Colorado Water Resources Research Institute

Annual Technical Report

FY 1998

Introduction

Research Program

WATER PROBLEMS AND ISSUES IN COLORADO

Coloradans still identify growth and its associated problems as the state's number one issue. From the urban, rural, and farming communities of Colorado's northern Front Range, southward through the Denver Metro area to Colorado Springs and Pueblo, and west across the Continental Divide, there is concern about sprawl and, growth, and their associated affects. While a majority of Coloradans do not want diminished agriculture in the state, urban growth is forcing cities to seek agricultural water rights as a source of supply for their growing communities. And the influx of new residents, which was expected to decline, shows no sign of doing so.

Protecting endangered species also remains a high priority. In 1994, the U.S. Fish and Wildlife Service gave special protection to 1,980 miles of the Colorado River and its tributaries to protect four native fish species: -- the Colorado squawfish, bonytail chub, humpback chub and razorback sucker.

The Three-States Cooperative Agreement was signed in 1997 by Wyoming, Nebraska and Colorado to protect endangered species such as whooping cranes along the Platte River near Grand Island, Nebraska. Water users in Colorado, Nebraska and Wyoming will need to provide 130,000-150,000 acre-feet of "new" water to the critical habitat in central Nebraska.

PROGRAM GOALS AND PRIORITIES

Reauthorization of the Water Resources Research Act for five years was signed on May 24, 1996, and again in FY1998, as in the preceding years of FY1996 and FY1997, each institute received a base grant of $20,000. The remaining funds were competitively awarded based on regional program priorities approved by the U.S. Geological Survey. With no funds allocated to a state institute research program, the CWRRI Research Planning Advisory Committee did not meet during FY1998.

USGS Competitive Grant Program

The principal objectives of the program were:

- to conduct research on important water resource problems of the region;
- to promote the dissemination and application of the results of the research; and

- to assist in the training of scientists in relevant water resource fields.

Research proposals were intended to address water resources problems of regional or multi-state significance. The following areas of emphasis were provided as "Illustrative Examples of Research Topics:"

- Ecosystem Approaches to Managing Riparian Areas in the Western United States
- Reassessing Salinity Management Policy
- Improving Decisions for Managing Major River Systems in the Western United States
- Impacts of Incremental Institutional Reforms for Drought Management of Western Water Resources
- River-Basin Level Nonpoint Source Pollution Control
- Native American Water Rights Issues
- Water Quality Impacts of Confined Animal Production Activities
- Water Conservation and Artificial Recharge of Aquifers
- Water Quality Problems Associated with Oil and Natural Gas Exploration and Development
- Institutional Infrastructure Changes for Holistic Water Management
- Impacts of Air Pollution on Recharge and Quality of Surface Water and Ground Water Supplies
- Evaluating Conservation Programs
- Flood Frequency Forecasting
- Effects of Urbanization on Floods and Water Quality
- Water Reuse
- Hydroclimatic Variation

Nationally, the program was divided into four regions for the competitive grants: the West, North Central, Northeast, and the Southeast and Islands. Each region received $800,000 for grants. The states included with Colorado in the Western region are Alaska, Arizona, California, Idaho, Nevada, New Mexico, Oklahoma, Oregon, Texas, Utah, Washington State and Wyoming.

Twenty-six proposals were entered in the regional competition. Colorado State University was the lead institution for three proposals and co-leader for the fourth. The proposal that was funded is described below, and titles of the other three submitted proposals follow.

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

Water users in the three basin states of Colorado, Wyoming, and Nebraska have effectively fully appropriated the flows of the South Platte, North Platte, and Platte Rivers -- primarily for irrigation uses. At the same time, species dependent on the habitat are listed as threatened or endangered. To comply with the ESA mandate for recovery of these species, the U.S. Fish and Wildlife Service estimates that on average as much as 373,000 acre-feet of additional water must be made available. In 1997 the Governors of Colorado, Wyoming and Nebraska, along with the Secretary of the Interior, signed a Memorandum of Agreement to develop a program to meet ESA requirements. A ten-person Governance Committee is responsible for implementation of the MOA. In the first 10 to 13-year increment of the agreement, the parties commit to reduce shortages to target flows at Grand Island an average of 130,000 acre-feet. Approximately half of the water commitment is to come from specific water projects in the three states. The remaining half is expected to come from water conservation and water supply options to be identified initially by a consultant and included in an action plan by the Committee. This proposed research will complement the efforts of the Committee and its consultant to identify potential water conservation and water supply projects. It will develop a conceptual analytical framework in which to evaluate the feasibility, effectiveness, and effects of alternative approaches for supplying additional instream flows to the central Platte River in Nebraska.

The principal investigator for the proposed research is Dr. Marshall Frasier, Department of Agricultural and Resource Economics at Colorado State. Dr. Robert A. Young of the same department, and Dr. Tim Gates, Department of Civil Engineering, are co-investigators. Co-investigators from other states are: Dr. Ari Michelsen, Washington State University-Vancouver; Dr. James Booker, Alfred University, NY; Dr. Garth Taylor, University of Nebraska; and Dr. Steve Gloss and Dr. Mark Squillace, University of Wyoming.

The other three proposals submitted were:

Integrating Biohydrology and Water Management to Benefit Native Fishes in the Western United States. Principal Investigator: Kurt Fausch, Department of Fishery and Wildlife Biology, Colorado State University. *Co-Investigators: Elizabeth Strange, Department of Fishery and Wildlife Biology, Colorado State University; Peter Moyle, Department of Wildlife, Fish and Conservation Biology, University of California, Davis; and Hiram Li, Assistant Leader, Cooperative Fish and Wildlife Research Unit, Oregon State University.*

Simulation Model for Design and Management of Irrigation and Drainage Systems for Water Quality. *Principal Investigator: Luis Garcia, Department of Chemical and Biological Resources, Colorado State University. Co-Investigators: Robert C. Ward, Director, CWRRI, Colorado State University; Todd P. Trooien, Kansas State University; and James C. Valliant, Colorado State University Cooperative Extension.*

Erosion Experiments on of Cohesive River Bends. *Principal Investigator: T. Papanicolaou, Washington State University. Co-Investigator: Pierre Julien, Civil Engineering, Colorado State* University.

STATE RESEARCH PROGRAM

The Colorado Water Resources Research Institute conducted a modest "seed" money research program in FY1998 that provided "start-up" research funds, or supplemented funds provided by local and state agencies and organizations, for projects deemed to be of priority by representatives of the participating agencies or organizations.

Inheriting Our Past: River Sediment Sources and Sediment Hazards in Colorado

River channels are dynamic natural systems that are continually changing. A channel reflects to some degree all of the processes operating within its drainage basin. These processes are ultimately controlled by geology and climate, which together determine regional topography, soil development, the growth of vegetation, and the land-use practices of people living within the drainage basin (*Figure 1*). Hillslope features such as topography, vegetation, and land-use will influence the characteristics of water and sediment yield from the hillslopes to the channel. The movement of water and sediment along the channel will then depend on channel and valley-bottom geometry, but will also influence that geometry.

Figure 1. Schematic diagram of relationships among factors controlling sediment movement along rivers. Contaminants may move in association with water and/or sediment.

There are four basic processes by which sediment moves down a hillslope. Mass movements involve the rapid downslope motion of large aggregates of sediment. These movements include rockfall, landslides, debris flows, and slumps. Sediment may also move downslope as individual particles or small aggregates.

Very intense rainfall on a slope of low permeability may create thin sheets of flowing water across the slope, and this water may carry sediment with it. The water may also concentrate into rills or gullies. The water's erosive force is greatly increased in these small channels. Both slopewash and rilling are particularly effective on sparsely vegetated slopes or on slopes that have been recently disturbed by something such as a forest fire. Finally, sediment may move very gradually downslope in cycles tied to freezing and thawing or wetting and drying. This process of soil creep may be effective even on densely vegetated slopes.

Once sediment enters a river channel, it may remain in place, or be transported downstream in dissolved, wash, suspended, or bedload. Dissolved load refers to material carried in solution in the water column. Dissolved load is high in drainage basins formed on rocks that are readily weathered and eroded, and in drainage basins where water moving slowly through the subsurface has time to react chemically with its surroundings before entering the stream channel. Wash load is composed of fine sediments that are carried in suspension and are deposited along the channel margins to only a limited extent. Suspended load is also carried in suspension, but these coarser silt, sand, and gravel particles move sporadically, being carried some distance and then stored for a time in the channel bed. Bedload is composed of the largest particles, which move by rolling, sliding, or bouncing, and always remain in contact with the channel bed. The grain size distribution and mode of transport of sediment will determine residence time within a river system: A clay particle that reaches a river from the hillslopes may be transported through the entire system in a few years, whereas a boulder that moves a short distance as bedload every few decades may remain in the river basin for millennia.

Figure 2. Schematic drainage basin illustrating natural sediment sources and sinks. This illustration may be applied to any scale of drainage basin.

The relative importance of the different components in *Figure 1* varies with location in the drainage basin (*Figure 2*). The upper portion of a drainage basin is primarily a source for water and sediment. The channels in this source zone tend to be steep and narrow, with bedrock or boulders forming the channel boundaries. Sediment introduced directly to the channels from the steep hillslopes is moved rapidly downstream, with relatively little sediment storage along the valley bottoms. In Colorado, this source zone is best represented by the Rocky Mountains.

The central portion of a drainage basin is primarily a transport zone for water and sediment. Channel gradient decreases in the transport zone, and the narrowly confined valleys of the source zone give way to broader valleys with well-developed floodplains and larger volumes of stored sediment. Sediment in storage throughout the transport zone has a longer residence time than sediment in the source zone, although the downstream sediment is periodically mobilized. Many of the channels on the plains of eastern Colorado and the plateaus of western Colorado have the characteristics of channels in the transport zone.

The depositional zone at the downstream end of a drainage basin has very low-gradient channels flowing across very broad valleys. This zone is a sediment sink, where the finer sands, silts, and clays that have been transported from the uplands are stored for long periods of time along the valley bottoms. For many of the rivers originating in Colorado, this zone lies beyond the state borders, although some examples can be found in the San Luis Valley.

Hazards associated with sediment

">The hazards associated with river sediment may be very local in scale, or they may affect a large portion of a river's drainage basin. Sediment hazards in Colorado take three basic forms: excess of sediment, decrease of sediment, and contamination of sediment.

Excess of sediment generally implies that flow in the channel is not capable of transporting all of the sediment supplied, resulting in a change of channel pattern, loss of specific channel features such as pools or spawning sites, filling of the channel and overbank flooding, or filling of a reservoir. Decrease of sediment implies that flow in the channel is capable of transporting more sediment than is being supplied. Consequently, the excess flow energy will be expended on channel erosion, resulting in bank collapse, bridge-pier scour, channel downcutting, and other changes. Sediments may be contaminated by materials toxic to humans and aquatic organisms, such as agricultural and urban pesticides or mining leachates. Sediments may also be contaminated by excessive levels of nutrients such as urban and agricultural phosphorus which create algal blooms that reduce dissolved oxygen and harm fish populations, a problem in many of the reservoirs in Colorado used for human recreation.

THE RIVERS OF COLORADO

">The State of Colorado includes seven major water basins with 105,600 miles of rivers and 3,260 lakes, reservoirs, and ponds. The State can be divided into three physiographic provinces; the eastern plains, the central mountains, and the western plateaus and canyons (*Figure 3*).

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Figure 3. The State of Colorado, with major drainage etworks and the three physio- graphic provinces. The eastern plains are the white band at the right of the figure; the mountains are indicated by the shaded band in the center of the figure; and the western plateau and canyon region is the white band at the left of the figure. The triangle at the western edge of the plains represents the city of Denver.

Each of these provinces has distinctive traits of geology, climate, soils, vegetation, topography, and land use that in turn produce distinctive types of river channels.

Many of Colorado's rivers have undergone substantial changes since 1800 as a result of human activities (*Figure 4*). In some instances, the effects of these activities completely dominate the natural controls on sediment movement into and along the rivers. However, there remain sediment issues that are unique to each of the three physiographic provinces because of the geologic and climatic characteristics of those provinces. The next section of this report highlights a series of examples of sediment hazards in Colorado.

Figure 4. The State of Colorado. Black dots indicate dams and reservoirs in the state, including very minor reservoirs.

SEDIMENT HAZARDS IN COLORADO

Human activities may indirectly affect river channels if the movement of water and sediment from hillslopes to channels is altered. Examples of such activities include timber harvest, crops, grazing, road construction, and urbanization.

Human activities may also directly affect river channels by altering the flow of water and sediment along the channel, as results from dams, flow diversions, channelization, beaver trapping, or placer mining.

Examples of hazards associated with excess sediment

North Fork Poudre River, Larimer County: The draining of Halligan Reservoir in late September 1996 was accompanied by the release of approximately 7,000 cubic yards of clay to gravel sized sediment that had accumulated in the reservoir. Flow from the drained reservoir was shut down immediately after the sediment was released, allowing the sediment to settle along more than 10 miles of river downstream from the reservoir. The immediate effect of the sediment release was a massive kill of aquatic organisms; the Colorado Division of Wildlife (CDOW) estimated 4,000 dead fish along the ten miles of channel immediately downstream from the reservoir. Over the longer term, the continuing presence of excess fine sediment along the channel has inhibited re-colonization by aquatic insects and fish. CDOW is now proposing to re-stock fish along a river that had supported a self-sustaining population prior to the sediment release.

Buffalo Creek, Jefferson County: Following a forest fire that burned 2,000 acres of the Buffalo Creek drainage in May 1996, massive sediment yields came from the burned hillslopes during a series of rainstorms in June and July 1996 and 1997. The highly weathered granite underlying the hillslopes provided a source of abundant sediment once the vegetation was removed during the fire. The summer rainstorms caused 9 floods that were greater than the 100-year flood (pre-fire conditions), as well as numerous smaller floods (R. Jarrett, U.S. Geological Survey, unpub. report). Sediment associated with the floods and debris flows filled channels and culverts, buried houses and other structures along the channel banks, and caused several million dollars in public and private property damage. Two lives were lost during the 12 July 1997 flood. The combination of excessive sediment and large woody debris that accumulated downstream from the burned area, in Strontia Springs Reservoir, reduced water quality in the reservoir and threatened reservoir operations to the point that the City of Denver flushed sediment from the reservoir three times between September 1996 and September 1997. Nutrients contained within this sediment introduced thousands of tons of nitrogen and phosphorus into Chatfield Reservoir, downstream from Strontia Springs, and affected water quality in Chatfield.

Examples of hazards associated with the decrease of sediment

Bessemer Ditch, Pueblo County: This irrigation ditch takes water out of Pueblo Reservoir on the Arkansas River.

Prior to construction of the reservoir, the ditch had a 15-18% water loss to infiltration. This increased to 45% water loss following construction of the reservoir. The change in infiltration rate has been attributed to the absence of fine sediment in the flow along the ditch; previously, this fine sediment accumulated in the cracks that form periodically along the ditch, filling the cracks and reducing water loss. Approximately 10 miles of the 35-mile long ditch have been lined with cement, following a $1 million lawsuit that forced the government to line the ditch.

Elkhead River, Moffat County: Elkhead Reservoir was constructed along the Elkhead River outside of Craig, Colorado in 1974. Landowners along the river have subsequently alleged that excessive erosion has occurred along this sand-bed meandering channel as a result of sediment retention in the reservoir. Approximately 4 miles of channel below the reservoir are affected, and in some areas the channel has migrated 70 feet laterally during the past 30 years.

Examples of hazards associated with contaminated sediments

California Gulch, Arkansas River basin, Lake County: The former mining area of California Gulch has been designated as a Superfund site by the U.S. Environmental Protection Agency. Concentrations of heavy metals (Mn, Fe, Cu, Zn, Pb, Mb, Cd) in the Arkansas River downstream from California Gulch are highly dependent on flow and tend to increase during high spring runoff. This suggests that these metals are abundant in the fine sediments that have traveled from the tailings piles to the river, and are now carried downstream in suspension during high discharges

South Platte River, Adams, Weld, Morgan, Logan, Sedgwick Counties: The lower portion of the South Platte River basin in Colorado has been impacted by various human activities since the 1850s. Agricultural and urban land use in particular have produced contaminants carried into stream channels by surface runoff and subsurface flow. These contaminants are stored in river sediments for varying lengths of time, as well as being transported by stream flow and accumulating in the bodies of aquatic organisms. Concentrations of these contaminants increase in summer and during stormwater runoff, but persist year-round. In addition, approximately 7,000 tons of nitrogen and 860 tons of phosphorus enter streams in the basin each year. Nutrient loads are highest downstream from Greeley, which has extensive feedlots.

OUR OPTIONS FOR MANAGING SEDIMENT AND WATER

Our abilities to mitigate the types of sediment hazards outlined in the preceding sections of this report are constrained by societal and legal considerations, environmental considerations, and technical considerations. Ultimately, mitigating sediment hazards will mean (1) keeping sediment out of sites where it creates a hazard, or removing the sediment once it reaches those sites; (2) supplying sediment to sites where its absence creates a hazard; or (3) containing contaminated sediment, or removing that sediment from sites where it creates a hazard. Water is critical to each of these mitigation methods because water is the most common agent of sediment transport, and the ratio of water/sediment will govern whether there is an excess or absence of sediment.

Societal and Legal Constraints

Because the system of prior appropriation serves as the ultimate basis for water allocation in Colorado, the ability to use water to supply or remove sediment from a site will be governed in many cases by the ratio of water costs to sediment-hazard costs. For over-appropriated rivers, the water necessary to reduce sediment hazards simply may not be available on a regular basis. At present, we do not have well-defined legal connections between water quality and water quantity. Continuing trends of population growth in Colorado will also constrain our uses of water. As demographic balance in the state continues to shift from agriculture toward urban and industrial consumption, both the pattern of water use and the cost of water will change.

A final legal constraint on water use is the State's legal obligations to other groups of water users downstream. As one of the Upper Basin states in the 1922 Colorado River compact, the State of Colorado's use of that river's water is strictly confined. We also have other obligations to surrounding states such as Nebraska that are downstream along the South Platte River. Native American groups are arguing for water rights, as in the case of the Ute Mountain Ute Indian Tribe and the Animas-La Plata project, and federal land-management agencies are also legally requesting water rights related to the lands under their jurisdiction. Sediment removal that is not water-based will be subject to legal constraints in the form of state and federal permitting procedures for dredging and filling operations.

Environmental Constraints

Legislation designed to protect environmental qualities, as well as public demands for environmental protection, will constrain some options for mitigating sediment hazards. Environmental legislation includes specific federal measures such as the Endangered Species Act, the Clean Water Act, and the Wild and Scenic Rivers Act. These Acts may regulate water, and hence sediment distribution. Enforcement of measures such as the Endangered Species Act, for example, may involved specifying the instream flow necessary to maintain an endangered species. Federal regulations also govern activities in specially-designated public lands including the national parks, national forests, and wilderness lands administered by the Forest Service or the Bureau of Land Management. State regulations such as those governing Colorado's Clean Water Act, which includes narrative sediment regulations administered by the State Water Quality Control Commission with oversight by the U.S. EPA, pose additional potential constraints. The enforcement of these various Acts by regulatory agencies may be limited by other legal constraints, such as prior appropriation or private property rights, because water quality is often related to water quantity. (The legal connection of water quantity and quality remains vague, however.) With increasing public demand for habitat preservation and outdoor recreation, it is no longer considered acceptable to mitigate sediment hazards to human structures at the expense of river ecosystems, as indicated by the public indignation following the deliberate release of sediment from Halligan Reservoir in 1996.

Technical Constraints

Our ability to mitigate sediment hazards is also constrained by our limited knowledge of the physical and chemical processes by which sediments and contaminants move through a river drainage basin. Our ability to mitigate sediment hazards may also be constrained by difficulties in identifying the source of the hazard.. There is geological evidence of decades-long cycles of sediment accumulation and subsequent erosion along these rivers, independent of human land-use, and these cycles seem to be inherent to rivers in arid and semiarid regions of the western United States. Because of this inherent variability in sediment yield, it may be difficult to determine the specific cause of an increase or decrease in sediment along a river. We also know far too little about the behavior of contaminants in natural environments. Some substances move downstream in solution, others are adsorbed onto particles of silt and clay and move only when the sediment moves. And, it has proven difficult to predict chemical changes in contaminants once they enter the environment. Legal, societal, environmental, and technical constraints pose numerous and complicated challenges for mitigating sediment hazards in Colorado as we enter the 21st century. Within these constraints, there are some basic steps that may be taken toward mitigating present and future hazards resulting from sediments.

RECOMMENDATIONS FOR THE FUTURE

We must begin by recognizing that we cannot restore the state's rivers to pre-19th century conditions, but we also cannot linearly extrapolate present patterns of water use without a serious degradation of the environment and our quality of life. The magnitude of the problem facing Colorado is suggested by the list of reservoirs within the State which are associated with some type of sediment hazard (Table 1). Americans have always struggled to find a balance between individual freedom and property rights versus the duty of the government to protect the rights and quality of life for the public as a whole. This is exemplified by past treatment of sediment issues in Colorado, where flow regulation or land use by private individuals or small companies may clash with governmental protection of clean water. Too often, decisions between these competing interests have been decided on a case-by-case basis, with legal precedents given equal or greater weight than scientific understanding of the physical processes involved. We begin, therefore, with two broadscale recommendations:

Sediment hazard issues must be considered at the scale of the entire drainage basin, rather than on a very site-specific basis.
The loss of reservoir storage capacity may be a direct result of poor land-use and lang-management practices upstream from the reservoir, and the sediment release designed in an attempt to restore reservoir capacity may damage aquatic habitat downstream. The point is that the reservoir is not an isolated entity; it is closely connected to processes upstream and downstream. Therefore, any long-term plan to mitigate sediment hazards at the reservoir must also consider upstream and downstream controls. In addition, sediment generated at one point along a river may be carried miles downstream before it is deposited. In practice, such an approach to hazard mitigation will probably require government oversight rather than piecemeal individual control. Although state government agencies have an abundance of work with existing regulations, it seems apparent that unless a knowledgeable, interdisciplinary oversight body is charged with the task of drainage-basin-scale management, problems will continue to be addressed within an inappropriately confined scope.

The process of effective mitigation of sediment hazards would be facilitated by a decision-making process resting on scientific understanding of sediment dynamics rather than on legal precedents or court mandates.
For example, following the 1996 sediment release from Halligan Reservoir, a group of state government employees, private water users, environmental activists, and research scientists was formed to develop protocols for reservoir sediment release that would avoid the environmental degradation associated with the Halligan release. This is a less divisive and costly approach than a lawsuit to compensate parties adversely impacted by the sediment release. If analogous groups could develop protocols for minimizing the types of sediment hazards outlined in this report, everyone in Colorado would benefit greatly. The development of such protocols depends closely on widespread recognition and understanding of sediment issues. The Colorado Department of Public Health and Environment’s 1998 303(d) report (Water Quality Limited Segments Still Requiring TMDLs) lists 85 river segments with sediment problems, 12 river segments with metal-contaminated sediments, and 6 river segments with nutrient contamination. At the more specific level, there remain several issues that must be addressed before we can effectively manage sediment. Each of these requires basic and applied research into sediment movement.

Sediment accumulation in reservoirs
This is one of the most widespread sediment hazards in Colorado. We must improve our understanding of how to limit sediment movement into, and accumulation in, reservoirs. Technologies exist for sediment dredging, bypassing, and flushing, but most of these are limited in application by cost or by downstream consequences such as possible water quality reduction from contaminants in the reservoir sediment.

Sediment transport along channels
Whether the excess sediment comes from basin-wide land use, reservoir release, or flow diminution, sediment accumulation and consequent loss of water quality and habitat remain a problem along many rivers. We need to develop models that describe how various types and quantities of sediment are transported along different types of channels. Such models could specify, for example, the minimum flushing flow necessary to prevent downstream pool sedimentation during a reservoir sediment release.

Contaminant dispersion and disposal
We are desperately in need of basic research on how individual contaminants combine with each other and with

sediment along a stream channel; where they are stored and when they are mobilized; how they affect aquatic organisms and humans; and how long they remain biologically dangerous. We also need to develop basic protocols on how to remove contaminated sediments; how removal is accomplished; who pays for removal; and where the contaminated material is to be stored. The hazards posed by sediment along rivers in Colorado are complex. Mitigation of these hazards requires a carefully planned and integrated approach. We can continue to deal with each sediment hazard as it develops at a specific site. This approach is reactive and costly in that the situation is allowed to reach a hazardous level before action is taken, and that action is very limited in scope. Or, we can develop a proactive means of mitigating sediment hazards by designing basin-scale protocols for anticipating and preventing sediment-related hazards such as sediment releases from reservoirs or the downstream transport of contaminated sediments. Satisfactory resolution of these conflicts will require that everyone involved understands the basic processes of rivers and sediment movement, the history of river and land-use changes in Colorado, and the constraints that currently limit our abilities to mitigate sediment hazards.

Task Force Members

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Development of the South Platte Mapping and Analysis Program (SPMAP)

Water managers in Colorado are facing many competing demands for water: such as, sustaining irrigated food production, providing high quality water to growing populations; mimicking natural flow rhythms to protect aquatic habitats for endangered species; and meeting the growing water recreation needs. The challenge facing water manager's decision-making demands development of sophisticated computer based technology to support decision making in the hopes that all needs can be met. In particular, there is a need to upgrade the technology used to manage the conjunctive use of surface and ground water resources in the South Platte Basin.

Modern decision support systems employed to enhance water management involve carefully matching data acquisition system design, modeling, and user interfaces to meet managers' needs. New approaches to water research are being employed on this project. University researchers are working hand-in-hand with water managers so that the computer tools are carefully crafted to fit the decisions.

In the 1970s and 1980s, CWRRI funded basic research to develop mathematical relationships (models) describing interactions between surface and ground water in alluvium aquifers along the South Platte River. Data acquisition and computer technology at the time did not permit integrating the models into data acquisition systems or user friendly interfaces with decision-makers. The ability to acquire basic resource management data via satellite combined with the exploding power of the microcomputer (both hardware and software) has provided water managers the ability to further develop decision support technology.

Since 1995 Dr. Luis Garcia, a Professor in the Chemical and Bioresource Engineering Department at Colorado State University, has been working with a number of local and regional water management organizations along the South Platte River below Denver. Each of the cooperating organizations agrees to financially support the research while also providing monthly feedback to the researchers on the latest developments. CWRRI has continued to match the water managers' funding. The water managers and university researchers form a 'team' that works closely on all aspects of the research.

As computer technology improves, new tools are being developed for the South Platte Mapping and Analysis Program (SPMAP). The SPMAP 'team' has been promoting the idea of 'modular' development based on a data-centered approach. This means that the data are generic and developed in such a way that all modeling efforts can use the same data. Individual models are being developed that can be part of a larger framework and can be substituted or added with little impact to the overall structure of the system.

Due to the modular and data-center approach, the SPMAP 'team' identified the development of an accurate spatial database and analytical tools for computing farm water budgets and consumptive use (CU) of ground water as two of the most pressing needs for the South Platte River Basin. Out-of-priority impact of ground water well pumping on South Platte River flows must be augmented, but this impact needs to be accurately quantified; thus, the need for spatial databases and associated analytical tools.

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

During 1997 and 1998, project efforts have focused on developing a Consumptive Use (CU) model and an interface for a Stream Depletion Factor (SDF) Model. Satellite images were purchased to determine irrigated land area, as well as field delineation, and crop type classifications. A Graphical User Interface (GUI) for the CU model was constructed. The system development has been modular and each component can be operated in a stand-alone mode. The user can use the GIS module to locate fields and the surface and/or groundwater sources that provide water to them, this information (along with the crop types grown in each field and weather stations) can then be stored in an ASCII file. The CU model imports the created ASCII file and uses it to create an input file which then is used to calculate the CU and any pumping requirements.

Current Development Efforts --This year's efforts have focused on the release of the Stream Depletion Factor (SDF) Model interface, called SDF View. This interface can be used to estimate the lag time from when irrigation well water is pumped from, or water is recharged to, an alluvial river aquifer and when a depletion or accretion happens in the river. Required input information for SDF View is irrigated consumptive use from well water or net recharge amounts and SDF values for irrigation wells or recharge basins. SDF View is a stand-alone interface for Windows 95/98/NT that has online and hard-copy documentation. SDF View was released as part of the Three State Agreement to the State of Nebraska to help them manage South Platte groundwater wells in Nebraska. Both the software and the documentation can be downloaded from the following website created for this project:

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

Additional efforts this year have included the development and release of GIS coverages to project participants, continued development of the South Platte Mapping and Analysis Program (SPMAP) and the Consumptive Use (CU) Model, the development of a GIS coverage for the South Platte SDF values, and software support. The Advisory Committee has met regularly throughout the year, and coordination of water management efforts has continued to benefit each of the project participants.

The current emphasis of this project is in developing a stand-alone capability for the CU Model. The current version must be used in coordination with SPMAP to develop input files. Although this makes the data entry tasks much easier and more comprehensive than current methods, the CU Model will be more flexible with a stand-alone interface. The stand-alone capability will also make the CU Model more powerful for modifying input data sets to do sensitivity analysis and multiple model runs. A new version of the CU Model complete with documentation should be available by the end of the summer 2000.

An additional goal for the future is to couple the SPMAP tools with a real-time water management system developed for the South Platte (SPWRMS). This capability will allow users to use current flow and diversion records for modeling tasks in SPMAP.

Team Participants

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Determination of High-quality Aquifers in Colorado

This project was developed to provide background information on Colorado groundwater resources which will assist the Water Quality Control Commission and the Water Quality Control Division in the development of a comprehensive state groundwater protection plan, and the identification of populations dependent on groundwater and aquifers of high quality. The project objectives are to:

- Identify all aquifers and determine those which meet the Domestic Use-Quality criteria;
- Identify the primary uses and the level of dependency on each aquifer;
- Determine the dependency of public water supply systems on groundwater in each area, if they have a well-

protection plan, and the population served;
- Estimate the number of private domestic wells in each area and the population served;
- Compare the populations served by public water supply systems with wellhead protection plans and those served by private wells;
- Provide an overview of growth in areas with aquifers of high quality; and
- Develop general maps of aquifers or areas of high-quality groundwater.

A key outcome of work by members of this team, presented earlier this year to the Colorado Water Quality Control Commission, was the discovery of a significant lack of comprehensive groundwater quality data. Many aquifers in the state have not been sampled, at least not to the degree that would allow a scientifically defensible evaluation of their quality. Moreover, most of the existing databases lack sufficient descriptive data, or "meta-data," necessary to fully compare the data to other sources, particularly with respect to sample location, sample depth, analytical methodology, and quality assurance/quality control parameters on the data.

The lack of information, particularly complete meta-data, make any statistical conclusions based on existing data, scientifically questionable, and likely, indefensible. This project, as originally proposed, was to accomplish the following objectives:

- Work together with the Colorado Water Quality Control Commission to develop a protocol for a statewide groundwater quality monitoring program;
- Organize and execute an educational effort to put the protocol in the hands of all agencies working with groundwater in the state; and
- Develop and deploy an Internet-based information source for all groundwater quality monitoring activities in the state.

However, it was determined that the above objectives represented future phases of work in this area, and were not completely in line with the immediate needs of the Commission. Further discussion resulted in altering the project design and narrow the scope of the work to the primary objective of documenting, as completely as possible, the existing groundwater quality databases in the state. Subordinate to that objective are a number of tasks which include:

- creating a list of contacts and database managers;
- gathering as much descriptive, or meta-data, for these databases as possible; and
- determining the degree of confidence that is possible in making decisions based on the existing data, particularly as it relates to comparing the various databases to one another to create a comprehensive "big picture" of groundwater quality in Colorado.

The student working on the project is projected to complete the first two tasks under the revised project by January 2000. The third task will begin in Spring semester, 2000, hopefully with a new graduate student who will take on the task of evaluating the databases for reliability and comparability, as their thesis topic.

Project Management Team Members

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and

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Description and Interpretation of Waterlogging and Salinity Problems in the Lower Arkansas River Valley, Colorado

There is growing evidence that the irrigated lands of the lower Arkansas River Valley are subjected to processes causing severe waterlogging and salinization. At a time when conjecture about the main causes and prognosis of the problems is growing, some people feel that conditions already have reached a crisis stage. Informal and anecdotal evidence abounds: salt crusting on soil surfaces, seepage and wet spots in selected fields, stunted growth of crops, and reduced crop yields. Over the last few years, we have initiated scientific investigations with the objectives of accurately documenting the problems and finding feasible and effective solutions.

During the 1999 cropping season, with support from the State-Based Water Research Program, we have collected extensive data in Otero and Bent counties. A battery of monitoring wells was installed over a representative region of about 50,000 acres. Preliminary analysis of data from more than 80 wells reveals average water table depths less than 5 ft below ground surface over about 70% of the region. The average measured salinity (as electrical conductivity, EC) of the water table in the study region was about 4 dS/m (3200 mg/l). Surface-water salinity was measured weekly throughout most of the season at more than 160 locations, including points in the Arkansas River, in seven major canals, in seven drains, and in two reservoirs. The average salinity of the water in the irrigation canals was 0.93 dS/m (700 mg/l), indicating low to moderate restriction in use for irrigation. Global positioning equipment was used to accurately locate each of the ground-water and surface-water sampling sites for use in a geographic information system.

The salinity of the soil (to a depth of about 3.3 ft) was measured in early June and again in mid August on 68 different fields distributed over the region. On each field, soil salinity (as electrical conductivity of saturated extract, ECe) was measured during each sampling using electromagnetic probes at an average of 64 locations (about 1 to 10 locations per acre). In addition, about 2000 soil samples were collected for use in calibrating the electromagnetic probes. The overall average soil salinity has been estimated as 2.8 dS/m (2000 mg/l). The average measured salinity exceeded the threshold level (level above which crop yield reductions are expected) on at least 70% of the fields, indicating significant soil degradation and declining yield. Actual yield losses currently are being estimated through harvest records on many of the fields that were studied.

Work currently focuses on statistical analysis of the spatial and temporal variability in salinity and waterlogging over the region and of the properties and processes that affect such problems. Over the last couple of weeks, slug tests were conducted in 67 of the monitoring wells for use in determining hydraulic conductivity. Such data are indicative of the ease with which water and solutes are transported in the subsurface environment.

Future plans include expansion and refinement of data collection to improve understanding of the nature of salinity and waterlogging problems; analysis of raw data and space-time relationships between data, especially correlation and relationships between water table depths and salinity, soil salinity and crop yields; topographic and hydrographic surveying to better describe the boundaries and elevations over the region; and preparation of a fully-documented database.

Without sound and timely intervention, it appears that the Valley will eventually succumb, at least in a large part, to the ill effects of salinization. A solid database will be needed to support decisions that will insure sustainability of the Valley's productive agricultural base and preservation of its rural communities.

Principal Investigators:
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Civil Engineering Department
Colorado State University

FY1998 WESTERN REGION GRANTS AWARD

Colorado State University is the lead university for one of four regional grants awarded in the FY1998 Western Region Grants Competition of the State Water Institutes Program. The project, "Meeting Time-Dependent Instream Flow Requirements in a Fully Appropriated Multi-State River Basin," will be conducted by researchers from Colorado State University, Texas A&M University, Alfred University (NY), the University of Nebraska, and the University of Wyoming.

Basic Project Information

Basic Project Information	
Category	**Data**
Title	Meeting Time-Dependent Instream Flow Requirements in a Fully Appropriated Multi-S River Basin
Project Number	1434-HQ-96-GR-02660
Start Date	09/01/1998
End Date	08/31/2000
Research Category	Social Sciences
Focus Category #1	Law, Institutions, and Policy
Focus Category #2	Economics
Focus Category #3	Management and Planning
Lead Institution	Colorado State University

Principal Investigators

Principal Investigators			
Name	**Title During Project Period**	**Affiliated Organization**	**Order**
Marshall Frasier	Assistant Professor	Colorado State University	01
Robert A. Young	Professor	Colorado State University	02
Ari M. Michelsen	Professor	Other	03

Problem and Research Objectives

SYNOPSIS

Project Number: C-01

Title:

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

Investigators:

Marshall Frasier, Colorado State University
Robert Young, Colorado State University
Ari Michelsen, Texas A&M University (formerly Washington State Univ.)
James Booker, Alfred University
Garth Taylor, University of Nebraska
Timothy Gates, Colorado State University
Steve Gloss, University of Wyoming
Mark Squillace, University of Wyoming
Robert Ward, Colorado State University
Ray Huffaker, Washington State University
Larry MacDonnell, Natural Resources Attorney

Congressional Districts:

Colorado - Fourth
Nebraska - First
Wyoming - WY At Large
Washington - Fifth
New York - Thirty-first

Focus Category: LIP, ECON, M&P, MOD, WS

Descriptors:

Institutional adjustments, economics, multiple-objective planning, decision models

Problem and Research Objectives

The rivers and aquifers of the western United States are a highly regulated system designed to maximize hu uses of water resources. Initial development of the necessary storage and conveyance facilities was underta primarily by private parties under emerging state laws emphasizing the prior appropriation doctrine. Water be appropriated for "beneficial" and typically offstream uses. Beginning in the 1930s the U.S. government developed planning and implementation strategies for managing water and related land resources in river ba multiple-purpose outputs. Later, federal projects continued to develop and expand this infrastructure. Emph was on water supply for irrigation, municipal and industrial water uses, floodplain management and power generation. In the Platte River Basin, as in others in the west, offstream water uses, primarily for irrigation, expanded to the point where only limited instream flows remain.

Despite little remaining unclaimed water, competition for existing supplies continues to grow, particularly a the Rocky Mountain Front Range. Within this difficult context, a new set of demands has arisen: instream fl protection. The most far reaching new demand in the basin results from the application of the federal Endan Species Act (ESA) to wildlife habitat in the central Platte River in Nebraska. Four species -- the Whooping Piping Plover, Interior Least Tern, and Pallid Sturgeon -- dependent on habitat associated with the Platte R central Nebraska are listed under the federal ESA as either threatened or endangered. A three mile wide, 56 long section of the central Platte River has been designated as critical habitat for the Whooping Crane unde ESA (1). To comply with the ESA mandate for recovery of these species, the U. S. Fish and Wildlife Servic estimated that, on average, as much as 373,000 acre-feet of additional water must be made available to flow through this reach each year (1).

In reaction to this call for up to a 33% increase in central Platte River instream flows, negotiations were undertaken between the basin states and the U.S. Department of Interior. In 1997 the Governors of Colora Wyoming, and Nebraska along with the Secretary of the Interior signed a Memorandum of Agreement (MC develop a program to meet ESA Requirements (2). The MOA is a Platte River basin-wide program to meet requirements for one area, the central reach of the Platte River. In the first 10 to 13 year increment of the agreement, the parties commit to reduce shortages to target flows at Grand Island an average of 130,000 ac feet.

A broad variety of approaches for addressing the Platte River basin's critical water problems (see Eisel and (3)) have been proposed. However, the feasibility, impacts and effectiveness of these proposed alternative approaches for enhancing instream flows are typically not well understood. In this paper, we begin the proc evaluating alternatives by summarize existing water uses and providing an overview of Platte River water resources. Secondly, we propose a framework for categorizing alternatives. Thirdly, and most significantly develop a set of preliminary principals and feasibility criteria for addressing proposed policy alternatives. Th preliminary analysis applies the principals for inclusion of potential alternatives in order to identify those opt with the greatest likelihood to successfully deliver water for endangered species use. Further research can th focus resources on alternatives that have the highest feasibility. This evaluation approach can be applied to similarly complex issues in other areas such as the Bay-Delta of California, the Klamath of Oregon and Cali the Truckee-Carson of Nevada and the Yakima in Washington.

Methodology

EXISTING WATER RESOURCES AND USES

The Platte River from its headwaters to Grand Island, Nebraska conveys a resource supporting current annu consumptive water use of 4.2 million acre-feet (4). In addition to these consumptive uses, an average instre flow of 1.1 million acre-feet (maf) is maintained at Grand Island (5). Together, this suggests an annual avera

inflow to the basin of over 5 maf, including transbasin diversions, and assuming no net depletions from surfa
groundwater storage. Surface water flows are regulated by storage reservoirs with a combined volume of 7.
(4). Tributary groundwater also plays an important role in storing and delivering water, particularly in Nebr
While the total volume of groundwater storage is not available, half of total agricultural diversions in the Ba
Nebraska are made directly from groundwater. Along the South Platte in Nebraska, over 90% of diversions
from groundwater.

Table 1 is developed to show a self-consistent annual water budget for the basin. Significant flows originate
each of the basin states, including Nebraska. Figure 2 illustrates the point that significant river flows apparen
originate within the Nebraska portion of the basin (6). In particular, note that as the Platte approaches Big I
annual streamflow increases, despite irrigation use and the lack of significant tributary inflows. Complex hyd
and extensive irrigation at the Wyoming - Nebraska state line (together with related litigation between the s
leads to some uncertainty on North Platte outflows from Wyoming to Nebraska; the figure given in Table 1
should thus be treated with caution. River discharges just downstream from the state line and represented in
Figure 2 should be similarly interpreted. South Platte flows at the Colorado - Nebraska state line consistentl
exceed interstate Compact obligations, and have in fact increased in past decades, most likely due to transba
imports from Colorado's western slope (8).

Table 1. Estimated Water Budget for the Platte River Basin to Grand Island, Nebraska.
All figures in thousand acre-feet per year; use is consumptive use.

	Inflow (a)	Use in CO and WY	Outflow to NE	Use in NE to Grand Island (b)	Flow at Grand Island (e)	F&W Stated Shortfall at Grand Island (e)
N. Platte	1,659	782 (b)	877 (c)	762		
S. Platte	1,904	1,517 (b)	387 (d)	303		
Main	1,792	–	–	850		
Total	5,358	2,299	1,267	1,915	1,144	396

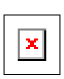
(a) calculated

(b) U.S. Geological Survey, 1998. (4)

(c) Wyoming Water Development Commission. 1990. (7)

(d) Colorado Division of Water Resources. 1995. (8)

(e) Derived from U.S. Fish and Wildlife Service, 1997. (5)



Source: Center for Advanced Land Management Information Technologies (CALMIT). 1998. (6)

Figure 1. Annual streamflow in Nebraska rivers. Grand Island is located at the indicator, just north of the I

Irrigation is the dominant water use in the basin, accounting for 93% of total consumptive use (Table 2). Ne
is the largest water user in the basin (1.9 maf), while Colorado and Wyoming have consumptive uses of 1.6
and 0.7 maf, respectively. Several notable extremes occur in Wyoming: only 78% of use in the South Platte
watershed within the state is by irrigation, the lowest proportion in the full basin. Unlike Colorado (9) and
Nebraska (10), most irrigation use in Wyoming (52% averaged across the North and South Platte) is for pa
and grass production (11).

Table 2. Consumptive water use in the Platte River Basin (to Grand Island, Nebraska). All figures in thousa
acre-feet per year.

		State									
		Nebraska				Colorado			Wyoming		
	Reach	North	South	Main	Total	North	South	Total	North	South	Total
Irrigation	Grass	118	21	143	282	108	61	169	288	23	311
	All other	627	266	694	1,586	51	1,213	1,264	283	7	290
	Total	745	287	836	1,868	159	1,274	1,433	571	29	601
Other Uses	Municipal	6	3	5	14	0	118	118	11	7	18
	Other	11	13	9	33	1	87	88	40	1	41
Irrigation share		98%	95%	97%	97%	99%	86%	87%	92%	78%	91%
Total		762	303	850	1,915	160	1,479	1,639	622	38	660

Source: U.S. Geological Survey. 1998. (4)

Principal Findings and Significance

ALTERNATIVES FOR MANAGING INSTREAM FLOWS

A broad variety and large number of approaches have been proposed to increasewater availability in the Pla
River Basin. The three state Cooperative Agreement has triggered the compilation of existing and new polic
proposals. Under the Agreement itself, for example, the states and Department of Interior propose to increa
present storage capacity of Pathfinder Reservoir in Wyoming, establish an environmental water account in L
McConaughy in Nebraska, and develop a groundwater recharge project near the state line in Colorado (2).
Following the processes of the National Environmental Policy Act (NEPA), public meetings were subseque
held to solicit “scoping alternatives.” Last year, a range of alternatives for evaluation was developed (12); th
are currently under study. A perspective on the range and nature of the proposed alternatives is gained throu
examples generated at each of these stages.

Public Meetings

In a set of public meetings, over 40 distinct alternatives were put forward and subsequently documented un category "Additional Water Through Conservation, New Supply, Other" (13). The alternatives encompass range of measures including irrigation efficiency improvements (e.g. canal lining), "revising water rates to encourage irrigators to save unneeded water," purchasing existing storage rights, increasing storage at vari locations, to mechanical means to increasing the river stage in the critical reach. Comments also expressed skepticism that water savings along the Front Range could in fact be conveyed downriver to the critical rea central Nebraska. Numerous additional comments were compiled under "Vegetation" and "Target Species/Habitat" (13).

Scope of Services

The list of potential alternatives generated at public meetings was narrowed slightly in the Scope of Service the consultant hired by the Governance Committee, but their list of alternatives to be considered remains qu broad and long (12). Work by the Water Committee in conjunction with the consultant has subsequently developed seven categories of alternatives: reservoirs, waterconservation, reuse, water marketing, ground w system integration and management, and watershed management (14).

Proposed Classification

The suggested alternatives might further be classified as those which involve:

1) changes in water system management;
2) changes in water use efficiency and requirements; and
3) transfers of water.

Changes in water system management include such things as increasing water storage (e.g. increasing the st capacity of existing projects or building new storage projects) and increasing conjunctive use of ground and surface water. Changes in water use efficiency and requirements includes such things as increasing irrigatio application efficiency, cropping changes, increasing conveyance efficiency, incentive pricing and evolving definitions of beneficial use. Water transfer alternatives include permanent sales of water rights, long-term a short-term leasing of water, dry-year contingent water purchases, exchanges and banking of water.

FRAMEWORK FOR ANALYSIS

Our research is independent of but intended to complement the efforts of the Governance Committee and it consultant. In particular, we develop a conceptual analytical framework in which to evaluate the feasibility, effectiveness, and effects of alternative approaches for supplying additional instream flows. First we refine t of alternatives proposed in the Scope of Services using five initial principal rules. Secondly, we begin a mor rigorous analysis with a preliminary examination of the feasibility of each of the alternatives.

Principals for Inclusion

Our initial screening focuses on the ability of alternatives to produce instream flows, protection of existing rights, voluntary transactions and compensation, third party impacts and recognition of existing compacts (The specific rules applied were: 1) Use of the option should be able to help produce increased streamflows central Nebraska; 2) Use of the option should not impair existing water rights; and 3) Use of the option sho diminish the economic benefits now produced by existing water uses except by voluntary agreement of the Use of the option should not impose uncompensated costs on those who are incidental beneficiaries of exist water uses (those without the legal protection of water rights); and 5) Use of the option should not require changes in existing compact or equitable apportionment decrees.

Feasibility Criteria

In this phase we begin a more rigorous analysis with a preliminary of the feasibility of each of the alternative initial analysis screens potential alternatives based on legal, physical, economic and institutional feasibility to identify those options with the greatest likelihood of being successfully utilized for delivering water instream endangered species. At the conclusion of this phase we will have identified the most promising options for providing increased stream flows in central Nebraska. This initial feasibility analysis of the alternatives focus six evaluation criteria.

Legal Feasibility. Can the alternative be implemented under existing state, interstate and federal laws and regulations?

Hydrologic Feasibility. Based on readily available information, does the hydrologic system have the physica capability that will result in increased stream flows in the lower reaches of the Platte River Basin during the necessary period of time for endangered species protection.

Water Potential. Appraisal of the quantity of water that could (a)potentially be made available, and (b) the reliability of the water supply.

Financial Costs. Assessment of the annualized per acre foot financial cost of the alternative.

Third Party Effects Likelihood and magnitude of positive or negative third party effects, such as changes in quantity, timing, quality reliability of water resources.

Political Feasibility. Assessment of the political feasibility of the alternative including factors such as likely political and social acceptability considering issues such as state sovereignty and equity in distribution of the financial, economic and hydrologic burden.

Using these criteria with available information as appropriate at the local, state or river basin level, provides preliminary assessment of the feasibility and alternatives. Combining this information for each alternative wi analysts and decision makers in identifying those alternatives that may have the greatest potential for satisfy selected objectives and conditions and should be the subject of further study.

APPLICATION: PRICE INCENTIVES

Water price incentives have been proposed as a method to encourage efficient use and conservation of wate supplies. The basis for this alternative is the assumption that increasing water use prices to more closely refl opportunity cost of water (foregone benefits in other uses) would result in conservation of water and increa quantity of water available for other uses such as instream flow. Although water markets can provide a mec to reflect the value of water in other uses, most water is priced at the system average physical cost of delive the water. These prices do not include the value or benefit of water in alternative uses. In theory, pricing is a voluntary economic method to achieve water conservation and efficient water use. Here we apply the feasib criteria presented above to develop a preliminary evaluation of the potential for pricing incentives to achieve increased flows for endangered species protection.

Legal Feasibility. There are essentially three possible levels of price incentive implementation: state, federal irrigation district. Under existing laws and institutions, states do not have the authority to implement price incentives that reflect the value or opportunity cost of water in different uses. A state water right entitles appropriators to the right to use water beneficially. The cost to deliver this water to the place of use is the appropriator's responsibility. A state does not have authority to price or charge for water per se. A similar situation exists for water supplied by U.S. Department of Interior Bureau of Reclamation (BOR) facilities. Legislation has been enacted by Congress that encourages or requires irrigation districts that receive water f BOR facilities to implement incentive pricing. At the same time, the statutory license necessary for BOR to achieve conservation pricing is lacking. The BOR operates under contractual, federal and state legal constra that limit it to only recouping construction, operating and maintenance costs. Again, there is no provision or authority that enables BOR to charge a price for water per se. Irrigation districts are intermediaries that pro farmers with water delivery facilities and management. Because most districts are nonprofit, farmer-owned cooperatives, they are operated to deliver water to district users at cost. Although districts' may have indivi internal reasons to encourage conservation of water through pricing or other means, there is no legal mecha for irrigation district price incentives that can be implemented by states or basin-wide. The ability to obtain w for instream flows through price induced conservation is further complicated by uncertainty and legal questi the ownership and transfer of "conserved" water. Overall, implementation of price incentives as a means to generate additional instream flows is considered not legally feasible in all three states.

Hydrologic Feasibility. If water could be generated through pricing incentives, it is likely that the hydrologi system would have the physical capability to deliver water for increased instream flows in the lower reaches Platte River basin.

Water Potential. Evaluation of the water quantity potential of price incentives is more complex. Studies hav shown that may stimulate farmers to improve application efficiency, reducing diversions and return flows (1 The net gain will depend on whether reductions in diversions in response to higher prices are offset by incre consumptive use. Another difficult issue is how this conserved water would be measured and monitored to e that it would not simply be diverted by other appropriators. Urban and residential water consumers are notc unresponsive to increases in price at current levels (demand is inelastic), but price increases will still result in reduction in consumptive water use. At the same time, increases in price may also encourage consumers to increase water use efficiency.

*Financial Costs.*The financial cost of price incentives is estimated to be low in comparison with other propo alternatives.

Third-Party Impacts. Third party impacts are estimated to be low.

Political Feasibility. The political feasibility of implementing price incentives is estimated to be low. Substa changes in law would be required, and the resulting private property right issues are unlikely to be resolved.

Application of the feasibility criteria demonstrates that pricing incentives would not only be impractical to implement, but could fail (at reasonable price levels) to significantly enhance flows.

CONCLUSION

The framework presented here offers one approach for preliminary consideration of suggested alternatives f addressing endangered species protection on the central Platte River. The approach distinguishes between alternatives which have the potential to reliably deliver water for endangered species use, are likely to be co effective, and are feasible under the legal and political constraints governing water management and allocati the three state basin. The framework is demonstrated by applying the set of feasibility criteria to a proposal pricing incentives as an approach to enhance instream flows. Applying the criteria clearly shows a range of difficulties with the particular proposal. Future work will require the application of the criteria to the wide r of proposed alternatives. The resulting conclusions will give a preliminary indication of the most promising approaches to enhancing Platte River flows. Given the enormous range of potential policy responses for inc flows, this approach demonstrates a necessary first step in policy evaluation. Detailed quantitative studies o alternatives should focus on the most viable of the alternatives. The work here lays the groundwork for reac the next more rigorous and targeted level of analysis.

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Descriptors

Institutional adjustments, economics, multiple-objective planning, decision models

Articles in Refereed Scientific Journals

Book Chapters

Dissertations

Water Resources Research Institute Reports

Conference Proceedings

Michelsen, Ari M.; James F. Booker and Marshall Frasier, 1998, Feasibility of Alternatives to Manage Platt
Instream Flows to Accommodate Endangered Species, "in" Proceedings, Water: Lessons of World Develop
Proceedings of Universities Council on Water Resources 1999 Annual Conference, Kamuela, Hawaii, June
July 2, 1999, Universities Council on Water Resources, Urbana, IL, pp. 214-219.

Other Publications

Information Transfer Program

The latest water information and research results are provided to Colorado water users, managers and the public via an active technology transfer program that includes:

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

WATER IN THE BALANCE -- a user-friendly new publication series that provides a condensed version of research completion reports that gives water users a 16-24 page review and analysis of the results of research conducted under the auspices of the State Water Institute Program.

COMPLETION REPORTS -- Final reports on completed research containing details of procedure, analysis of data and conclusions reached.

TECHNICAL REPORTS -- Technical information of interest to water resource professionals.

INFORMATION SERIES -- Information of general public interest on water-related subjects.

OPEN-FILE REPORTS -- Complete reports of research that are provided at cost upon request. These reports consist primarily of theses and dissertations from CWRRI-funded research projects.

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WEB PAGES

CWRRI maintains three home pages on the World-Wide Web: The CWRRI Homepage, the Water Center Homepage, and the Colorado Water Knowledge Homepage.

The CWRRI Home Page includes:

A History of CWRRI; Site Map and Jump Station; Research Programs; The Ival V. Goslin Collection; Newsletters; Publications; Useful Water Links; Upcoming Events; Jobs in Water Resources; CWRRI Kids' Zone; and listings of faculty with water expertise and courses available at Colorado Universities. The URL is: **http://cwrri.colostate.edu**

The Water Center Home Page provides:

A description of the Water Center; the people involved; an overview of Water Center programs; a list of meetings, seminars and short courses; jobs in water resources; educational opportunities; water-related courses at CSU; and a list of faculty with water interests and expertise. The URL is: **http://watercenter.colostate.edu**

The Colorado Water Knowledge Home Page contains a huge list of water facts!

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

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

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

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

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

The URL is: **http://waterknowledge.colostate.edu**

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MEETINGS AND CONFERENCES

CWRRI sponsored or cosponsored the following water conferences in FY1998

23rd Annual Colorado Water Workshop
Western State College, Gunnison, Colorado

The 1998 Colorado Water Workshop was held July 29-31 on the campus of Western State College in Gunnison. The meeting's theme, World Water Lessons for a Changing West: On Management, Conservation, and Public Education, provided attendees the opportunity to learn how others are approaching water problems around the world, across the United States, and across time. Texas Senator Buster Brown described Texas's efforts to address a number of emerging water management issues via Senate Bill 1.

Floyd Dominy, Former Bureau of Reclamation Commissioner, reviewed the issues facing water managers in the mid-1900s and commented upon the changes that have taken place since then.

The Colorado Water Workshop '*Living Legend*' for 1998 was John Fetcher, a rancher from the Elk River area north of Steamboat Springs. John's involvement with water development and management in the Steamboat area is truly legendary.

Dick MacRavey, Executive Director of the Colorado Water Congress, wrapped up the three-day meeting with some conclusions on how we in Colorado will have to approach solving our water conflicts.

The 9th Annual South Platte Forum -- NOT IN MY WATERSHED!
Changes In Water and Land use in the South Platte Basin
October 28-29, 1998 -- Raintree Plaza Conference Center,Longmont, Colorado

Keynote Speakers: Justice Gregg J. Hobbs, Jr. Ed Quillen, Denver Post Columnist	Special Geographical Presentation Dr. William Riebsame, University of Colorado Author of Atlas of the New West

Instream Flows...Coming Soon to a River Near You
Moderator: Dan Merriman, Colorado Water Conservation Board

Fred Anderson	Former Colorado Senator	*Colorado's Instream Flow Law: A History of Legislation*
Melinda Kassen	Colorado Trout Unlimited	*Colorado's Instream Flow Program: A Future Perspective*
Patty Wells	Denver Water	*Issues in the Implementation of the Instream Flow Program*

The Miracle of Fishes and Flows
Moderator: Jay Skinner, Colorado Division of Wildlife

Don Ament	Colorado State Senator	*Title TBA*
Jay Stafford	Colorado Division of Wildlife	*Managing Native Fish for the Future*
Dale Strickland	Western EcoSystems Technology, Inc.	*Platte River Endangered Species Partnership*

Models, Maps and Modems
Moderator: Kevin Denny, U.S. Geological Survey

Luis Garcia	Colorado State University	*South Platte Mapping and Analysis Program (SPMAP)*
Donald Schrupp	GIS Department, Colorado Division of Wildlife	*Using GIS in Environmental Science and Assessment*
Tony Selle	GIS Department, U.S. EPA	*Using GIS in Environmental Science and Assessment*

Days of Swine, Bovine, and Roses
Moderator: Mahdi Al-Kaisi, Colorado State University

Tom Haren	Colorado Cattle Feeders	*The Future of the Livestock Business in Colorado* *Myth, Perceptions, and Reality*
Derald Lang	Colorado Water Quality Control Commission	*Confined Animal Feeding Operations Control Regulations in Colorado*
3rd Speaker	Dave Luer	*The Hog Farm Industry in Colorado*

The ABCs of TMDLs
Moderator: Russ Clayshulte, Denver Regional Council of Governments

Sarah Johnson	Colorado Water Quality Control Division	*The Total Maximum Daily Load Process*
Ray Christiansen	Colorado Farm Bureau	*Agriculture and TMDLs*
Robert Wiygul	EarthJustice Legal Defense Fund	*TMDLs From the Conservation Perspective: Getting from Point A to Non-Point B*

Can't We All Just Get Along
Moderator: Gene Schleiger, Northern Colorado Water Conservancy District

Alan Covich	Colorado State University	*Cooperative Efforts for Ecosystem Management*
Rob Sakata	Sakata Farms	*The Agricultural Perspective*
Hubert Farbes, Jr.	Brownstein, Hyatt, Farber and Strickland	*The Legacy of Two-Forks: Partnership or Pestilence?*

Hydrology Days

The Institute cosponsors the annual AGU Front Range Branch Hydrology Days held at Colorado State University each April. American Geophysical Union members and university students from Colorado, New Mexico, Wyoming, Montana, and Utah meet annually to hear professional papers on new research and development advances in hydrology.

STUDENT INTERN PROGRAM

The Institute continued its Student Intern Program in FY1998, a program designed to increase student interest in water issues.

Developed water education/careers programs and exhibits for children's water festivals including one at Ames College, Greeley, sponsored by the Central Colorado Conservancy District for grades 4-6; and also for festivals sponsored by the cities of Greeley and Fort Collins/Loveland and the Roaring Fork Water Conservancy District.

Helped maintain, improve and update the CWRRI World Wide Web Homepages.

Monitored press reports and prepared newsletter summaries of water issues in Colorado; researched background of unfolding water issues and developed in-depth articles.

USGS Internship Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	5	N/A	N/A	N/A	5
Masters	6	2	N/A	N/A	8
Ph.D.	2	1	N/A	N/A	3
Post-Doc.	N/A	N/A	N/A	N/A	N/A
Total	13	3	N/A	N/A	16

Awards & Achievements

UCOWR Awards

Neil S. Grigg, Professor of Civil Engineering and a principal investigator for many prior Water Institute grants, received the Warren Hall Medal. UCOWR (The Universities Council on Water Resources) presents the medal to acknowledge contributions in the field of water resources planning and management. Dr. Grigg has been Department Head of the Civil Engineering Department at Colorado State University since 1991. He has published five books and many articles in the field of water resource engineering and management. He was instrumental in creating the Water Center at CSU to foster cooperation among colleges and departments and to integrate disciplines working in the field of water resources. Dr. Grigg served as Director of the Colorado Water Resources Research Institute from 1988 to 1991.

Tom Cech, Executive Director of the Central Colorado Water Conservancy District and originator of water festivals for school children in Colorado, received the UCOWR Award for Education and Public Service in Water Resources. The Colorado Water Resources Research Institute has presented "Water Careers in Education" at the annual festivals since their inception.

COLORADO WATER KNOWLEDGE Web Page

The Colorado Water Knowledge web page was chosen and highlighted by Yahoo.com as one of the best children's educational sites on the web. The web page was developed by Dr. Freeman Smith and students through a grant from the Colorado Commission on Higher Education.

The website was also selected as a featured site in StudyWeb as one of the best educational resources on the web. StudyWeb updates are provided to media and educational resources around the world.

The Scottish Office of Education Department requested permission to include the website in a CD-ROM for secondary school teachers and lecturers of Geography. The CD-ROM will be a teaching resource which the Scottish Council for Educational Technology (SCET) will produce for non-profit educational purposes.

Publications from Prior Projects

Articles in Refereed Scientific Journals

Tyler, Daniel, 1996, Delph E. Carpenter and the Principle of Equitable Apportionment, Western Legal History, pp. 35-53.

Book Chapters

Dissertations

Ellington, David Sandor, 1997, A GIS Based Hydrologic Simulation Model to Investigate the Nonpoint Source Pollution Potential of Irrigated Agriculture in the South Platte River Basin, Colorado, M.S. Thesis, Dept. of Civil Engineering, Colorado State University, Fort Collins, Colorado, Library Call #TD424.8 .E55 1997, Morgan Library, Colorado State University.

Patton, Omar, 1999, Value of Irrigation Water in Northeast Colorado, MS Thesis, Dept. of Agricultural & Resource Economics, Colorado State University, Fort Collins, Colorado, Morgan Library, Colorado State University.

Stevenson, Timothy R., 1997, Water Transfer Effects on Vegetation and Streamwater Quality in South Park, Colorado, M.S. Thesis, Dept. of Rangeland Ecosystem Science, Colorado State University, Fort Collins, Colorado, Morgan Library, Colorado State University, 119 pp.

Van Steeter, Mark M., 1996, Historic and Current Processes Affecting Channel Change and Endangered Fish Habitats of the Colorado River Near Grand Junction, Colorado, Ph.D. Dissertation, Department of Geography, University of Colorado, University of Colorado Library, Boulder, Colorado, 180 pp.

Claessens, Luc, 1996, The Complementary Relationship in Regional Evapotranspiration and Long-term Large-scale Water Budgets, M.S. Thesis, Department of Civil Engineering, Colorado State University, Fort Collins, Colorado, Morgan Library, Colorado State University, 159 pp.

Nichols, Rebecca, 1997, Irrigation Water Use in the Yampa River Basin, M.S. Thesis, Dept. of Soil & Crop Sciences, Colorado State University, Fort Collins, Colorado, Morgan Library, Colorado State University.

Paschke, Suzanne S., 1998, Evaluating the Hydrogeology of the Pleistocene Nussbaum Alluvium, Colorado, Using Vertical Variability Analysis and Numerican Modeling, Ph.D. Dissertation, Dept. of Geology and Geological Engineering, Colorado School of Mines, Golden, Colorado, Colorado School of Mines Library, Call Number T3055 ER, 152 pp.

Water Resources Research Institute Reports

Hannula, Steven R. and Eileen P. Poeter, 1995, Temporal and Spatial Variations of Hydraulic Conductivity in a Stream Bed in Golden, Colorado, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, Open File Report No. 11.

Smith, D.H., R.H. Nichols, F.M. Smith, Kent Holt, 1998, Irrigation Water Use in the Yampa River Basin, Water in the Balance No. 8, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, 80523, 24pp.

Mauch, Jennifer.Proceedings, Grow with the Flow: Growth and Water in the South Platte Basin, 1997 South Platte Forum. Information Series No. 87.Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, 80523. 40pp.

Schmidt, Laurie, Editor, 1998, Not in My Watershed! Changes in Land and Water Use in the South Platte Basin, Proceedings of the 9th Annual South Platte Forum, Oct. 28-29, 1998, Information Series No. 88, Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO, 80523, 32pp.

Conference Proceedings

Tyler, Daniel, 1997, The Silver Fox of the Rockies: A Critic's View of Delphus Emory Carpenter and the Colorado River Company, Proc., 75th Anniversary of Colorado River Compact, May 28-31, 1997, Santa Fe, New Mexico, Water Education Foundation, 717 K St., Suite 517, Sacramento, California, 95814.

Other Publications

Tyler, Daniel, 1997, Delphus Emory Carpenter and the Colorado River Compact of 1922, Prepared under contract for the Colorado Water Conservation Board, 76 pp.

Rieke, Elizabeth, Wendy S. Rudnik, David H. Getches, and Teresa A. Rice, 1996, The Watershed Source Book: Watershed-Based Solutions to Natural Resource Problems, Natural Resources Law Center, University of Colorado, Boulder, Colorado.