that the threshold is verified or superceded by thresholds represented through community composition.

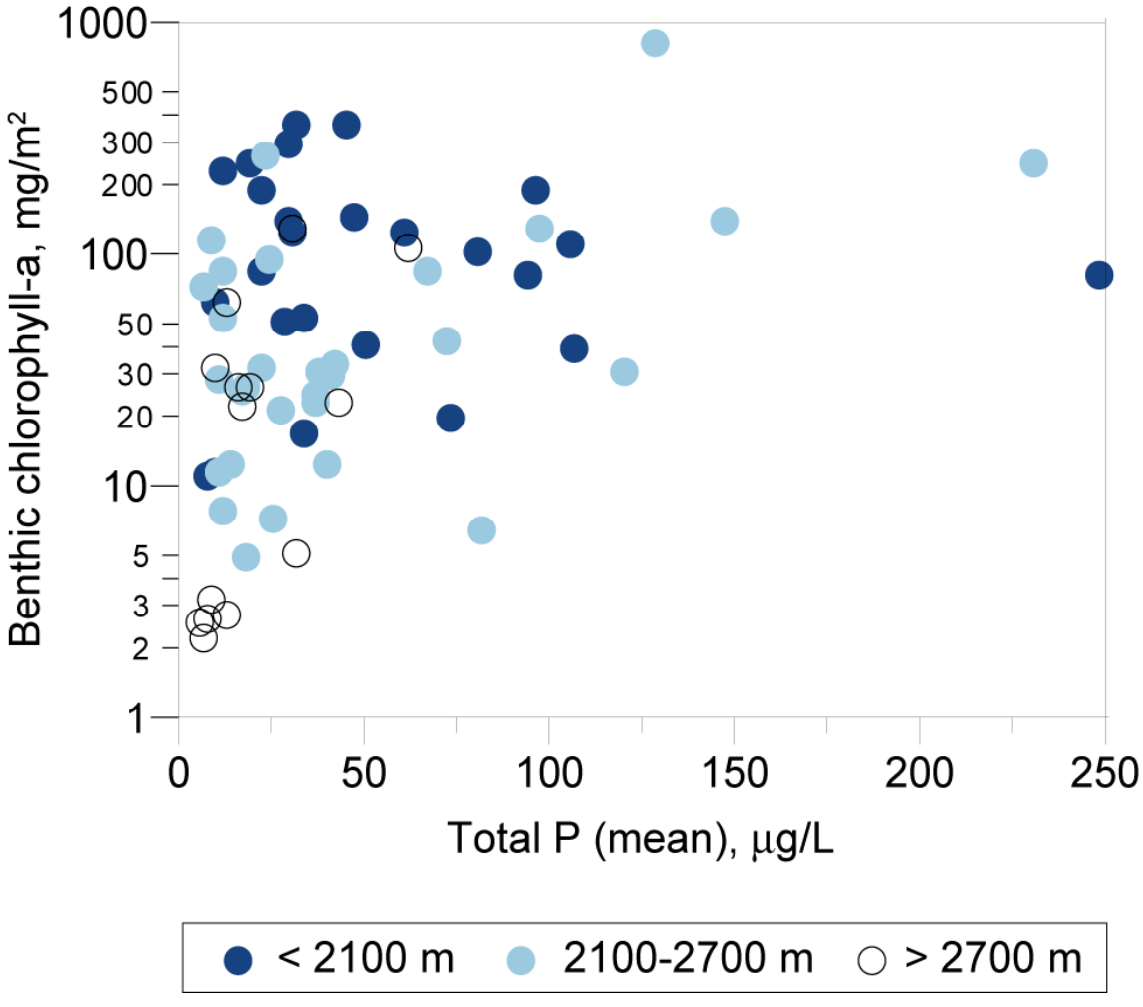


Figure 2. Benthic (periphyton) chlorophyll *a* in relation to mean total P for all dates. Open circles = high sites, Dark circles = low site, intermediate circles = intermediate sites.

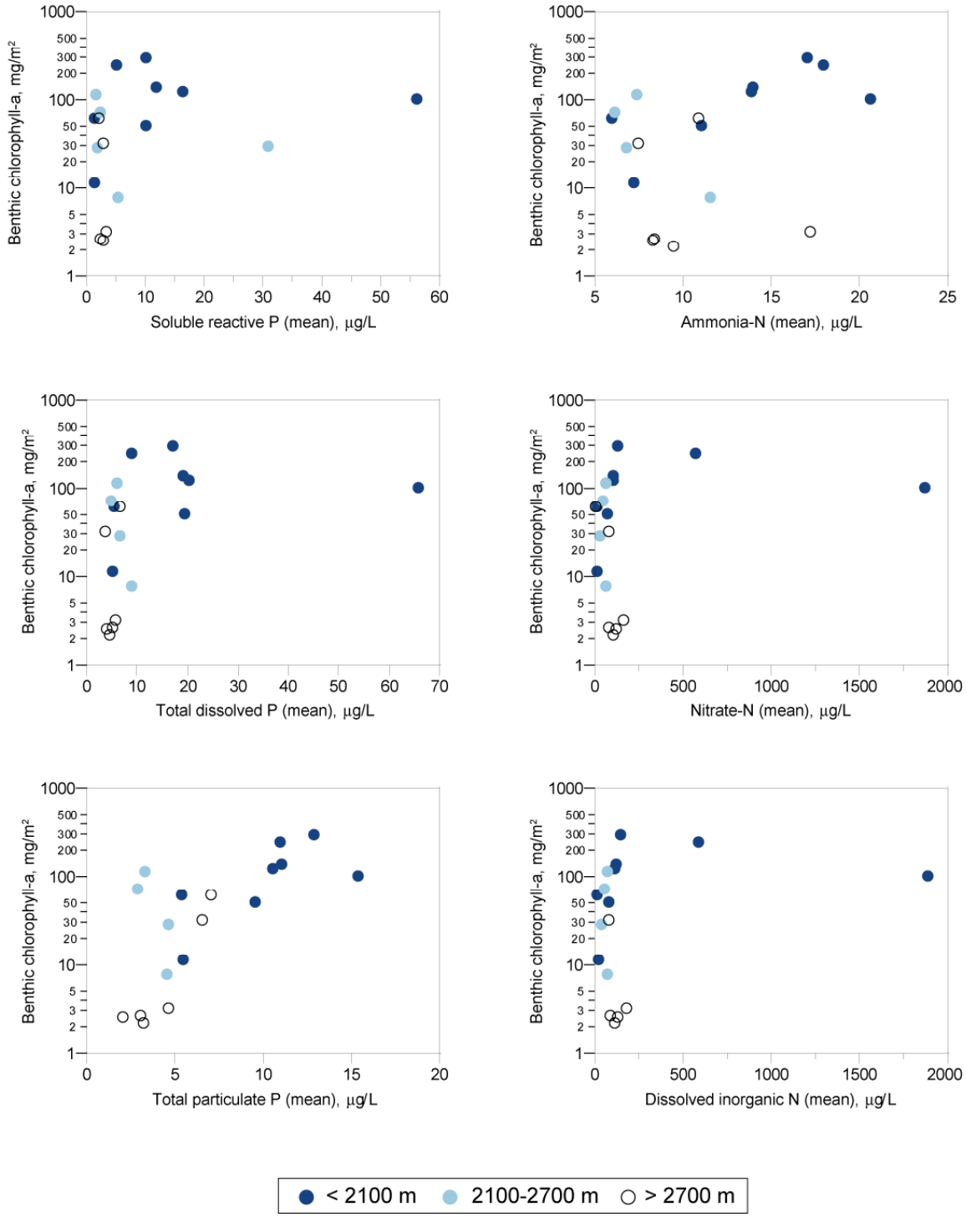


Figure 3. Benthic (periphyton) chlorophyll *a* in a relation to mean concentration of nutrients. Site coding same as for Figure 2.

Information Transfer Program

CWRRI encourages and engages in a variety of activities in support of technology transfer. Delivery methods include newsletters, web pages, and seminars. Participation in meetings allows staff to stay current with issues and research needs. By administering fellowships and scholarships, we encourage the growth of future water experts and provide them a venue for networking with the current water professionals in the state.

Technology Transfer/Information Dissemination

Basic Information

Title:	Technology Transfer/Information Dissemination
Project Number:	2002CO8B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	4th
Research Category:	None
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Robert C. Ward

Publication

1. Barta, Rachel, Israel Broner, Joel Schneekloth, and Reagan Waskom, 2004, "Colorado High Plains irrigation practices guide: water saving options for irrigators in Eastern Colorado," Special Report No. 14, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado.
2. Barta, Rachel, Robert Ward, Reagan Waskom, and Dan Smith, 2004, "Stretching Urban Water Supplies in Colorado: Strategies for Landscape Water Conservation," Special Report No. 13, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado.

Newsletter

Colorado Water is the bimonthly newsletter co-sponsored by the Colorado Water Resources Research Institute. The newsletter provides 1800 water professionals, legislators, policy makers and academics, researchers, and members of the general public regular information about research, resources, meetings, issues and conversations around water.

In 2004, the newsletters focused on major themes such as conjunctive management of ground and surface water, non-point-source pollution, international water connections of Colorado researchers, the history of water use, management and policy, and water transfers. Authors for these articles represented all of the major groups of readers for our newsletter, as summarized in this table.

AUTHORS	AFFILIATION	Number of Articles
Water managers		3
Legislative and legal personnel	Justice of water court Colorado Legislator League of Women Voters	3
Consultants/engineers		1
Graduate students		6
U.S. Government personnel	Bureau of Reclamation Agricultural Research Service National Oceanic and Atmospheric A	3
Colorado state agency personnel	State Engineers Office Department of Agriculture Department of Public Health and the Environment State Forest Service Attorney General	6
Colorado School of Mines	Environmental Sciences and Engineering	1
University of Colorado	Natural Resources Law Center	1
Colorado State University	History Civil Engineering Soil and Crop Sciences Forest, Rangeland, and Watershed Stewardship Library Agriculture and Resource Economics Cooperative Extension Political Science	23

Regular articles in the newsletter keep readers current on the holdings and accessibility of the Water Resources Archives in the Morgan Library on the Colorado State University campus. Over the years, the publicity has encouraged state water professionals and faculty members to donate their papers to the archive, and prompted interested parties to make donations for preservation and accessibility work on collections already held in the library.

In an effort to provide a two-way street between water researchers and water managers/users concerning research, education, and outreach accomplishments and needs, regular features of the newsletter include information on recently awarded grants in the area of water research is regularly included. Additionally, updates and progress reports on the research are published as they become available. Meetings in Colorado where water issues are discussed are always featured in the newsletter. Calls for papers and registration information are provided regularly. A running calendar of professional development and public education meetings occupies the last page(s) of each issue.

Web pages

CWRRI has maintained a web presence for a number of years, and the main goal for improvement this year was to upgrade the pages to increase accessibility of CWRRI publications while maintaining or reducing publication and distribution costs. With five report series (Completion Reports, Technical Reports, Special Reports, Information Series, and Water in the Balance) and hundreds of publications, streamlining distribution with web access makes sense in terms of the costs of printing, mailing, and staff processing time. In the past, documents with a high request rate were converted to on-line access. This year we began a more comprehensive program to convert all documents to on-line access, and more than 100 of the 200 completion reports were converted to on-line distribution. The systematic process for conversion begun on the completion reports will extend to the other series of documents in the next fiscal year. Our URL is http://cwrri.colostate.edu.

Seminars

CWRRI and the Water Center coordinate regular seminars for students and public on current water topics. Below is the synopsis of the purpose of the seminar and a roster of speakers.

"The Changing Role of 'Planning' in Navigating the Future of Water Management in the West"

The Fall 2004 Water Resources Seminar provided insight into modern concepts of water resources planning, a key water management tool that explores and navigates the future of water management decision making.

For many years, increasing and changing water demands in the Western United States were addressed through the planning associated with each new proposed, federally funded, water project. In the last 30 years, the federal government removed itself from the water resources planning and development process, moving the responsibility for water resources planning to interstate, state and local organizations. The recent drought in Colorado and the West exposed a number of water management issues that had not been properly addressed under the current planning processes. The Colorado legislature funded a Statewide Water Supply Initiative, in essence, a statewide water planning process.

When the states cannot resolve interstate water conflicts, or conflicts between historical uses and new federally mandated uses of water such as the Endangered Species Act, the federal government finds itself involved in water crises and conflicts. Water 2025 is the Department of Interior's latest initiative to find ways to reduce the crises and conflicts that emerge among states and competing water uses in the modern West.

Planning is a water management tool that has been viewed both positively and negatively over the past 30 years. The purpose of this seminar was to invite a series of speakers to examine the function and

future role of water resources planning in the western United States. More specifically, we asked our speakers to:

1. Explain the theories and practice of water resources planning;
2. Study the history of water resources planning in the West;
3. Examine the ways it is currently being employed (e.g. the Statewide Water Supply Investigation and Water 2025); and,
4. Explore how it might be used in the future to seek a commonly supported approach to water development and use.

Speakers:

"Planning as a Water Resource Management Tool" -- **Neil Grigg**, Professor, Department of Civil Engineering, CSU

"Colorado's Use of Planning in Managing Water Resources" -- **Eric Wilkinson**, General Manager, Northern Colorado Water Conservancy District, and Past-Chair of the Colorado Water Conservation Board

"The Northern Integrated Water Supply Project: Planning in Action in Northern Colorado" - **Carl Brouwer**, Project Manager, Northern Colorado Water Conservancy District

"Water Planning as Viewed from Experience with the Corp of Engineers and in the practice of Colorado Water Law" -- **John Hill**, Attorney, Bratton & McClow, LLP, Gunnison, Colorado

"Economic Analysis and Water Resources Planning" -- **Bob Hamilton**, Manager, Economics Group, Bureau of Reclamation, Denver, Colorado

"Decision Support Systems: Role in Planning and Management" -- **Larry Brazil**, CEO, Riverside Technology, Fort Collins, Colorado

"Water 2025: Preventing Crisis and Conflict in the West" -- **Brian Person**, Area Manager, Eastern Colorado Area Office, Bureau of Reclamation, Loveland, Colorado

" Water Resources Planning for a System that Needs a Quick Fix and Double Capacity" -- **Peter Binney**, Director, City of Aurora Utilities Department, Aurora, Colorado

"The Future of Water Resources Planning" -- **Leo Eisel**, Managing Engineer, Brown and Caldwell, Denver, Colorado

"Colorado Statewide Water Supply Investigation Results" -- **Rick Brown**, Scientist, Water Supply Protection, Colorado Water Conservation Board

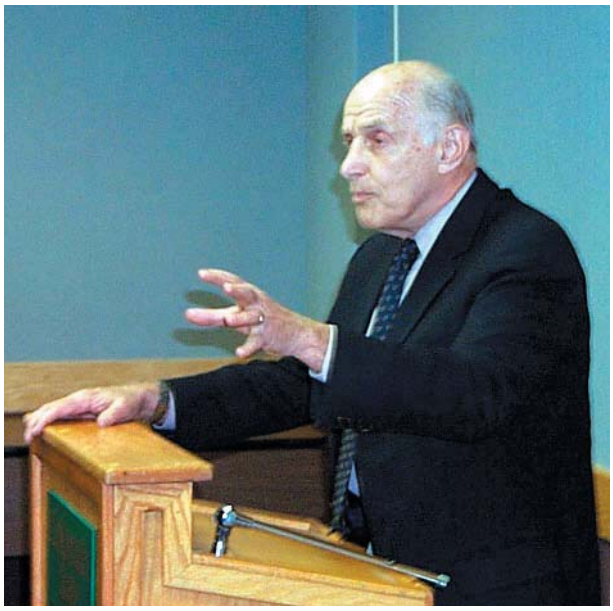
Other Seminars

In addition, CWRRI publicizes water related seminars, water short courses, and other professional development opportunities such as:

- CSU College of Agriculture, Department of Agricultural and Resource Economics
- CSU College of Business, Department of Economics
- U.S. Forest Service Rocky Mountain Research Station
- CSU College of Agriculture, Department of Soil and Crop Sciences
- CSU College of Engineering, Department of Civil Engineering
- Colorado School of Mines short course offerings
- Colorado Foundation for Water Education river tours and K-12 educator workshops
- Colorado Water Congress workshops, seminars, meetings
- South Platte Forum annual meetings
- Lower South Platte Forum biennial meetings
- University of Colorado short course offerings

Joe Sax Discusses Western Water Rights

Joe Sax, Professor Emeritus at the University of California-Berkeley Boalt Law School, presented a seminar to 60 students, faculty and water professionals on the evening of March 3, 2005, at Colorado State University. The seminar was sponsored by the Mac Foundation.



Professor Sax discussed ownership of water rights, role of public oversight in ownership, transitions in society which impact water rights, compensation for lost benefits or rights, and limited supplies. Describing transitions which impact the West such as rapid urban growth, changing social values, and quantification of Indian water rights, Sax asked, "How do we manage transitions in the use of water amid social transitions, when the supply of water is basically fixed?" He went on to discuss options available to individuals and as a society to deal with droughts, changing or increasing demands for water, protect rural community economies and resolve conflicts over water.

Meetings

These are some of the Colorado water meetings which the Director and/or staff of CWRRI participated in or helped to publicize:

- Colorado Section of American Water Resources Association , Arvada , CO , April 30, 2004
- Consortium of Universities for the Advancement of Hydrologic Science met with faculty from University of Colorado and Colorado State University, June 22, 2004 -- explain concept of hydrologic observatories
- Table of Contents, June 5, 2004 Morgan Library, Colorado State University Dan Tyler on Delph Carpenter and Robert Ward on evolving concept of "limits" to water use
- Four States Irrigation Council 52nd Annual Meeting, June 12-14, 2004, University Park Holiday Inn, Fort Collins, CO.
- Groundwater in the West, June 16-18, 2004, Natural Resources Law Center at University of Colorado, Boulder
- Colorado Water Workshop, July 28-30, 2004, Western State College in Gunnison, CO - interface of science and politics in development of water resources in 21st century
- Summer Convention of the Colorado Water Congress, August 26-27, 2004, Aspen, Colorado
- 2004 Colorado Nonpoint Source (NPS) Forum entitled "Watershed Planning: Blueprint for Action," September 8, 2004, Glenwood Springs, Colorado
- Fifth Annual Colorado Watershed Assembly Conference: Planning for the Future, September 9-10, 2004, Glenwood Springs
- Colorado's Future 2004: Economic Development and Policy, October 22, 2004, sponsored by Colorado Institute of Public Policy, held at University of Colorado, Colorado Springs, Robert Ward moderated a panel on examine connections between science, water policy, and economic development.
- Morgan Library, Colorado State University, meeting to discuss the future of the Water and Agricultural archives, November 11, 2004
- 15th Annual South Platte Forum, "Navigating the Future, Water Supplies in the South Platte" October 27, 28, Longmont, CO
- Colorado Water Congress 47th Annual Convention, January 27,28, 2005, Denver, Colorado.

CWRRI Funds Three Graduate Fellowships for 2005

Occurrence and Fate of Organic Wastewater Contaminants in Wastewater Systems and Implications for Water Quality Management
Kathleen DeJong
Colorado School of Mines

In the Colorado Front Range and Rocky Mountain region, residential wastewater management in the suburban fringe and mountain resort settings is commonly achieved by Onsite Wastewater Systems (OWS). These systems, like their municipal counterparts, can and must be designed, installed, operated, and managed to protect human health and environmental quality. In Colorado there are over 600,000 OWS in operation, serving about 25% of the state's population, and 7,000 to 10,000 new systems are installed every year. These systems process over 1000 billion liters of wastewater each year that is then discharged into the environment. There is almost no information regarding the occurrence and fate of Organic Wastewater contaminants (OWCs) in these systems and the potential for adverse impacts of discharge into receiving waters including impacts on ecosystems and human health. Kathleen's study will provide new information on (1) the occurrence and magnitude of pharmaceuticals, consumer products, and other OWCs in onsite wastewater system effluents from different types of sources (e.g., residential, commercial, institutional) and (2) the removal efficiencies that can be expected for commonly occurring OWSs during wastewater effluent percolation through unsaturated soil prior to groundwater or surface water recharge.

Additional funding for this project is provided by Colorado School of Mines.

Hydrologic Analysis and Simulation of the Upper Colorado River System
Julia Keedy
Colorado State University

The severe drought in the western United States in the past few years has reminded us how vulnerable water users in the state are to the variability of water supply. Many rivers of the state, including the Colorado River system, reached record or near record low flows causing widespread shortages and impacts to municipal water supply, agriculture, etc. Current procedures for analyzing the streamflows (e.g. based on the so-called index sequential techniques) rely completely on the observed historical records and may give an optimistic view of future flows, which in turn could lead to unanticipated water shortages. Julia will work to improve the hydrologic data base for the upper Colorado River system so that it includes records at least from 1906 through the current drought to allow a better understanding of the multidecadal flow patterns and better assessment of the long term flow trend of the system.

Additional funding for this project is provided by the Colorado River Water Conservation District.

Colorado's Evolving Irrigated Agriculture: Economic Accounting and Impact Analysis

Jennifer Thorvaldson
Colorado State University

Colorado's irrigated agriculture is evolving as water is transferred from farming to urban uses. In the next twenty-five years, Colorado's population is expected to exceed 7 million people and an additional 632,000 acre-feet of water will be needed in cities to support their needs. An estimated 300,000 irrigated acres will "dry up" as water transfers occur. Similarly, groundwater irrigation will be reduced as new augmentation rules take effect, as Colorado meets its interstate compact obligations, and as the Ogallala aquifer continues its "planned depletion". Colorado's crop production has thrived with its water resources and, in turn, crop production has supported commercial livestock, meat packing and dairy industries. Each of these primary agricultural industries has encouraged economic development directly, through the purchase of inputs, and indirectly, through the wages and salaries of employees. Given the finite nature of water supplies, an important question is how the economic base will change as irrigated agriculture's scope is reduced. Importantly, the impacts may be quite different in Colorado's surface water basins because of the diversity in the basin's economic base and heterogeneous cropping patterns. Jennifer's study will establish the economic demographics for four basins (Arkansas, Republican, Rio Grande, and South Platte) and develop a model representing the economy and economic interactions within each basin with an end goal of analyzing the economic impacts of reducing irrigated agriculture.

Additional funding for this project is provided by the Colorado State University Agricultural Experiment Station.

USDA Special Needs Grant Funds Three Graduate Fellows at CSU

A Cooperative State Research, Education, and Extension Service (CSREES) award funds three graduate fellows in their research on water management issues critical to Colorado agriculture. All three fellows are in their final year of research. In addition to three-years annual stipend of $22,000, the students receive a travel allowance to attend two national technical conferences to present their findings.

Alisa Wade began her doctoral work at Colorado State University Fall Semester, 2003. A member of the Forest, Rangeland, and Watershed Stewardship department in the College of Natural Resources, her work explores landscape ecology with a focus on how public land management actions impact watershed health. Use of Geographic Information Systems (GIS) to assess the impact of various management options is part of her watershed impact study.

Curtis Cooper is engaged in the study of salinity issues in Colorado for his doctoral studies. Working on an interagency project to assess salinity and waterlogging issues in the Arkansas River Valley. During his time at CSU, he has worked with faculty in Forest, Rangeland, and Watershed Stewardship (College of Natural Resources), Civil Engineering (College of Engineering) and Soil and Crop Sciences (College of Agriculture.)

Travis Schmidt, doctoral candidate in Fishery and Wildlife Sciences in the College of Natural Resources, is studying ecotoxicology. His work complements research on global climate change, particularly in the areas of ultraviolet radiation, dissolved organic carbon, and heavy-metal interaction with stream benthic communities.

Upper Yampa Water Conservancy District Scholarship Awarded At CSU

Upper Yampa Water Conservancy District (UYWCD) funds a scholarship in support of CSU students preparing for careers in water-related fields. The scholarship provides financial assistance to committed and talented students who are pursuing water-related majors at CSU.

The Upper Yampa Water Conservancy District Scholarship Recipient for the 2005-06 academic year is **R. Morgan Cate**. A senior majoring in Construction Management at CSU, Cate is from Steamboat Springs. He is interested in designing and constructing high performance buildings which contribute to sustainability and shape a high quality, healthy living environment. Cate has taken courses in sustainable construction at CSU and worked for McStain Neighborhoods as a student intern on high performance residential construction. He also serves as Vice President of the Design Build Club at CSU. He'll graduate December, 2005.

For the summer of 2005, Cate interns for R.A. Nelson of Vail, Colorado. The construction company is currently involved with two LEED certified projects that promote sustainable construction and utilize resource efficient technology. Cate says that all construction has an environmental impact, and his long term goal is to practice and employ appropriate technologies for sustainable development/construction in both the residential and commercial sectors.

Robert Ward (left), chair of the CSU Water Center Scholarship Committee, congratulates Morgan Cate for receiving 2003-04 Upper Yampa Water Conservancy District Scholarship.

Big Thompson at Milliken, Colorado

Staff

Robert C. Ward, director of the CWRRI, actively works to foster communication between water professionals, water policy makers, and water scholars in the various institutions of higher education in the state of Colorado. He coordinates several campus water seminars which provide CSU students the opportunity to converse and network with members of the water community in Colorado.

In addition, he is chair of the Water Section of National Association of State Universities and Land Grant Colleges, past president of NIWR, Associate Editor of Water Resources IMPACT, and a member of the National Water Quality Monitoring Council, the Colorado Water Quality Monitoring council, the Bureau of Reclamation's Research Steering Committee, the Scientific Organizing Committee for Monitoring Tailor-Made Workshop in the Netherlands, and the Poudre Heritage Alliance. In addition he supports and participates in activities of the Colorado Water Congress, a state-wide organization of water users and managers.

Doris Carpenter, Ward Carpenter, and Robert Ward attended the Tables of Contents gala at the Morgan Library on the CSU campus.

Gloria Blumanhourst maintains the administrative functions of CWRRI including accounting, grants assembly, publication production, and website management.

Brad Wind of Northern Colorado Water Conservancy District and Reagan Waskom speak during American Water Resources Association Colorado Section annual meeting in April, 2004.

Reagan M. Waskom, Water Resources Specialist and Associate Director for the Colorado Water Resources Research Institute, is engaged in a variety of research/educational activities including selenium issues on Colorado's West Slope, agricultural water quality educational project funded by the United States Department of Agriculture and groundwater education project funded by the Colorado Department of Agriculture.

Waskom currently serve as a member of the following boards and advisory committees: USDA-CREES Committee for Shared Leadership for Water Quality, Colorado Water Availability Task Force, Colorado Foundation for Water Education, Colorado Watershed Assembly Outreach Committee, USDA-NRCS State Technical Committee, Colorado AWARE Advisory Board, Fort Collins Water Board, Colorado Dept of Public Health and Environment NonPoint Source (EPA 319) Advisory Council.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	4	4	0	0	8
Masters	3	2	0	0	5
Ph.D.	4	2	0	0	6
Post-Doc.	0	0	0	0	0
Total	11	8	0	0	19

Notable Awards and Achievements

Robert A. Young: 2004 Warren A. Hall Medal Honoree

Robert A. Young, Professor Emeritus of the Department of Agricultural and Resource Economics at Colorado State University, was awarded the 2004 Warren A. Hall Medal at the annual conference of the Universities Council on Water Resources (UCOWR) in Portland, Oregon on July 21, 2004. Young, respected leader in the advancement of water resource economics and policy worldwide, has covered a broad range of topics during his 40-year career. His contributions include work on non-market valuation of water-related goods and services, valuation of water for private (crop irrigation, industries and households) and public good (instream flows and water quality), pricing reform, and management of ground water, water quality, and water supply investment. Dr. Young has a long, continuous, and impressive record of research, teaching and service contributions. The Warren A. Hall Medal is a memorial established by friends and family of Warren A. Hall, and is presented by the UCOWR to recognize unusual accomplishments and distinction of an individual in the field of water resources. The nomination for this award was coordinated by CWRRI staff.

Student Awards

Tristan Wellman received An Outstanding Student Research Award in Hydrologyfrom the American Geophysical Union in December 2003 for his work with Eileen Poeter on the Use of low-cost data to simulate fractured-aquifer watersheds for management of Water Quality and Quantity project.

Water Archives Grows at Colorado State University Libraries

Donations to the Water Resources Archive this year came both in terms of donated papers and funds to care for endangered collections already held by the Archive. The papers of Maurice L. Albertson were added to the Archive, and enrich the collection with information on Civil Engineering courses taught at Colorado State University as well as Albertsons many international connections and projects. Albertsons career, still in progress, spans more than fifty years. More than 140 boxes of materials came to the archive in this donation. In processing the Delph Carpenter papers which were donated to the Archive last year,

archivists discovered mold in a substantial portion of the collection -- a result of a flooded basement where the documents were stored prior to donation. With the help of Dan Tyler, historian and author of the book The Silver Fox of the Rockies: Delphus E. Carpenter and Western Water Compacts, the library was able to garner more than $40,000 to purchase mold cleaning equipment and supplies as well as staff time to process the donation. CWRRI encourages and supports the efforts of the Water Resource Archive by presenting regular features on materials in the collection and the process of donating and preparing collections for access by students, scholars, and water professionals.

Publications from Prior Projects

1. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Articles in Refereed Scientific Journals - Wellman, Tristan, and Eileen Poeter, 2005, "Estimating spatially variable representative elementary scales in fractured architecture using hydraulic head observations," Water Resources Research, Vol. 41, No. 3.
2. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Articles in Refereed Scientific Journals - Thyne, Geoff, Cuneyt Guler, and Eileen Poeter, 2004, "Sequential analysis of hydrochemical data for watershed characterization," Ground Water, v. 42, no. 5, pp. 711-723.
3. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Book Chapters - Poeter, Eileen, Geoff Thyne, Greg VanderBeek, and Cuneyt Guler, 2003, "Ground water in the Turkey Creek Basin of the Rocky Mountain Front Range in Colorado," in press in Engineering Geology in Colorado: Contributions, Trends and Case Histories, ed. Douglas Boyer, Paul Santi, and Pat Rogers, Association of Engineering Geologists Special Publication 15 and Colorado Geological Survey Special Publication 55.
4. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Dissertations - Masters Thesis: VanderBeek, Greg, 2003, Estimating Recharge and Storage Coefficient in a Fractured Rock Aquifer, Turkey Creek Basin, Jefferson County, Colorado, Masters Thesis, Department of Geology and Geological Engineering, Colorado School of Mines.
5. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - Wellman, Tristan and Eileen Poeter, 2004, "Optimizing the predictive accuracy of hydraulic head observations to delineate continuum scales in the phreatic fractured rock aquifers," The Finite-Element Models, MODFLOW, and More 2004 conference, Carlsbad, Czech Republic.
6. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - Wellman, Tristan and Eileen Poeter, 2004, "Evaluating hydraulic head data as an estimator for spatially variable equivalent continuum scales in fractured architecture using discrete feature analysis," Dynamics of Fluids in Fractured Rock Conference, Sponsored by Lawrence Berkeley National Laboratory, February.
7. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - Wellman, Tristan and Eileen Poeter, 2003, "Estimating equivalent continuum scales in fractured aquifer watersheds using Discrete Feature Network Simulation," Fall AGU Meeting, Eos, 84 (46) abstract

H42B-1071.

8. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - Day, Sharon, Geoff Thyne, and Eileen Poeter, 2003, "Using statistical analyses to characterize effects of population growth on water quality," Geol. Soc. Amer., Abstracts with Programs, 35 (5), p. 30.
9. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - Vanderbeek, Greg, Eileen Poeter, Geoff Thyne, and John McCray, 2003. "Ground-water availability in Turkey Creek Basin, Colorado," Geol. Soc. Amer., Abstracts with Programs, 35(5).
10. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - Dano, Kathleen, Eileen Poeter, and Geoff Thyne, 2002, "Geochemical and geophysical determination of the fate of septic tank effluent in a mountain watershed," Colorado. Geol. Soc. Am. Abstracts with Programs, 34(6).
11. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - Day, Sharon, Geoff Thyne, John McCray, and Eileen Poeter, 2002, "Evaluation of the effects of population growth on water quality in a mountainous watershed, CO," GSA Abstracts with Programs, 33 (4).
12. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - Guler, C. and Geoff Thyne, 2002, "Hydrochemical evolution model and characterization of flow in a fracture crystalline rock aquifer, Turkey Creek, Colorado," Geol. Soc. Am. Abstracts with Programs, 34 (6)
13. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - Thyne, Geoff, Sharon Day, John McCray, and Eileen Poeter, 2002, "Evaluation of the effects of population growth in mountain watershed water quality," EPA Fractured Rock Aquifers 2002 Focus Conference, Denver, Colorado.
14. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Other Publications - VanderBeek, Greg, Eileen Poeter, Geoff Thyne, and John McCray, 2002, "Ground-water availability in Turkey Creek Basin, CO," GSA Abstracts with Programs, 33 (4).
15. 2002CO2B ("Enhancements to the South Platte Mapping and Analysis Program (SPMAP)") - Conference Proceedings - Matter, M.A., Garcia, L.A., and Fontane, D., 2004, "Requirements of endangered fishes and water supply forecasting: use of physical characteristics of streamflows in snowmelt-dominated rivers," presented at the 23rd Annual Hydrology Days, Fort Collins, CO, March 10-12.
16. 2002CO2B ("Enhancements to the South Platte Mapping and Analysis Program (SPMAP)") - Conference Proceedings - Eldeiry, A., Garcia, L.A., Ahmed Samy A. El-Zaher and El-Sherbini, M., 2004, Furrow "Irrigation system design for clay soils in arid regions," published in the proceedings of the 23rd Annual Hydrology Days, Fort Collins, CO, March 10-12.
17. 2002CO2B ("Enhancements to the South Platte Mapping and Analysis Program (SPMAP)") - Other Publications - Patterson, L., and Garcia, L.A., 2003 "User centered decision support tools for computing augmentation requirements in the South Platte River," published in Colorado Water, October 2003, Colorado Water Resources Research Institute, Colorado State University, Ft. Collins, CO.
18. 2002CO2B ("Enhancements to the South Platte Mapping and Analysis Program (SPMAP)") - Other Publications - Garcia, L.A., 2003, "Pumping and augmentation in the South Platte: Impacts and

opportunities," Assessing the Impacts of Prolonged Severe Drought on Aquatic Ecosystems and Water Quality of the South Platte River Basin, conference, Colorado, Fort Collins, April 3-4.

19. 2002CO2B ("Enhancements to the South Platte Mapping and Analysis Program (SPMAP)") - Conference Proceedings - Elhaddad, A. and Garcia, L.A., 2003, "Soil salinity mapping using satellite images," poster presented at the 23rd Annual Hydrology Days, Fort Collins, CO, March 31-April 2.
20. 2002CO5B ("Determining the Fate of Non-source Pollution from Septic Tanks in Turkey Creek Basin, Colorado, and Delineating Improved Management Practices") - Water Resources Research Institute Reports - Dano, Kathy, Eileen Poeter, and Geoff Thyne, 2004, Investigation of the fate of individual sewage disposal system effluent in Turkey Creek basin, Colorado, May 2004, Completion Report 200, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado.