WATER IN THE BALANCE

No. 2
August 1995

"Improved computer support could help decision makers evaluate alternative solutions to changing demands."

Colorado Water Resources Research Institute

Colorado State University

Initiating a Water Management Decision Support System for the South Platte River Basin

From the *Rocky Mountain News*, December 16, 1994: Denver Mayor Wellington Webb announced that one of his top priorities is to have the South Platte River running full, year round, through downtown Denver and past the new stadium at Coors Field. The mayor did not elaborate on the source of the increased flow.

The next day, the *News* ran a follow-up story headlined: "Fixing South Platte would be a tangled mess." Water officials and consultants asserted that all options to provide aesthetic flows were complicated by existing water contracts, numerous water rights, increasing demands due to growth, and "other constraints."

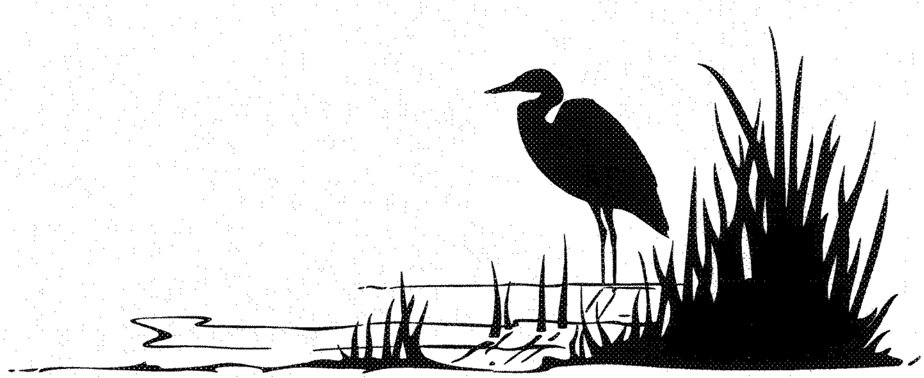
The South Platte basin faces evolving and increasing demands for water. Faced with severely limited supplies, the water management objective remains unchanged: satisfy demands without injuring existing uses. The major issues in the basin today appear to be:

1. formulation of strategies to provide minimum streamflows,

2. satisfaction of municipal demands without injury to agriculture, and

3. evaluation of water quality issues.

Improved computer support could help decision makers evaluate alternative solutions to changing demands. This issue of *Water in the Balance* looks briefly at the demands and constraints in the basin, the concept of a Decision Support System (DSS), and the current state of computer modeling for the South Platte.



An Open Letter on Decision Support Systems

Dear Reader:

In the past few years a lot of attention in the water management community has been given to Decision Support Systems (DSS). For example, the Colorado Water Conservation Board and Division of Water Resources are currently in a large, multi-year process of developing a DSS for the Colorado River. It is the goal of this project to evaluate the feasibility of applying decision support system technologies to the Platte River basin in general and the South Platte basin in Colorado specifically. So, what is this concept of DSS? Is this just the latest technological fad that will be hot for a few years then sit on the shelf when the next new and improved technology comes along? What are the costs and what are the benefits of a DSS? Will the use of a DSS really improve the management of Colorado's river systems? These are significant questions that should be discussed by Colorado's water community.

The basic concepts of DSS are not particularly new. The components of any general decision making process might be defined as intelligence, analysis and choice. These three components exist whether or not computers are used. Computing technologies, however, can greatly assist in these areas. In the early 1970s, concepts of modern decision support systems emerged from the business management field and were articulated by authors such as Keen and Scott-Morton. They see DSS as a means to improve the *quality* of decisions by effectively combining the intellectual resources of decision makers with the information processing and management capabilities of computers. Decision support systems are intended for use with *unstructured* problems, that is, those problems whose complexity prevents "cut-and-dried" solutions. Water resources management certainly fits within the unstructured problem category. By synthesizing information from various sources, I define a Decision Support System as an *integrated computing framework*, consisting of a data base, model base and a user interface/dialog facility. Within this definition can be seen the elements of intelligence (data base), analysis (model base) and choice (user interface/dialog facility). Considering that many water resource modeling and data collection efforts also began in the 1970s, one recognizes that we have been working on the various elements of a DSS for the past 20 years. However, it is only in recent years that we have had computing hardware and software capable of providing a truly *integrated* computing framework.

When applying the concepts of DSS to water resource management, there are many challenges. First, there are still challenges with the technology. While we are able to build sophisticated systems, the larger basin scale applications require significant development efforts, and there are still many hardware and software limitations to be overcome. There is the problem of the required complexity of models and data to effectively analyze interconnected surface and groundwater systems such as the South Platte. Complex systems require complex models which in turn require significant data resources. Consolidating existing data resources for use in a basin-wide DSS has it own set of challenges. Data structures, time series and reliability of data can vary widely. Water quantity and water quality data may be in different time series and measured at different locations.

Second, there are new challenges with organizational structures to implement and manage a DSS. It must be stressed that a DSS is not an end-product, but is a constantly evolving framework. All three components of data base, model base and user interface/dialog facility will be dynamic. They will be expanding and evolving constantly with time. Therefore, it is critical that the organization that develops the DSS be committed to maintaining and evolving the system. There are important questions in terms of who will be allowed access to the DSS, what models or analysis tools will be provided and the needed protocols for maintaining and expanding the data base. It is equally critical that the users of the DSS be clearly identified and the DSS structured to provide the informational support to the users in such a way that the quality of their decisions is truly improved. This implies an ongoing evaluation process to ensure that the DSS is meeting the needs of the decision makers.

Third, the use of a DSS really implies a paradigm shift to a more open information system. This means that all users have potential access to the same data and the same analysis tools. This is a significant departure from the current system of different agencies often using their own models and own data resources. This may also have significant implications for conflict resolution through the water court system. The decision process will likely become more subject to public scrutiny.

The goal of this project was to examine the issues surrounding the feasibility of eventually implementing a DSS for the South Platte basin. This basin is extremely complex to manage, and there is strong support among its water users to continue to improve the quality of water management in the basin. This project wanted to provide a snapshot of current water management practices in the basin, identify potential users and identify potential issues surrounding the data base, model base and user interface/dialog facility of a future DSS. The intent is to provide a common starting point from which to address this issue.

Sincerely,

Darell G. Fontane

Dr. Darrell G. Fontane
Engineering Associate Professor
Colorado State University

The South Platte

Evolving Demands

The growing Front Range population, new mandates for instream flows, and a strong traditional agriculture present different, and often conflicting, needs for water. Colorado's explosive population growth, with the attendant water supply dilemmas, seems to generate front page news every week.

The controversy over federally mandated flows for migratory habitat in Nebraska is a matter of continuing debate, and is the subject of ongoing Memorandum of Agreement (MOA) talks between Colorado, Nebraska, Wyoming, and the U.S. Department of the Interior. This issue will eventually affect water management on the South Platte. The Colorado Division of Wildlife (DOW) warns of declining native species within the state, and is seeking ways to provide additional or improved aquatic habitat in Colorado.

Other instances of instream demands include aesthetic flows, such as those sought by Mayor Webb and those the city of Boulder has been working to provide in Boulder Creek. Demands for recreational use are also growing as rafting, fishing, and other water-based recreation increase in popularity.

Agricultural irrigators in northeastern Colorado hold some of the most senior water rights on the river but, as upstream uses change, water quality becomes an increasingly important issue for downstream users, no matter what their date of priority.

These situations illustrate some of the driving forces behind the increasing competition for water in the South Platte Basin.

Constrained Supply

After years of litigation and a forty million dollar Environmental Impact Statement (EIS), Denver Water failed in its attempt to obtain permits for the Two Forks reservoir. Similarly, plans for the Narrows reservoir on the South Platte have been abandoned, and permits for the Wildcat reservoir, on a tributary, were denied. There is now, effectively, a moratorium on large-scale structural solutions such as these, limiting the set of available alternatives with which to meet new demands. Attempts to initiate new trans-mountain diversions will also encounter vigorous opposition, due to concern over environmental and endangered species issues.

The institutional complexity of water rights on the over-appropriated South Platte further squeezes the system. The transfer of a water right from one point to another affects the return flows from that water right and, in turn, may injure downstream water users that depend on those return flows. The Water Court in Greeley conditions transfers so as to prevent injury to other vested rights, while the State Engineer's Office (SEO) is charged with administering the court's decrees and curtailing diversions according to their legal priority.

As the river system operates closer and closer to its absolute capacity, administrative decisions become increasingly critical. The new South Platte Water Rights Management System (SPWRMS) is a water rights accounting software that was delivered to the SEO in 1994. SPWRMS has already proven itself valuable to the Division One Engineer's office for daily operations, but would require additional modeling components to become an effective long-range planning tool.

Finding Solutions

Partial solutions to these evolving demands and constraints may lie in better coordination of reservoir operations, further development of conjunctive use potential, and more innovative trading and cooperation between decreed water users.

In some cases, exchanges have allowed more flexible use of existing supplies. One well-documented case involves the City of Fort Collins, Water Supply and Storage Co., North Poudre Irrigation Co., and the Platte River Power Authority. The entities involved were able to use computer modeling to evaluate the trade before any water actually changed hands.

When water exchanges or sales are proposed, existing users are often forced to resort to litigation to preserve their rights. This results in high legal and engineering costs, and can place an unfair burden on owners of vested water rights. With an accepted and accessible basin model these costs might be avoided, or at least reduced.

Even with increasing demands, unappropriated water still flows in the South Platte during some parts of the year. Colorado needs to explore ways to more fully realize its entitlement under the interstate compact with Nebraska and maximize the beneficial use of that entitlement, while meeting ecological needs the year around. Development of a DSS could be the next step in this exploration.

Initiating a South Platte Decision Support System

Defining DSS

A Decision Support System (DSS) is a computerized system of databases and models, with a user interface that invites operation without requiring a degree in computer science. In the past, water management models have been constructed to require data input formulated specifically for the model. The DSS concept now being initiated for the Colorado River involves one central database and a "suite" of models which will all access that same database. A single user interface will access all the models, providing continuity between applications.

A Decision Support System is intended to facilitate the development and evaluation of alternative solutions to ill-structured or ill-defined problems. A DSS does not automate the decision process; it is specifically intended for problems that cannot be automated. A DSS supports decision making, it does not make decisions.

Equipped with the proper models, a water management DSS could assist in evaluation of proposed trading scenarios and augmentation plans by analyzing the potential flow and quality effects. If a DSS is developed, it should address at least the major issues identified above: minimum streamflow strategies, preservation of agriculture in the face of growing urban demands, and water quality.

Current Status of South Platte Decision Support

In recent years, several efforts have been made toward development of decision support for the South Platte. Denver Water currently models the South Platte drainage from the headwaters to Henderson and has discussed expanding their model to Julesburg. The South Platte Water Rights Management System (SPWRMS) is an effective tool for daily operation and employs several user interface techniques that would be desirable in a DSS. The Colorado Water Conservation Board (CWCB) contemplates duplicating the framework of the new Colorado River DSS (CRDSS) for the South Platte. At least two dissertations addressing decision support on the South Platte have been written recently at Colorado State University.

John Eckhardt's 1991 dissertation, "Real-time Reservoir Operation Decision Support Under the Appropriation Doctrine," details a decision support tool for operation of two or more reservoirs. Eckhardt wrote a spreadsheet program to evaluate management options, taking into account water rights. He noted that operators suffer more from information overload than lack of information, and showed how a systems approach can help them sort out their options. His program was intended for real-time operating support, as opposed to system planning or modeling. Eckhardt's model is relevant for multiple reservoir operation on the South Platte when the relationships between reservoirs are known. It did not specifically include a groundwater flow component, and was not intended as a model of the entire basin.

Jeffrey Fredericks completed his dissertation in 1993, titled "Decision Support System for Conjunctive Stream-Aquifer Management Under Priór Appropriation." Like Eckhardt, Fredericks employed some standard, off-the-shelf software (DBase, Quattro Pro, IDRISI, MapInfo) in his system, but also developed several specialized routines for reading data from external data bases. MODSIM, an interactive river basin management model developed at CSU, was used to model the river and tributary aquifer. MODRSP, developed at the University of Arizona to model groundwater behavior, was used to generate aquifer response coefficients for input to MODSIM. An existing augmentation plan on a fifty mile reach of the lower river was used as a test case, with inflow and outflow assumed. Fredericks's framework could conceivably be expanded to include the entire basin, but it is clear that the entire basin is considerably more complex than his test case.

Current Status of Potential DSS Components

Databases:

Fredericks accessed several data sources for his test case, including the USGS, US Bureau of the Census, the Colorado State Engineer, and the records of the augmentation plan that he modeled. He performed an extensive inventory of existing water resources data and noted that no central facility exists for data collection and distribution. While he found that most data was available in a digital format, the various formats were not always compatible.

The SPWRMS database includes many of the spatial and surface flow characteristics, as well as the legal flow priorities, that would be needed for a South Platte DSS. This system is also set up for real-time data acquisition from the state's satellite telemetry scheme.

CWRRI has identified several data needs that currently are not being met, but that are necessary to model the stream-aquifer relationship of the lower basin. These include acreage and crops irrigated under individual ditches, well pumping amounts, ungaged return and tributary flows, reservoir operations rules, and river gain/loss relationships. In addition, some practitioners believe the spatial characteristics of the South Platte aquifer are still not adequately known.

Models:

In his 1994 CWRRI paper, "Initiating a Water Management Decision Support System for the Platte River Basin," Robert Leaf reviewed some of the streamflow models that have been used in the South Platte Basin. Models reviewed included the network model BESTSM, network optimization models MODSIM and CRAM, and SAMSON, a complex, physically based model that attempts to simulate all of the processes occurring in a stream-aquifer system such as the lower South Platte.

BESTSM and MODSIM are in use today in several applications. A version of BESTSM, developed by Boyle Engineering of Lakewood, was modified for use by Denver Water as their system model. MODSIM, developed at CSU by John Labadie, is in use by the City of Greeley and the Northern Colorado Water Conservancy District.

SAMSON was developed at CSU in the 1980's, primarily by Jorge Restrepo and Hubert Morel-Seytoux. It has extensive input data requirements, not all of which are readily available. The model has been applied to the lower South Platte for calibration and verification, but the lack of accurate input data apparently halted development several years ago. Among potential users, there seems to be a paradoxical wish for a model that would yield the detailed output promised by SAMSON, but without the complex input.

SPWRMS is an accounting model for water rights that simulates "legally prescribed" flows using rule routing (lag/loss table). For simulation of flows higher or lower than average, the lag/loss table must be adjusted. In order to adjust the lag/loss table, either professional judgment or output from another model (or both) are required.

The Northern Colorado Water Conservancy District (NCWCD) has been working for several years on development of a point flow model for the lower South Platte; it is now in the final stages of development and will be attached to SPWRMS in 1995. The Northern Point Flow Module will be used to determine historic reach gains and losses between gage points, and historic river flows above and below diversion structures. Although still not a physically based model, this software will help improve evaluation of well withdrawals and aquifer recharge operations, as well as promote an understanding of the associated stream gains or losses by stream reach.

Interfaces:

The feasibility study for the CRDSS, completed in 1993 by Dames & Moore / CADSWES, investigated three types of user interface: command line, forms based, and interactive graphics. A command line interface requires all requests for action to be typed in. Although this kind of interface demands the least in terms of system hardware and software, it also offers the least in terms of "user friendliness."

A forms based interface leads the user through a series of "fill-in-the-blanks" screens, and helps to structure the use of a DSS. An interactive graphics interface offers a Windows-type "point-and-click" environment and requires the most in terms of hardware and software. The CRDSS is being developed with both forms-based and interactive graphics interfaces. Users with low-end platforms will be able to

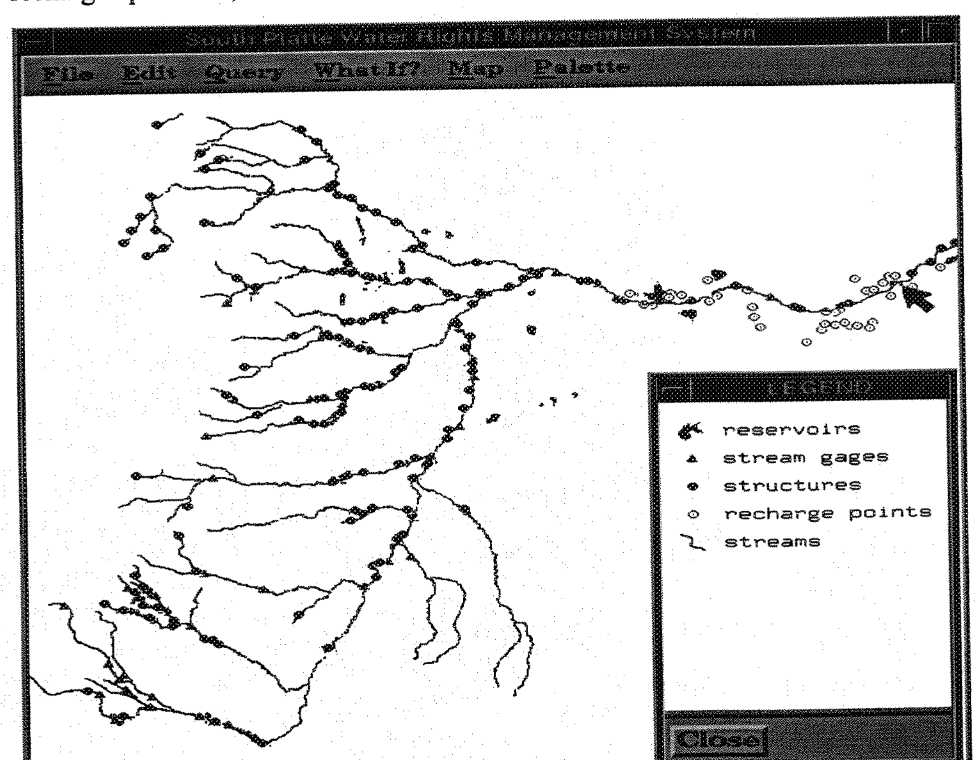


Figure 1. SPWRMS Graphical Interface.

access the system through the forms-based menus; platforms that support high-end graphics may use either.

Like CRDSS, SPWRMS uses both graphical and forms-based interfaces. Information about a particular point of interest (diversion structure, inflow point, etc.) can be accessed by "pointing and clicking" at the appropriate spot on the plan view. Figure 1 shows this interface with the Balzac streamflow gage being selected (arrow). The view may be zoomed in or out, and various levels of detail may be chosen. The user may also bypass the graphical environment to utilize the forms-based interface.

SPWRMS graphical output offers hydrographs of the river at any structure; multiple hydrographs may be plotted at the same time. Figure 2 shows a hydrograph at the Balzac gage, selected in Figure 1 above. During their first season with the new system, the Division One Engineer's office was able to utilize these displays to recognize relationships that had previously gone undetected.

Implementation Plan for DSS

Colorado's two most recent efforts toward decision support for water management, CRDSS and SPWRMS, could both be utilized in the effort to implement a DSS for the South Platte.

In the past, water resources computer models have been written to address one specific problem or environment. Much of the information about a particular river basin, for instance, would be included in the model's code. Recent DSS designs, including CRDSS, have used a "data-centered" approach, where one or more databases contain all the information necessary to model a situation.

The advantage to this approach is that multiple generic models, each of which serves a different purpose, may be configured to access the same central database. The models themselves do not contain any situation-specific information in their coding; they read all relevant information from the database. The major disadvantages of the data-centered approach have been model run times and start-up costs.

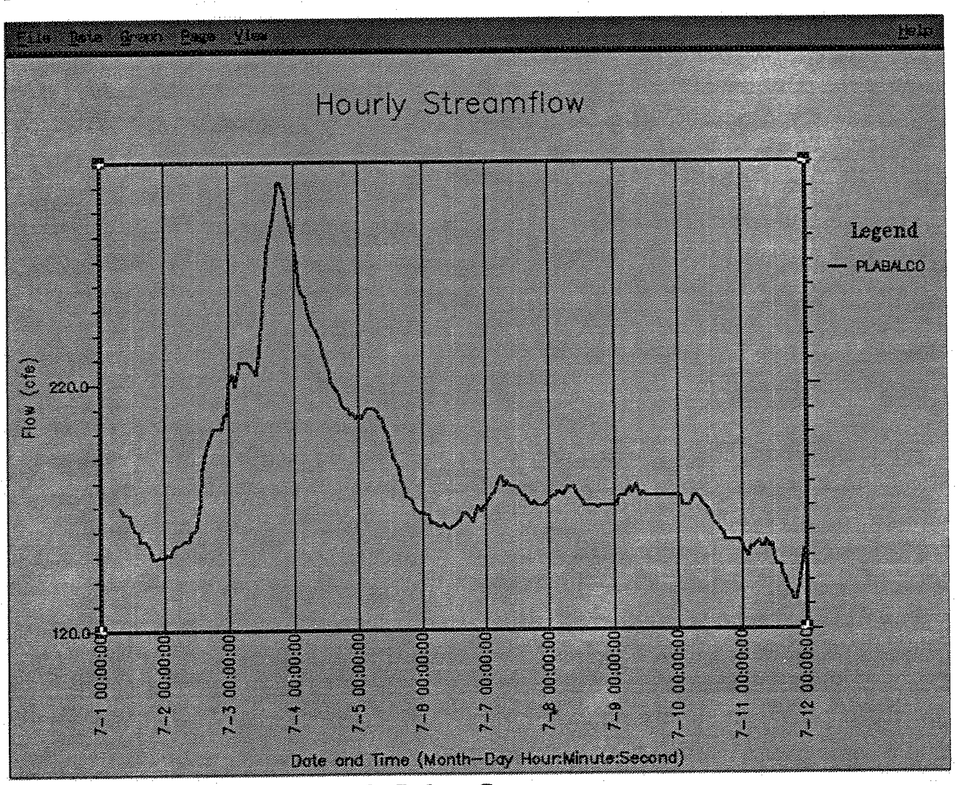


Figure 2. SPWRMS Hydrograph, Balzac Gage.

SPWRMS is not strictly a modular application and, in its present configuration, is not suited to provide the interface for a system on the scale of CRDSS. SPWRMS does, however, have the capability to perform "what-if" modeling for daily administrative planning. Much of the effort that went into creating SPWRMS should be useful and transportable for development of a more extensive DSS. In particular, the spatial topology – the way basin features relate to each other – of the GIS interface of SPWRMS could form the basis for a graphical DSS interface. In addition, the relational database used by SPWRMS stores many institutional and physical characteristics of the basin that would be needed by water resource planning models and water quality models.

Any serious attempt to model the lower South Platte basin must account for the tributary aquifer. The current methods of calculating well depletions and recharge accretions provide acceptable results, but additional improvement would be desirable. The NCWCD's Point Flow Module is a step toward providing a calibration tool for stream reach gains and losses.

The CRDSS water resources planning model is not configured to include well pumping and tributary aquifer recharge. While the CWCB is considering use of the CRDSS framework for a South Platte DSS, this is one of the major modifications that will be necessary. CWRRI is taking a look at the SAMSON model, and considering its potential as a module of a South Platte DSS.

SPWRMS has an effective user interface with which the Division One

Engineers and the District Commissioners are becoming familiar. While the interface is not in "ready-to-use" form for a more comprehensive DSS application, it could be modified or duplicated. SPWRMS databases contain, in readily accessible form, much of the basic information a DSS will require. Lastly, SPWRMS is currently set up to run on UNIX work stations in Greeley and Denver, and offers access to PC's via modem.

CRDSS is now in its second year of development. Many of the database design, population, and access decisions made during the first year could be duplicated for a South Platte DSS. The consumptive use models and water resource planning models within CRDSS are being designed for a modular system. The consumptive use model should, therefore, require only slight modifications to be used in a South Platte DSS. The South Platte water resources planning model must include surface/groundwater interaction; the CRDSS planning model would need to be modified.

Three major technical hurdles remain, then:

1. Final development and calibration of a basin-wide, surface/groundwater model,
2. Development and calibration of an appropriate water quality model, and
3. Most importantly, development and verification of the database to support the models.

In order to populate the database for a South Platte DSS, routines similar to those used by Fredericks in his dissertation will have to be developed. These routines will read information from an existing database, perform any necessary conversions, and write the information to the South Platte database. Population of this database is arguably the most critical step in DSS development; indeed, it has been the Achilles' heel of several modeling efforts. Table 1 lists some of the data requirements, and possible sources.

Table 1. Data Requirements for South Platte DSS

DATA	SOURCES
Streamflow	USGS Gage Records, SEO, SPWRMS
Aquifer Properties	USGS - Hurr/Schneider
Climate	NWS, NCWCD, SCS Snotel
Water Rights	SEO, SPWRMS
Historic Surface Water Use	SEO, Ditch Companies
Historic Groundwater Use	SEO, GASP, Conservancy Districts, Irrigators
Spatial Topology	SPWRMS
Operating Rules	Reservoir Owners, Ditch Co.'s, Conservancy Districts
Crop Data	SCS, Ditch Co.'s, Conservancy Districts, Remote Sensing
Soil Types	SCS
Water Quality Data	Metro WW, Denver Water, USGS, DPHE, DOW

Institutional Issues

In addition to the technical hurdles, at least two fundamental institutional issues must be addressed. The most obvious is the question of who will develop, maintain, and operate the DSS. CRDSS is being developed under the purview of the Water Conservation Board (CWCB) and the Division of Water Resources, but an extensive team with a full-time project manager, sub-contractors, and technical advisors was assembled for the project. CRDSS development is expected to take four and a half years; over $2 million has been invested in the first two years.

While the South Platte Basin is smaller than the Colorado Basin, it is arguably more complex to model. To be effective, development of a DSS should occur incrementally, with close communication between model developers, water users, and government administrators. The SPWRMS development team notes that some of the features they liked most are unused, while other routines, added almost as afterthoughts, have become important tools to the Division One Engineers. The NCWCD's Point Flow Module is an example of an incremental step that will lead to a better understanding of South Platte basin hydrology. The completed DSS must be acceptable and accessible to basin water managers and users.

Another institutional issue involves the legal constraints governing water salvage and exchanges. The phrase, "use it or lose it," is often cited as one of the basic principles of Colorado water law, and it is often argued that the Colorado system offers no incentive for vested users to conserve water. In recent years, several bills have been introduced in the State Legislature that would encourage users to "salvage" water by using more efficient practices. To date, none of the bills have passed. Colorado law also lacks mechanisms for short term transfers, although several entities are now investigating ways to address the situation. Rice and MacDonnell explore these issues and possible modifications to Colorado water law in their recent CWRRI paper, Agricultural to Urban Water Transfers in Colorado: An Assessment of the Issues and Options. The value of a Decision Support System will be diminished without the institutional flexibility to use it.

Conclusions

Increasing pressures on the South Platte system are well known and well documented. Colorado's population growth is making national news, agricultural water is being transferred to municipal uses, and the consequences to local economies and other water users are of grave concern. Added to these problems are environmental mandates for instream flows and water quality requirements. While it can be argued the South Platte is efficiently managed and used today, the situation is changing rapidly. A Decision Support System for the South Platte could help Colorado address these problems.

Contact Information

The following professionals provided information, advice, and encouragement for this issue of *Water in the Balance*. Their expertise should prove valuable in the development of a South Platte DSS. Information on contacting them is included here in the hope that it will facilitate further discussion and development of a South Platte DSS.

John Altenhofen
NCWCD
PO Box 679
Loveland, CO 80539
Ph: 970/667-2437

Alan Berryman, P.E.
Division I Engineer
800 8th Ave., Suite 321
Greeley, CO 80631
Ph: 970/352-8712

Ross Bethel, P.E.
Leonard Rice Consulting
2401 15th St. , Suite 300
Denver, CO 80202-1143
Ph: 303/455-9589

Tom Cech
CCWCD
3209 W 28th St.
Greeley, CO 80631
Ph: 970/330-4540

John Eckhardt, P.E.
Riverside Technology, Inc.
2821 Remington
Fort Collins, CO 80525
Ph: 970/223-3944

Dr. Luis Garcia
IDS Group
Colorado State University
Fort Collins, CO 80523
Ph: 970/491-5144

Dr. Timothy Gates
Civil Engineering Department
Colorado State University
Fort Collins, CO 80523
Phone: 970/491-5043

Dr. Neil Grigg
Civil Engineering Department
Colorado State University
Fort Collins, CO 80523
Ph: 970/491-5048

James Hall, P.E.
Assistant Division I Engineer
800 8th Ave., Suite 321
Greeley, CO 80631
Ph: 970/352-8712

Doug Kemper
City of Aurora
1470 South Havana
Aurora, CO 80012
Ph: 303/695-7386

Jerry Kenny
Boyle Engineering Corporation
165 South Union Blvd.
Lakewood, CO 80228
Ph: 303/987-3443

Dr. John Labadie
Civil Engineering Department
Colorado State University
Fort Collins, CO 80523
Ph: 970/491-6898

Daries Lile, P.E.
Colorado Water Conservation Board
1313 Sherman Street, Room 721
Denver, CO 80203
Ph: 970/866-3441

David Little
Denver Water
1600 W 12th Ave.
Denver, CO 80254
Ph: 303/628-6000

Dr. Daniel Luecke
Environmental Defense Fund
1405 Arapahoe
Boulder, CO 80302
Ph: 303/440-4901

Paddy McCarthy
CADSWES - CB 421
University of Colorado
Boulder, CO 80309
Ph: 303/492-3972

Jack Odor, P.E.
GASP
PO Box 974
Fort Morgan, CO 80701
Ph: 970/867-5298

Steve Schmitzer
Denver Water
1600 W 12th Ave.
Denver, CO 80254
Ph: 303/628-2000

Dr. Robert Ward
CWRRI
410 N USC
Colorado State University
Fort Collins, CO 80523
Ph: 970/491-6308

Bart Woodward
Riverside irrigation District
PO Box 455
Fort Morgan, CO 80701
Ph: 970/867-6586

Darrell Zimbelman, P.E.
NCWCD
PO Box 679
Loveland, CO 80539
Ph: 970/667-2437

Some Useful References

Altenhofen, Jon. "Water Supply and Water Quality Goals in the Northern District." 18th Colorado Water Workshop. Gunnison, 28-30 July 1993.

---, "South Platte Basin Study Review." NCWCD Memorandum, 01 Feb. 1995. Northern Colorado Water Conservancy District, Loveland.

Bittinger, Morton W., R.E. Danielson, N.A. Evans, W.E. Hart, H.J. Morel-Seytoux, and M.M. Skinner. Impact of Irrigation Efficiency on Water Availability in the South Platte River Basin (TR 13). Fort Collins: Colorado Water Resources Research Institute, 1979.

Crookston, Mark and Gary Hoffner. 1992 Irrigation Management Education Program. Loveland: Northern Colorado Water Conservancy District, 1992.

CWRRI South Platte Team. South Platte River System in Colorado: Hydrology, Development, and Management Issues (working paper). Fort Collins: Colorado Water Resources Research Institute, 1990.

Dames & Moore / CADSWES. Feasibility Study Report for a Colorado River Decision Support System (prepared for Colorado Dept. of Natural Resources). Denver: Dames & Moore / CADSWES, 1993.

Eckhardt, John. "Real-time Reservoir Operation Decision Support Under the Appropriation Doctrine." Diss. Colorado State University, 1991.

Fredericks, Jeffrey W. "Decision Support System for Conjunctive Stream-Aquifer Management Under Prior Appropriation." Diss. Colorado State University, 1993.

Grigg, Neil S. Water Resources Management. Review Draft, June 1994. Fort Collins: CSU Department of Civil Engineering.

Hendricks, D.W., H.J. Morel-Seytoux, and C. Turner. Water for the South Platte Basin (IS 37). Fort Collins: Colorado Water Resources Research Institute, 1979.

Hurr, Theodore R. Effects of Water-Management Practices on the Flow of the South Platte River, Colorado. Publication 117 de l'Association Internationale des Sciences Hydrologiques Symposium de Tokyo: December 1975.

Klein, Kathleen C., ed. Seeking an Integrated Approach to Watershed Management in the South Platte Basin. Proc. of the 1993 South Platte Forum. 27-28 Oct. 1993, Fort Collins. Fort Collins: Colorado Water Resources Research Institute, 1994.

Klein, Kathleen C., ed. Integrated Watershed Management in the South Platte Basin: Status and Practical Implementation. Proc. of the 1994 South Platte Forum. 26-27 Oct. 1994, Greeley. Fort Collins: Colorado Water Resources Research Institute, 1994.

Labadie, John and John Shafer. Exploring Ways of Increasing the Use of South Platte Water (IS 41). Fort Collins: Colorado Water Resources Research Institute, 1980.

Laura, Della. "Water Resources Decision Evaluation Model." Diss. CSU, 1974.

Leaf, Robert. "Initiating a Water Management Decision Support System for the Platte River Basin." Unpublished report. Fort Collins: Colorado Water Resources Research Institute, 1994.

League of Women Voters of Colorado. Colorado Water. Denver: LWVC, 1992.

Northern Colorado Water Conservancy District. Point Flow Analysis Software for the Lower South Platte River v1.1. Loveland: Northern Colorado Water Conservancy District, 1994.

Obmascik, Mark. "How Long Before the Well Runs Dry?" Denver Post 24 Oct. 1994, final ed.: 1A.

---. "South Platte's Rare Fish in Trouble." Denver Post 16 Mar. 1995, 1B.

Rice, Teresa and Lawrence J. MacDonnell. Agricultural to Urban Water Transfers in Colorado: An Assessment of the Issues and Options (CR 177). Fort Collins: Colorado Water Resources Research Institute, 1993.

South Platte Basin Water Management Committee Newsletter. Volumes 1-3. Loveland: Produced by Northern Colorado Water Conservancy District on behalf of the committee, 1988-89.

South Platte Research Team. Voluntary Basinwide Water Management: South Platte River Basin, Colorado (CR 133). Fort Collins: Colorado Water Resources Research Institute, 1987.

The Platte: A River Under Siege. New York: National Audubon Society, 1988.

"3-State Talks on River, Wildlife in Jeopardy." (AP). Denver Post 10 Mar. 1995, 5B.

Tyler, Daniel. The Last Water Hole in the West. Niwot: University Press of Colorado, 1992.

USGS. Water Resources Data Colorado, Vol. 1, Missouri, Arkansas, Rio Grande Basins. Denver: USGS, 1993.

Van Schilfgaarde, Jan. "America's Irrigation: Can It Last?" Civil Engineering Mar. 1990: 67-69.

Verangia, Joseph B. "Fixing South Platte would be tangled mess." Rocky Mountain News 17 Dec. 1994, 5A.

Viessman, Warren Jr. "Water Management: Challenge and Opportunity." American Society of Civil Engineers, Journal of Water Resources Planning and Management 116 (1990):155-69.

Warner, James W., Jon Altenhofen, Jack Odor, and Brandon Welch. Recharge as Augmentation in the South Platte River Basin (TR 21). Fort Collins: Colorado Water Resources Research Institute, 1994.

Weber, Brian. "Webb wants South Platte to run like a river again." Rocky Mountain News 16 Dec. 1994, 4A.

Woodring, Richard Craig. "A Data-Centered Paradigm for Enhancing Water Resource Decision Support Systems." Diss. Colorado State University, 1994.

Woodward-Clyde Consultants. South Platte River Basin Assessment Report (prepared for CWCB, Colorado Dept. of Natural Resources). Englewood, CO: Woodward-Clyde, 1982.

Wright Water Engineers. Preliminary Report: Study of Integrated Water Use, South Platte River Basin, Water District No. 8 (prepared for Coordinator of Natural Resources, State of Colorado). Denver: Wright Water Engineers: 1968.

Acronyms

BESTSM	Boyle Engineering STream Simulation Model (Boyle Engineering Corporation, Lakewood, CO)
CADSWES	Center for Advanced Decision Support for Water and Environmental Systems (University of Colorado, Boulder)
CRDSS	Colorado River Decision Support System
CWCB	Colorado Water Conservation Board
CWRRI	Colorado Water Resources Research Institute
DNR	(Colorado) Department of Natural Resources
DOW	(Colorado) Division of Wildlife
DPHE	(Colorado) Department of Public Health and Environment
DSS	Decision Support System
EIS	Environmental Impact Statement
GASP	Groundwater Appropriators of the South Platte Basin
GIS	Geographic Information System
MOA	Memorandum of Agreement
Metro WW	(Denver) Metropolitan Waste Water Reclamation District
NCWCD	Northern Colorado Water Conservancy District
NRCS	(USDA) Natural Resources Conservation Service [formerly SCS]
NWS	(US) National Weather Service
SAMSON	Stream Aquifer Model for management by Simulation and OptimizatioN (CWRRI, Fort Collins)
SCS	(USDA) Soil Conservation Service [now NRCS]
SEO	(Colorado) State Engineer's Office
SPWRMS	South Platte Water Rights Management System
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey

About the Colorado Water Resources Research Institute and Water in the Balance

The Colorado Water Resources Research Institute (CWRRI) exists for the express purpose of focusing the water expertise of higher education on the evolving water concerns and problems faced by Colorado citizens. CWRRI strives to constantly bring the most current and scientifically sound knowledge to Colorado's water users and managers. For more information about CWRRI and/or the water expertise available in the higher education institutions in Colorado, please contact CWRRI at the address below or by phone or fax as follows:

Phone: (970) 491-6308
Fax: (970) 491-2293

"Water in the Balance" has been created in the spirit of informing the public about complex water management issues. This issue briefly summarizes the efforts in the South Platte River basin to initiate a decision support system.

This document was written by Henry H. Kuhnhardt and Darrell G. Fontane. The activities on which this report is based were financed in part by the Department of the Interior, U.S. Geological Survey, through the Colorado Water Resources Research Institute under Grant Number 14-08-0001-G2008/3, Project 4; Grant Number 14-08-0001-G2008/4, Project 4; and Grant Number 14-08-0001-G2008/4, Project 05. The contents of this publication do not necessarily reflect the views and policies of the people listed on page 9 or the Department of the Interior, nor does the mention of trade names or commercial products constitute endorsement by the United States Government.

Colorado State University

Colorado Water Resources Research Institute
410 North University Services Center
Fort Collins, CO 80523

Bulk Rate
U.S. Postage
PAID
Fort Collins, CO
Permit No. 19