SOUTH PLATTE RIVER SYSTEM

IN COLORADO

Hydrology, Development and Management Issues

By the CWRRI South Platte Team

Working Paper

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PREFACE

The water management system of the South Platte River basin has evolved since 1860. It is comprised of physical infrastructure having thousands of components and an institutional infrastructure based upon the doctrine of prior appropriation. The system works through the initiatives of some 6000 water rights holders as administered by the Colorado State Engineer. It provides for 4.5 million acre-feet of diversions and only about 1.8 million acre-feet of annual water supply.

The system has reached its limit to provide without new sources of imported water. New demands are from the municipal sector, and increasingly they will be satisfied by purchases from the agricultural sector.

Water availability is important to every economic and social activity in the basin. The system is complex, and the only way to analyze proposed alternatives with respect to basin-wide impacts is through the use of models of the whole system.

This document was prepared to provide a comprehensive picture of the South Platte water system so that its present complexity is understood. From this understanding the issues, present and future, are more easily discerned.

A need is for adjustments to practices developed under the appropriation doctrine. An organizational vehicle is needed -- a Federation of South Platte Water Users -- to permit voluntary cooperation in extending the utility of South Platte water.

This report is a working paper from a two-year project by a group of CWRRI researchers, the "CWRRI South Platte team," who have worked on South Platte problems over a twenty year period. Putting some of this research into practice to benefit water users was the theme of the project. The researchers were: Norman A. Evans and William Raley (CWRRI) , Henry Caulfield (CSU Political Science) , Robert Young (CSU Agricultural and Natural Resource Economics), Neil Grigg, David Hendricks, John Labadie and Hubert Morel-Seytoux (CSU Civil Engineering), David McWhorter (CSU Agricultural and Chemical Engineering), J. Ernest Flack (CU Civil Engineering) and J. Gordon Milliken (corresponding DRI member). Text for this working paper was generated primarily by David Hendricks and Norman Evans.

The South Platte Team produced a project final report entitled "Voluntary Basinwide Water Management in the South Platte Basin," CWRRI Completion Report No. 133.

The text in this working paper was developed for an educational report that CWRRI planned to issue as a produce of the South Platte Team work. However, with the complexity of the South Platte Issues, including the Two Forks EIS and downstream environmental concerns, the issues have changed too rapidly; thus the educational report was not completed as planned. In spite of this change in plans, CWRRI felt that the explanations in this draft report are worthwhile for distribution to researchers and managers seeking information about the river. In particular, the South Platte Water Management Committee may find the ideas useful as they undertake their study.

Disclaimer: The data in this report were assembled for educational and illustrative purposes. While they are believed to be generally accurate, they should be checked before using for planning or management purposes. The text was generated in 1983-4 and does not reflect recent Two Forks developments.

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1.1 Beginnings. The South Platte water system is a product of the enterprises of the early settlers. They came in 1858 with the Colorado gold rush, and started the irrigated agriculture which we know today. The first diversion of water was from Clear Creek about mid 1859 to irrigate two acres of land. The first water right has a date of appropriation October 1, 1859 from Boulder Creek, via the Lower Boulder Ditch. By December 31, 1859 the first ten water rights were established, diverting water from Boulder Creek, Clear Creek, and Bear Creek. In 1860 diversions were made from the St. Vrain Creek and the Cache La Poudre River, and from the Big Thompson River in 1861. In 1875 irrigation development had progressed so far that dry ditches were experienced and a second stage of development was initiated in construction of an extensive system of off-stream storage reservoirs. By 1889 430,000 acres of land were under irrigation, and by 1909 the irrigated acreage was 1,140,000 acres.

1.2 Water Rights. The 1876 Colorado Constitution codified the appropriation doctrine, a virtual way of life in the west, and the idea of beneficial use. It sets forth the primacy of water as an economic necessity to agriculture, with priority to domestic use during times of shortage. The body of case law based upon this constitutional foundation defines the water rights system.

> "The right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied. Priority of apapropriation shall give the better right as between those using the water for the same purpose; but when the waters of any natural stream are not sufficient for the service of all those desiring the use of the same, those using the water for domestic purposes shall have the preference over those claiming for any other purpose, and those using the water for agricultural purposes shall have preference over those using the same for manufacturing purposes."

1.3 Development Evolution. Under the appropriation doctrine the South Platte water system has undergone continuous evolution in complexity. Five stages are suggested here. The first four are characterized by procurement of different types of new supplies. By the fifth stage the system has become complex and is marked by reallocation vis a vis development of new supplies. Cooperative management using information technology could help in this stage by showing opportunities, not easily discernable by conventional means, to resolve conflicts, and to obtain further utility from the fixed supply.

Stage	Characteristic	Period	Infrastructure	Management Initiatives
I	Few demands	1858	Canals	Individuals
II	Low summer flows are allocated	1860-1870	Diversion works and canals	Mutual irrigation companies
III	Annual flows are allocated	1870-1900	Off-stream storage	Mutual irrigation companies
IV	Imported water is obtained, flood flows are allocated	1890-2000	Tunnels, canals, large projects	Irrigation companies, USBR Big Thompson project, Denver Moffat and Roberts Tunnels
V	Reallocations	1970-2020	Information technology	Voluntary cooperative decision making

1.4 Present System. The present South Platte water system has evolved under thousands of individual initiatives for water development. The security afforded by the water right has been the basis. Each enterprise is autonomous, related to the others only insofar as they require the return flows of others. The appropriation doctrine, "first in time, first in right," provides for the use of the water supply until none remains, and then to search for opportunities not evident to others or requiring more investment capital. The outcome, only 100 years after the first diversion, is a complex water system, built incrementally, project by project. The "management" has always been "passive", not "active", and is driven by each water right holder using water by priority.

1.5 South Platte Issues. The water issues of today in the South Platte are those arising from full use of the water resources, coupled with continuing growth and economic development. Some of those issues include: (1) capturing and storing flows leaving the state in excess of compact requirements, (2) how to use the alluvial aquifer of the South Platte to benefit farmers needing it and without harming senior appropriators, (3) how to reuse water to the maximum extent, (4) dealing with urbanization and the new equilibriums caused in reconfigurations of water use and in displacements of agriculture, (5) maintenance of water quality and ecological protection, (6) protection of ground water quality from hazardous wastes, oil field brines and passive discharges, (7) developing a policy for meeting drought.

1.6 Voluntary Cooperation. Some have asserted that, as with Adam Smith's theory of capitalism, the "unseen hand" of the water rights system has guided the individuals toward a collective optimality, and that all that is needed are large storage projects to reduce the loss of entitlement water that leaves the basin. This assertion is true to an extent; the system may approach optimality through the concern of each user toward improving his own individual welfare with respect to water use. For example, the average annual water supply of native stream runoff is about 1.4 million acre-feet, with about 0.3 million acre-feet of additional imported water. Total water withdrawal is about 4.5 million acre-feet annually, indicating extensive recycling. This extensive use and reuse may have reached a limit, however, on what can be done without voluntary cooperation. A forum for voluntary cooperation is needed to provide knowledge about what opportunities are possible to make further improvements, and to negotiate new arrangements deemed desirable by the parties involved. A technical difficulty with providing information is that the system is highly complex and opportunities are difficult to sort out. New computer-based modeling technology, developed at Colorado State University by the Colorado Water Resources Research Institute, can sort out the behavior of the system and provide the information needed.

1.7 Information Technology. The South Platte water system is fully developed and is complex. The framework for decision making will be in the future, as it has been historically, those individuals and organizations holding the 6,200 water rights decrees. The "unseen hand" which guides the decision making in this context must be founded upon information derived from means more sophisticated than during the evolving years. Computer-based technologies are needed to provide the information. Two models which can help are CONSIM and SAMSON. CONSIM simulates the surface water system. SAMSON simulates all hydrologic processes including ground water using a daily time increment. These models can provide information for decision making within the South Platte water system. Traditional studies over the past twenty years have also given understanding and specific knowledge needed to make informed decisions and are still necessary. These include such research problems as scientific irrigation to green lawns, urban water conservation, defining reuse opportunities, and social impacts of agricultural water purchases. Research goes hand in hand with practice when changed steadily by development pressures.

2. HYDROLOGY

2.1 Water Activities

2.2 Physiography and Precipitation

2.3 Basin Streamflows - Annual Distribution

2.4 Basin Streamflows - Annual Averages

2.5 Imported Water

2.6 Ground Water

2.7 Reservoirs

2.8 Diversions, The Plains South Platte River

2.9 Irrigation

2.10 Lower Reaches

2.11 Population

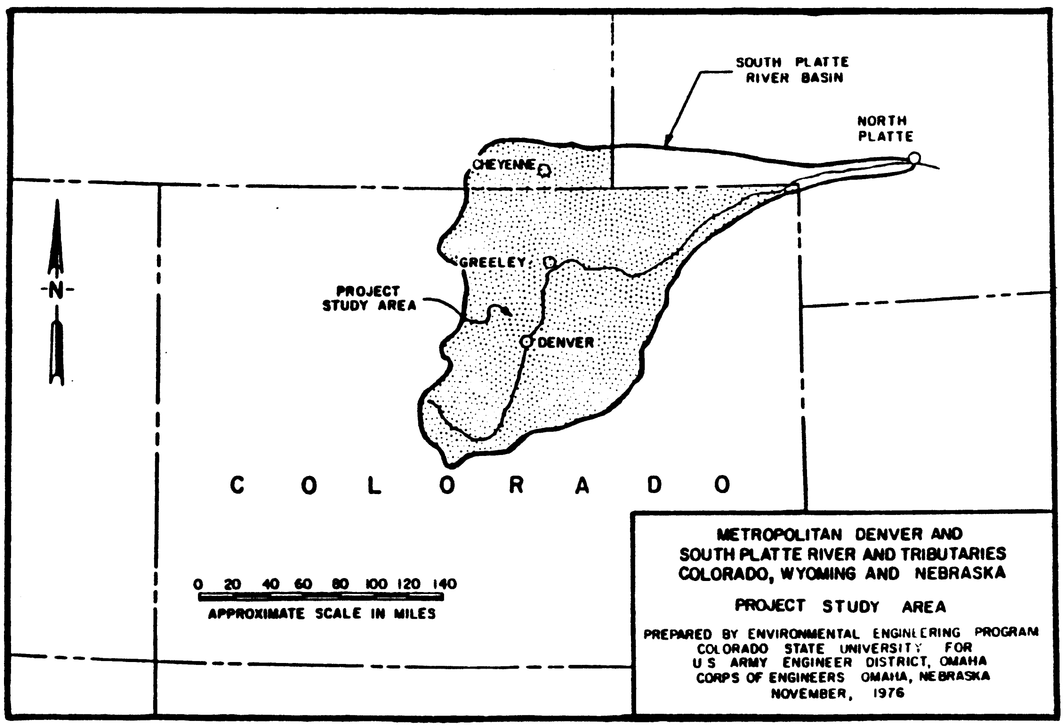
2.12 Water Reuse

2.13 Issues

2.1 Water Activities. The water system of the South Platte River basin is complex. In the plains it is man-dominated by 542 irrigation diversions, and municipal water uses by Denver and five other major metropolitan areas. The irrigation diversions carry water to 1.2 million acres of land. Some 370 reservoirs store 2,200,000 acre-feet of water. About 4,500 direct flow rights and 1,300 storage rights are operative. Each water right is autonomous, but the junior rights are passively dependent upon those senior.

2.2 Physiography. The area of the South Platte River basin is 24,300 square miles, with 19,020 square miles in Colorado. The western portion of the basin is dominated by the front range mountains interspersed with 14,000 feet peaks. The plains begin at about 6,000 feet elevation and slope to the east, having 3,500 feet elevation at Julesburg.

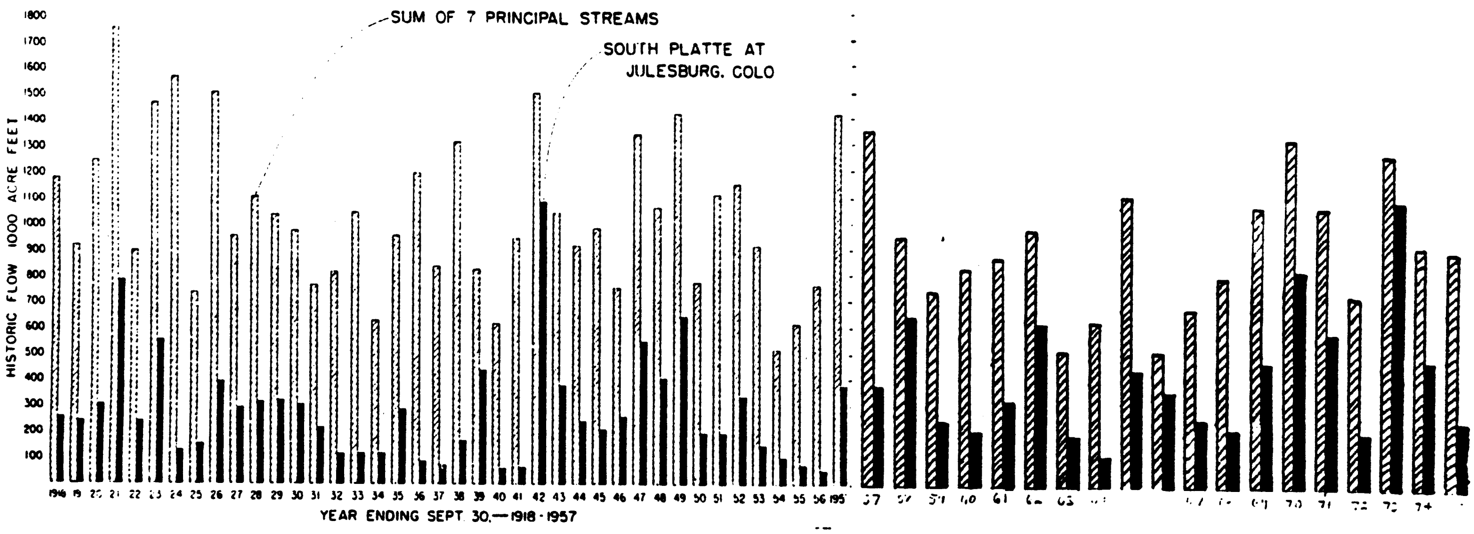
Precipitation. The average October-April-precipitation in the basin varies from 3 inches in the lower plains to 22 inches in the mountains, and is 6 inches and 15 inches for the plains and mountains, respectively, during May-September. Most of the annual water supply for the basin is held in the mountain snowpack, which melts during the spring and becomes the spring runoff.



Map of South Platte basin in Colorado; basin boundaries should be superimposed on satellite map of Colorado

2.3 Basin Streamflows - Annual Distribution. About 70 percent of the annual streamflow of the basin occurs during spring runoff from the winter snowpack. The streams carrying most of this runoff are the South Platte River and its mountain tributaries, e.g. the North Fork, Bear Creek, Clear Creek, Boulder Creek, St. Vrain Creek, the Big Thompson River, and the Cache La Poudre River. During the rest of the year flows of the mountain streams are sustained by continued snowmelt from higher elevations, and ground water. The annual hydrographs shown are typical and indicate the wide variations which can be expected between drought years and wet years. The hydrographs illustrate the low carrying capacity of irrigated acreage when using only summer flows as in the period 1860-1870. When off-stream storage was developed during the period 1870-1900 the winter and spring flows could be captured, a large expansion of irrigated acreage became possible. Since the peak flows exceed the aggregate flow capacity of the diversions to off-stream storage it is inevitable that peak flows will be lost. Even with in-stream storage the runoff volume during some years will exceed the volume of storage.

FLOWS OF SOUTH PLATTE RIVER



The bar graphs compare native runoff from seven major South Platte tributary streams (the South Platte River, Clear Creek, S. Boulder Creek, Boulder Creek. St. Vrain Creek, the Big Thompson River, and the Cache La Poudre River) with basin outflow. The wide variations from year to year is readily evident. Also it is clear that consumptive use of the native flows is very high, nominally 70 to 80 percent.

2.4 Basin Streamflow - Annual Averages. The average annual surface water runoff from the South Platte River and its tributaries is about 1.2 million acre-feet. This is exclusive of imports. But it varies widely from year to year. During the 1953-56 drought the runoff averaged 842,000 acre-feet per year, while it was about 1.9 million acre-feet in 1970. The annual flows leaving the basin at Julesburg vary widely also, ranging from 50,000 acre-feet to over one million acre-feet, and averaging about 350,000 acre-feet.

2.5 Imported Water. Some 20 ditches and tunnels transport 370,000 acre-feet of water from the North Platte, the Colorado, and the Arkansas River basins to the South Platte River system. The Big Thompson Project accounts for 227,000 acre-feet; the Windy Gap Project will add another 50,000 acre-feet. Projects for which conditional decrees have been granted would add about 130,000 acre-feet.

2.6 Ground Water. The deep ground water aquifers of the Denver basin have not been exploited extensively. The volume of storage in these aquifers is estimated as 250 to 300 million acre-feet, with 40,000 to 100,000 acrefeet/year recharge.

The alluvial aquifer from Denver to Nebraska has about 25 million acre-feet of storage. About 1.6 million acre-feet of water was pumped from it in 1970. The aquifer is recharged from irrigation and canal seepage, and so it is a part of the surface water supply. It is valuable as a storage reservoir.

Both of these reservoirs can have a role in a drought strategy. The development of the Denver basin aquifers should be limited for such reason.

2.7 Reservoirs. There are some 370 reservoirs in the basin having storage capacities in excess of 500 acre-feet. The collective storage volume is about 2.2 million acre-feet, secured by 1,200 decreed storage rights. Horsetooth Reservoir and Carter Lake have a combined storage capacity of 263,000 acre-feet and are a part of the Big Thompson Project.

2.8 Diversions. During the 1970 water year the total surface water diversions were nearly 3 million acre-feet. Irrigation water use was over 2.5 million acre-feet, municipal water use was 300,000 acre-feet, and industrial water use was 110,000 acre-feet. Some 542 ditches diverted water for irrigation.

The Plains South Platte River. After leaving the mountain canyons, and even within the canyons, the South Platte River and its tributaries are subject to sequences of ditch diversions by irrigation companies. The ditches lose water to the alluvial aquifer by seepage, and the aquifer gains water also from deep percolation from irrigation. The diversions cause the flow in the river to be depleted to zero along many reaches, until it is built up again due to replenishment from the aquifer, and then another diversion occurs. The river flow is discontinuous. The streams are the location for virtually all water activities. The hydrology of the lower streams is thus man-dominated, since the diversions and storage control the occurrence of water in the system.

2.9 Irrigation. Irrigated acreage in the South Platte River basin totals about 1.3 million acres, distributed mostly adjacent to tributary streams, e.g., Boulder Creek, St. Vrain Creek, Big Thompson River, Cache La Poudre River.

2.10 Lower Reaches. About 500,000 acres of land are irrigated along the South Platte River between Henderson and Julesburg. Some 57 ditches divert about 950,000 acre-feet of water in this reach. These lands are irrigated by direct flow rights from canals, by storage from reservoirs, and by pumping from alluvial aquifers. The total storage capacity of off-stream reservoirs is 274,000 acre-feet. Virtually all water diverted by canals and to off-stream storage during the period July to April is comprised of return flows from the upper irrigated lands and then sequential return flows from the lower lands.

2.11 Population. The 1970 basin population was 1.5 million, up from 1.2 million in 1960. In 1980 it was nearly 2 million. Projections indicate the population could reach 3 million by the year 2000. The nominal per capita water use was 220 gal/person/day in 1970, but was only 165 for Boulder. The 220 gpcd figure is about 0.25 acre-feet/person/year. If the drought water supply is assumed to be 600,000 acre-feet streamflow, and 200,000 acre-feet imported water, then the population "carrying capacity" of the basin, based upon water, is 3.2 million persons. With water conservation this could be 4.3 million.

2.12 Water Reuse. That water reuse is practiced is evident from the [water diversions/water supply] ratio. Adding surface water diversions of 3.0

million acre-feet to the 1.6 million acre-feet of pumping from the alluvial aquifer gives 4.6 million acre-feet of water withdrawal. The native water supply averages 1.2 million acre-feet of runoff and 370,000 acre-feet of imported water. Thus the reuse ratio is 4.6/1.57 or about 3.0. This indicates a highly efficient system is already in operation. But if irrigated agriculture is to remain in place, without being extensively disrupted, cities and water districts must enter into formal reuse agreements such that any purchased water rights also provide for right to return flows and for makeup water.

2.13 Issues. Some of the salient features of the South Platte water system discussed in the foregoing sections are:

(1) Modeling for Information- Thousands -of water use actions occur during any given month. Subsequent passive hydrologic processes determine the next occurrence of the water withdrawn. To understand how this system works and new opportunities, models are needed to depict it and to provide information.

(2) Voluntary Cooperation.- Continued population growth and industrial development is inevitable. Agricultural water use is threatened as agricultural land is purchased and as cities and water districts purchase agricultural water rights. Voluntary cooperation is needed if the agricultural economic base is to be preserved.

(3) Storage of Flood Flows. Annual water production varies between 600,000 acre-feet and 2,000,000 acre-feet. Drought is a statistical certainty. To reduce the adverse effects of drought, storage is needed to draw upon during drought. Deep aquifers are possible for this purpose. The water rights system ought to recognize this need and provide for a "drought water right." The proposed Narrows Reservoir, if built, could also provide a "drought pool" with associated drought water rights.

By the same token the years of high runoff exceed the capacity of the system to divert and store water and even to use it. Because these flows occur only infrequently, this water could have strategic utility if stored for drought.

(4) Storage of Entitlements. The South Platte system utilizes its water to a remarkable extent. Average annual basin outflow is only about

300,000 acre-feet compared with 1.4 to 1.7 acre-feet of native flows and imported water. The Colorado-Nebraska Compact requirement amounts to about 48,000 acre-feet. The proposed Narrows Reservoir could capture some of this water. But there is a limit to the new water uses, since there must be enough outflow to maintain the basin salt balance.

(5) Conjunctive Use. The South Platte aquifer provides 25,000,000 acre-feet of storage. The amount of "active" storage and how this active storage can be used conjunctively with surface flows needs can be defined by the SAMSON model.

(6) Water Reuse. A "passive" water reuse is practiced extensively in the South Platte and has been since early development. The total water diversions (about 4.5 million acre-feet) exceed the annual water supply (about 1.5 million acre-feet) by a factor of 3 to 1. Still as urbanzation occurs a "planned sequential" water reuse must be accomplished through cooperation between cities and water districts and irrigation water districts.

(7) Water Quality. The problems of BOD and disease have been arrested through the water quality control programs since the mid-1960's. Hazardous wastes due to spills and passive releases are a remaining problem. Salt accumulation on the lower irrigated lands is a potential hazard that should be investigated further. If not arrested the duration of irrigated agriculture on some lands could be limited.

3. WATER RIGHTS INSTITUTIONS

3.1 Institutions

3.2 Appropriation Doctrine

3.3 South Platte Compact

3.4 Administration

3.5 Adjudication

3.6 Organizations

3.7 Changes Needed

3.1 Institutions. In the western United States the Doctrine of Prior Appropriation has been institutionalized. This means that it is a way of life, that its implementation is expected and that the mechanisms for doing this are established. Three categories of institutionalization are (1) informal, which includes norms and cultural values, (2) contractual arrangements, and (3) formal, which includes laws, administration and adjudication, and organizations. The appropriation doctrine incorporates all. The particular institutionalization of the appropriation doctrine provides the management framework for its implementation. The elements of it are described in these pages.

3.2 Appropriation Doctrine. Water law in Colorado is founded upon the Doctrine of Prior Appropriation. It has four major elements:

(1) water in its natural course is public property not subject to private ownership;

(2) a vested right to the use of water, a "usufructuary" right, may be acquired by appropriation for beneficial use;

(3) the first person to use the water is first in right; and

(4) beneficial use is the basis, the measure, and the limit of the right.

The Colorado Constitution, Section 6, Article XVI, is the cornerstone of the Appropriation Doctrine in Colorado. Over the years it has been embellished by statute, court rulings, administrative procedures and practice.

Some of the supplemental principles are:

(1) "Beneficial use is the use of that amount of water that is reasonable and appropriate under reasonably efficient practices without waste for the purpose for which the appropriation is lawfully made." (CRS 37-92- 103). The amount of water diverted and accepted as a right has generally been limited to historic use.

(2) Two kinds of rights are: (1) direct flow, measured by flow over a specified time, and (2) storage, measured by volume.

(3) Beneficial uses, in addition to domestic, agricultural, and manufacturing uses, include impoundment for recreation, including fish and wildlife, and appropriations for minimum flows for natural streams and levels of lakes as required to preserve the natural environment.

(4) Priorities among beneficial uses does not affect the rule of "first in

time is first in right." However, a preferred water use (for example, domestic use) can take water from a less-preferred use (for example, agriculture), but only with payment of just compensation.

(5) Water rights are dated to the time when the first clear appropriation step was taken, assuming that the water project then contemplated was then diligently pursued. A "conditional decree" is the form of the right during the development period. After the water right is "perfected" it may become an "absolute decree."

(6) Water rights may be sold or exchanged, but transfers of water may not damage an existing right.

(7) In addition to the natural flow of water in a stream and to developed water (i.e., stored water), water to which rights may be claimed are salvaged waters, foreign waters (transbasin diversions), waste and seepage waters, diffused surface waters, and municipal reuse waters. Each has its own legal characteristics and associated rights.

(8) Groundwater is also subject to water rights. With respect to appropriation of non-tributary or designated groundwaters (i.e., those subsurface waters which are not hydraulically connected to natural streams) the doctrine of prior appropriation governs, but is modified to permit full economic development of groundwater resources.

(9) With respect to appropriation of tributary groundwaters (i.e., those subsurface waters that are hydraulically connected to natural streams), the doctrine of prior appropriation applies. Such rights are to be integrated with surface rights in such a way as to maximize the beneficial use of all waters of the state.

(10) Augmentation plans are defined by law as a "detailed program to increase the supply of water available for beneficial use ... by development of new or alternative means or points of diversions, by pooling water resources, by water exchange projects, by providing substitute supplies. of water, by the development of new supplies of water or by any other appropriate means" (C.R.S. 37-92-103).

Any entreprenurial activity proposing a new development or a change in the way water is used must comply with these rules applied within an already complex South Platte water system.

3.3 South Platte Compact. The South Platte Compact between Colorado and Nebraska was signed in 1923 and governs the interstate relationship with Nebraska. It provides that: (1) between October 15 and April 1, Colorado has full use of all flow within its boundaries, except for one canal beginning near Ovid, and flowing into Nebraska; (2) between April 1 and October 15, Colorado will divert water with a priority after June 14, 1897 only if the mean flow at the Interstate Station is greater than 120 cfs; (3) Nebraska is not entitled to receive any water beyond that necessary to supply entitled beneficial uses in Nebraska. The obligated flow to Nebraska amounts to 47,127 acre-feet per year. Historically the annual volume of flow always has exceeded the Nebraska entitlement, averaging over 300,000 acre-feet per year. It has been an objective of water interests in Colorado to capture more of the Colorado entitlement. The Narrows Reservoir is one means proposed.

3.4 Administration. The Colorado State Engineer is vested with the responsibility and the authority to administer the water laws. This includes the Colorado Constitution, statutes of the Colorado Legislature, and rulings of the water courts. The task is decentralized to eight Division Engineers. The Division 1 Engineer, with office in Greeley administers water rights within the South Platte River basin. The day to day operations are overseen by water commissioners. If a "call" is placed upon the river by a senior appropriator the most junior appropriators must yield their water to the senior. The water master implements the system. But in addition, the water master may act as a broker, going above and beyond official duties, to find areas of cooperation which will minimize conflicts. Such activities may or may not have legal sanction, but provide the ways to make the system work. The role of the water master is thus critical to a well functioning water system.

3.5 Adjudication. Any application for a water right, to have any worth, should be adjudicated. The application is filled with the State Engineer. This is done prior to any activity to develop the right. Any party may challenge the application in court on the basis that his right may be injured. If the applicant's case stands up in court he is given a "conditional decree."

When the water right is exercised then an absolute decree is granted. The priority data of the water right is the date of application. During the period of the conditional decree, the applicant must demonstrate "due diligence" in perfecting the right.

3.6 Organizations. Water management organizations include water districts, municipalities, private ditch companies, public irrigation districts, water conservancy districts, groundwater management districts, water users associations, etc. Around Denver there are 209 water management organizations of various sorts. The mutual irrigation companies number about 175, and there are 8 irrigation districts, and an untold number of public water supply districts serving suburban and rural land areas with drinking water. The natures of these various organizations are summarized in the following.

Private Incorporated Companies. Private ditch companies own and operate canals and reservoirs and divert water from natural water courses to irrigators and private entities. These companies are now largely incorporated, private, non-profit mutual companies. Examples are the North Poudre Irrigation Company and Water Supply and Storage Company.

Irrigation Districts. Public irrigation districts were authorized in 1905 (Colorado Revised Statutes, 37-41) to enable the majority of landowners within a county to form a district to provide irrigation and drainage works and acquire water rights, etc. An example is the Bijou Irrigation District.

Water Conservancy Districts. Water conservancy districts are of two types. The first type, authorized by law (Colorado Revised Statutes, 37-2), may be formed to prevent loss of life and property by floods and have general authority for development, utilization, and disposal of water for agricultural, municipal, and industrial uses. But they do not regulate or administer water rights or construct facilities to develop and manage water supplies.

The second type of conservancy district authorized by statute (Colorado Revised Statutes, 37-45) has broad powers to own water rights and to plan, finance, construct, operate, and maintain water resources development projects on a multi-county basis itself or via contract with the federal government, for the benefit of its shareholders (i.e., ditch companies, water district, municipalities, etc.). An example is the Northern Colorado Water Conservancy District.

Groundwater Management Districts. Groundwater management districts were authorized in 1965 (Colorado Revised Statutes, 37-90). One can be formed when the State Groundwater Commission, an entity within the State Water Resources Division, establishes a designated groundwater basin (Colorado Revised Statutes, 37-90-106). These districts are for the management of non-tributary groundwater and have the authority to regulate the use, control, and conservation of the district's groundwater subject to water rights and statutory constraints. No groundwater management districts currently exist in the South Platte River Basin. However, the Denver bedrock aquifer has the potential to become a designated groundwater basin.

Groundwater Associations. A groundwater association is a private non-profit mutual corporation formed to develop and operate augmentation plans or benefits to its members. Members are well-owners. The Groundwater Association of the South Platte, with headquarters in Fort Morgan, is now the only association of this type in Colorado. The Central South Platte Conservancy District has a subdistrict which performs similar functions.

Water Users Association. Water Users Associations have been established in part of the South Platte River Basin. These associations, composed of representatives of irrigation districts, mutual water companies, conservancy districts, municipalities, domestic water districts, have been formed for the purpose of sharing information, concerting members views in testimony upon proposed state legislation, and otherwise encouraging cooperation between water interests in tributary basins. An example is the Cache La Poudre Water Users Association.

Municipal Water Districts. Municipal Domestic Water Districts are authorized to own water rights, develop water supplies, and provide water treatment and distribution services. Similar services within the basin can be provided by smaller private cooperative or profit-making water utilities.

River Basin Authorities. River Basin Authorities have been authorized by statute (Colorado Revised Statutes 37-93) for three segments of the South Platte as separate authorities. These authorities, which are to be governed by boards of directors appointed by county commissioners, would have the power to develop ground and surface water facilities, finance such facilities by taxation and issuance of bonds, and establish standards for the proper utilization of water. Although this legislative authority has existed since 1963, no such authorities have been established.

3.7 Changes Needed. As the water system of the South Platte changes, and as information is developed, adjustments in the water rights system could provide opportunities for holders of water rights to benefit. The objective of any changes should be to provide additional flexibility in the system to take advantage of opportunities. A few areas pertain to drought conditions, reuse exchange and conversion of direct flow water rights to volumetric rights. These ideas are outlined in the following.

1. Drought condition.
   - a) Criteria for a declared drought ought to be developed.
   - b) During a declared drought all water rights holders should be able to draw on surface water sources or groundwater sources (H.C. should check this), and there should be a limited right to groundwater storage reserved for drought. The drought management model of the NCWCD might be appropriate for other parts of the South Platte.
   - c) How water rights are exercised would be modified for the period of a declared drought.
2. Flexibility. Junior appropriators should be able to elect to pay senior appropriators if an agreement is made between the two, and if there is advantage to both.
3. Water Exchanges. Urban-agricultural water reuse exchanges should be encouraged. This is especially important as urbanization encroaches on agricultural lands and water rights are purchased.

4. Volumetric Water Rights. Those who hold direct flow rights who wish to convert to volumetric water rights could be given incentive by being able to sell the excess.

4. CURRENT WATER MANAGEMENT

4.1 The Present System

4.2 Basin Water System

4.3 Exchanges of Water

4.4 Use of Imported Water

4.5 Conjunctive Surface-Groundwater Management

4.6 Water Markets

4.7 River Administration

4.1 The Present System. Present management and water infrastructure has evolved incrementally since 1858 under the appropriation doctrine. Each water right decreed under this doctrine is autonomous to the extent that other water rights holders are not injured by any actions on the part of any one. An example would be changing the point of diversion. To stand legally this action must be adjudicated, at which time other parties, claiming injury, may protest.

What has evolved is a complex system of mutually interdependent autonomous projects. The project of the most senior water right holder is most independent, and probably is the simplest and least expensive. A simple diversion structure and canal may comprise the project. All other water rights holders must defer to this senior right. The most junior water right, on the other hand, is dependent upon the established configuration of water uses of all water rights holders more senior. Any change within this system may affect the availability of water to this most junior water right. At the same time, the project of this junior water right holder is likely to be the most conplex, and the most expensive. It is likely also that the most junior water right holder has the dichotomous of being both desirous of having additional water or water more reliably available, and perhaps will not want to risk reducing the water already reliably available, as any change in the system could do.

But within this framework of the appropriation doctrine, considerable flexibility is possible. Every junior water right holder can enter into agreements for exchanges, leases of water, sales, etc. to improve the utility of the water right.

4.2 Basin Water System. The native flow of the South Platte River system is about 1.5 million acre-feet annually, with about 426,000 acre-feet imported water from 34 diversion structures. During any given day of the year this water is diverted according to seniority of priority date by those water rights holders wishing to exercise their water right. To exercise a water right the water right holder has constructed infrastructure facilities. Irrigation companies may possess diversion dams, canals, off-stream storage reservoirs and ditches while municipal water utilities or districts may build diversions, storage reservoirs, water treatment plants and wastewater treatment plants. Diversion structures number about 600 (check) and there are about 150 (check) off-stream storage reservoirs to irrigate about 1.3 million irrigated acres of which 793,000 acres are irrigated on a regular basis. Each municipal water utility must have its own water right and its own facilities. It is common practice also for some of the larger utilities to sell water to the smaller ones, thus acting as a wholesaler. The Northern Colorado Water Conservancy District is a wholesaler for the imported water from the Colorado River developed by the USBR Colorado Big Thompson Project.

Total diversions within the basin for irrigation and municipal and industrial uses are about 4.5 million acre-feet, which includes ground water pumping from the alluvial aquifer. Return flows from these diversions sustain flows in the downstream direction, all the way to Julesburg, thus permitting a sequential reuse. Each use consumptively uses a portion of the water applied and the total basin-wide consumptive use is about 1.5 million acre-feet, the same as the native water supply, with the rest flowing across the state line to Nebraska.

In the lower part of the river, from Henderson to the state line, the alluvial aquifer, which stores some 25 million acre-feet of water has become increasingly important to the junior appropriators using this water. Its development began about 1900 to supplement their less reliable water rights. The pumping withdrawals were 420,000 acre-feet by 3000 irrigation wells and 1 million acre-feet in 1980 by 5000 wells.

4.3 Exchanges of Water. Operation of the South Platte water system is not so straight forward as suggested in the foregoing descriptions. In theory, the water is diverted according to priority until, taking into account return flows, the river is dry. But those junior appropriators, who could be without water, have used initiative to find ways to have water, when otherwise they would go without, and still maintain the viability of the priority system, and thus squeezing additional utility from the basic water supply. One such way includes exchanges.

If a senior appropriator is downstream and the junior appropriator is upstream, the junior may satisfy the senior by providing storage, collected during the time of year when the senior appropriators are not diverting water. By agreement then, the junior diverts water upstream that would otherwise have to pass downstream to the senior. The senior meets his needs by drawing upon the junior's stored water, located near the senior. With this arrangement, the junior is better off and the senior is no worse off.

4.4 Reuse of Imported Water. In 1969 the Colorado water law was modified to permit reuse of new imported water. Fort Collins (FC) provides an example of how this water can be reused.

The city imports 4,000 acre-feet annually, which it stores in Joe Wright Reservoir (and is 3,055 acre-feet after losses). Also Water Supply and Storage Company (WSS) imports about 4,000 acre-feet annually, which it stores in Long Draw_ Reservoir. To reuse this water to the maximum extent FC and WSS worked out an exchange plan which required the cooperation of a third party, the North Poudre Irrigation Company (NP), who owns 7,636 acre-feet of water in Horsetooth Reservoir.

The plan involves FC and WSS sending their water from Joe Wright (3,055 AF) and Long Draw (4,581 AF) to NP (total 7,636 AF). Then FC makes up the 4,581 AF to WSS from its Horsetooth water. At this time FC has 7,636 AF of reusable foreign water credits in Horsetooth Reservoir. It has gained a net of 4,581 AF of reusable water which was the WSS Long Draw water, transferred to Horsetooth Reservoir for Fort Collins.

In addition, the nearby Rawhide project (PRPA) owns 4,200 AF from the Windy Gap Project. Instead of this water being delivered to Rawhide directly, it will be delivered to Horsetooth and the FC account. The other 7,636 AF of reusable water from the FC account in Horsetooth is used by FC, with 3,436 AF losses, leaving 4,200 AF which is available for reuse. This is taken by Rawhide. In return, FC has 4,200 AF of reusable water from Windy Gap, that would have gone to Rawhide.

4.5 Conjunctive Use of Surface and Groundwater. Alluvial deposits underlie most of the irrigated lands within the South Platte and are hydraulically connected to the river, which includes tributaries. As irrigation was commenced widely, beginning about 1870, the water table rose below these irrigated lands, establishing an hydraulic gradient toward the streams. By about 1930 equilibrium was established between the rate of irrigation, the levels of the water tables and the return flows. The return flows from the upper streams, the Cache La Poudre, the Big Thompson, the St. Vrain, etc., then sustained flows to the lower reaches of the main stem, from Henderson to the state line, which formerly were almost dry. These return flows became the basis for new water rights in the lower reaches for irrigation of about 800,000 acres between Henderson and the state line. From this irrigation the underlying alluvial aquifer was saturated, return flows were established, and again were the basis for new water rights. In aggregate, return flows within the basin are about 1 million acre-feet by 1930. The alluvial aquifer from Henderson from the state line has an estimated storage of 10-25 million acre-feet.

By 1950 many of the lower basin irrigators began to construct wells drawing supplementary water from the alluvial aquifer. Even though the aquifer was hydraulically connected to the river, most farmers assumed they could withdraw water from beneath their property. By the late 1960's the surface water appropriators wanted the pumping stopped. In recognizing the senior rights of the surface water appropriators, the Water Right Determination and Administration Act of 1969 provided that the well owners could develop an augmentation plan, to be approved by the State Engineer. Under this plan, pumping could continue but those pumping must make up the diminished flows in the river. The amount to be made up is then the question. Although the "Glover formula," by Professor Robert E. Glover, was considered an acceptable methodology, a 5 percent rule was adopted for expediency. Under this rule the streamflow must be augmented by 5 percent of the amount pumped. This is handled by groundwater pumpers associations.

By 1980 about 5,000 wells had been constructed pumping a total volume of 1 million acre-feet annually. A conjunctive use of ground and surface water had evolved over a 50 year period in which more of the total water supply was made available to more users by operating both surface water and ground water as a system.

Additional water use can be obtained from this conjunctive use system. Because the system has so many components and so many interactions, the cause-effect relationships of present and proposed developments cannot be known empirically. The only way to handle such a problem is by means of a model such as SAMSON, which has been developed at CSU over a 15-year period. The model covers the South Platte aquifer from Henderson to Julesburg, and it has a daily time increment. In other words, the model can provide daily management information as well as guidance for long term strategic planning on how to develop conjunctive use to the fullest extent, and how to recharge the aquifer.

4.6 Water Markets. A water right owner can rent excess water or sell the right. The only limitation is that changes associated with the transfer cannot injure other water right owners.

Prior to the 1970's there were few sales of water rights in the South Platte basin separate from the land. Such sales were conducted between two parties dealing directly with one another. During the 1970's,- however, about four brokerages emerged designed specifically for buying and selling of water rights. While water rights often are recorded in the land deed this is not required, and there is no required public record of water rights owners.

The market price of a water right depends upon its priority, which determines whether the right will yield much water and whether court adjudication is necessary. The CBT water can be transferred without court action and it has high reliability and flexibility of use, and therefore it has highest market value. In 1962 CBT water sold for $40 per acre-foot and in 1982 it was $2500, while direct flow rights sold for $1500. In 1984 the price of CBT water was about $1100. These price changes reflect the fact that a great deal of speculation was involved.

The transfers have been from agriculture to municipal and industrial water users. Generally, municipalities require about 3 to 4 acre-feet of water rights to be transferred to the city per acre of land annexed.

4.7 River Administration. The State Engineer of Colorado administers water law. This includes statutory directives, court decisions, and interstate compacts. Seven Division Engineers responsible to the State Engineer were authorized under the Water Right Determination and Administration Act of 1969.

The Act also provided for a water court system. One water judge is designated by the State Supreme Court for each division. The water judge is a district judge who may hear other cases, but water matters have priority. The water judge appoints referees who are delegated to make administrative decisions.

The day to day administration of the water rights priorities is under a water commissioner, responsible to the Division Engineer. The commissioner makes daily measurements of the water available in the river and from that determines the eligibility of the water rights owners. Allowable diversions may be modified by deferral of water by some users, exchanges between users, use of imported water by particular users, and the use of stored water by particular users. The commissioner enforces the priority system and seeks to maximize the number of users satisfied.

5. MANAGEMENT PROBLEMS AND ISSUES

5.1 Litigation and Conflict

5.2 Growing Urban Demands

5.3 Management Options - Water Conservation

5.4 Management Options - Transbasin Diversions and Reuse

5.5 Management Options - Transfers from Agriculture

5.6 Water Quality

5.7 Water Quality Maintenance

5.8 Deep Aquifers

Introduction. Economic and social activities in the South Platte have not as yet been rate limited by water. But as new demands emerge and as additional problems loom ahead for the South Platte water system this could happen. We do live in a water-short region. One of the major ones is how to handle the growing urban water demands and yet maintain a viable irrigated agriculture. With careful conjunctive planning and perhaps a policy to encourage this, both can be achieved. Related are concerns about maintaining water quality and meeting the new challenges as they emerge, and a policy for utilization of the deep bedrock aquifers in the Denver vicinity. Related to this is development of a strategy for coping with prolonged drought. As the population grows drought will have more serious social and economic consequences. Handling litigation is another issue. The number of cases has increased each year and a large burden of legal defense is placed upon present users to protect their water right. With attention to these emerging issues we can proceed to the next century with confidence that water will serve the greatest social utility.

5.1 Litigation and Conflict. Conflicts in use of the South Platte waters have been increasing over the years as wants for water have exceeded supplies. Senior appropriators must have constant vigilance to protect their water rights from those who seek to modify the system with augmentation plans. Litigation is the mechanism of resolution of the conflicts generated. Some of this could be alleviated by voluntary cooperation to provide ways to identify exchanges between water users and to more readily assess the impacts of a proposed change on the senior appropriators.

5.2 Growing Urban Demands. The South Platte Basin has most of the population of Colorado. Also it has the most productive agricultural lands. About 84 percent of the water supply of the basin is used by agriculture.

More water will be used by the urban sector over the next decades as population increases, while agricultural use will not change. Cooperation between urban and agricultural users is essential if the agricultural economic base is to be maintained. A policy is needed to encourage this.

The basin population will increase 40 to 50 percent by the year 2000 to 2,869,000, of which 770,000 will be in Boulder, Longmont, Loveland, Greeley, and Fort Collins, with most of the remainder in the Denver metropolitan area.

5.3 Management Options - Water Conservation. The impacts of increasing water demands of urban growth on agriculture can be reduced by several approaches. One is to cause higher efficiencies by water conservation programs, which would include: universal metering, increasing price structures, water saving plumbing fixtures, and limited landscaping for new homes. Reductions in per capita water demand from 215 gallons per capita per day (gpcd) to perhaps 165 to 185 gpcd could be achieved. The rate at which these programs are implemented is dependent upon the unique situation of each utility and its ownership of water rights. If a city is growing rapidly and its supplies are marginal already, then these options will be implemented differently than for a city having ample supplies.

Water conservation, while a noble idea to many, also poses risk to the municipality practicing it. The increased risk of catastrophic shortage during drought should be considered. For example, a recent study comparing drought reserve requirements of a conserving and nonconserving city showed that the former required about 40 percent more reserve storage than the latter.

5.4 Management Options - Transbasin Diversions and Reuse. Some of the supply to meet new urban water demands will come from transbasin diversions. The Windy Gap project will soon (date) be importing nearly 40,000 acre-feet per year from the Colorado River through Colorado-Big Thompson Project facilities. The Denver Metropolitan area study is assessing the importation of additional west slope water as a part of its area-wide plan. The Denver Water Department has conditional decrees for additional water from several west slope rivers and proposed projects to perfect those rights.

With increased imported water some additional return flows will be available. But the amount will be limited by the reuse options exercised as the new imported water has this right attached. This is true for the Windy Gap water, and the Blue River Decree requires Denver to reuse its imported water.

5.5 Management Options - Transfers from Agriculture. In 1984 only about 16 percent of the virgin water supply was used by the municipal and industrial sectors. But the trend is toward purchase of shares of CBT water and stock in mutual irrigation companies by municipalities, and industries. Private investors also own shares speculating that prices will increase. The CBT water is a high grade investment because of the reliability factor. During droughts the shareholders have had deliveries of about 80 percent of the declared share water.

For direct flow rights, the more senior the priority, the higher is the value. These rights are purchased mostly through stock in irrigation companies.

Theoretically the use of water by the urban sector then agriculture is logical. The consumptive use by urban use is only about 30 percent of the water withdrawn. Thus 70 percent is still available for agriculture. Further, agriculture can use the treated wastewater. This is sequential reuse. If done as a planned sequential reuse project both sectors may benefit. But if the municipality, an industry, or an investor purchase the shares to simply transfer the shares of water, the viability of the irrigated agriculture is seriously threatened. There are examples of deterioration of ditch systems caused by this practice.

The most desirable scenario would be for agriculture to be maintained intact without urbanization of the producing lands with an agreement to use treated sewage effluents from the municipality using the water in planned sequential reuse. But if agriculture is displaced additional water will be available to the lower South Platte because the return flows from cities is higher than from agriculture.

5.6 Water Quality. In 1950 virtually all wastes - from municipalities and from industries were discharged from outfall sewers directly into the water courses. Over the decades of the fifties, sixties, and seventies, cleanup began, with concerted effort during the 1970's. Because of this steady program the discharge of organic wastes is not a major problem that it was until just a few years ago. The municipalities have, for the most part, efficient wastewater treatment and industries too have complied. Thus efforts have shifted to other problem areas.

Ammonia discharges by municipalities are a current issue, concerning the toxic effects on fishes. Nitrification, the conversion of ammonia to nitrates, is expensive. The question in the plains streams is whether the slight ecological benefits are worth the cost. In the mountains, however, where the streams have very high values in their pristine state, highly stringent stream standards and effluent standards have logic.

A current problem includes groundwater contamination. This still has not been regulated adequately and consequently valuable water supplies are jeopardized irreversibly. Examples include nitrate contamination of drinking water aquifers from mountain subdivisions, toxic wastes from the Lowry landfill and from the Rocky Mountain Arsenal, and midnight dumping of oil field brines. The need for legislation to protect groundwater has been recognized since the 1950's (the arsenal problem has been discussed since at least 1961), but there has been no stimulus to precipitate it.

Salt balance in the lower reaches of the South Platte River is a problem that should be investigated and dealt with before the productivity of lands is reduced severely. Water quality of storm water runoff may require further investigation. It makes little sense, however, to attempt to control so-called nonpoint pollution from agriculture. Unless existing or potential uses of the water are impaired there is no basis for concern. Provision of drinking water of adequate quality is a major problem of many communities along the South Platte River. Brighton and Fort Lupton, for example, use the alluvial aquifer, which is not suitable as a source of drinking water.

5.7 Water Quality Maintenance. The key issues at this time relate to maintenance of water quality rather than extensive restoration. The major goals of the 1972 Clean Water Act have been achieved and the present challenge is to maintain vigilence and handle selective problems. Some of the principal ones are enumerated.

1. The drinking water problem in the Fort Lupton-Brighton area is acute with respect to TDS and nitrate levels. This same problem may exist for all communities from Brighton to Julesburg which use the shallow aquifer as a source of drinking water.

2. The available information on water quality exceeds the capacity to interpret and utilize it. The problem is not the amount of information. Much data can be interpreted and assimilated easily if done in accordance with a plan. Most, however, has been collected on an ad-hoc basis and one set of data is not consistent with another.

3. Oil field brine disposal in Weld County is a major problem. Its regulation under the Oil and Gas Commission should be evaluated.

4. Protection of mountain streams, which are under strong development pressures, should be evaluated.

5. Water quality data management needs to be evaluated.

6. Salinity management alternatives for the lower South Platte should be studied now.

7. Exchanges based on reuse will play an increasingly more prominent role in the future.

8. Municipal drinking water topics requires research support.

9. The studies on ammonia toxicity to fish life ought to be summarized and utilized in water quality standards.

10. An audit of water quality accomplishments since 1970 should be conducted.

5.8 Deep Aquifers. The issues of how to use the deep bedrock aquifers of the

Denver Basin is important since the aquifers represent, in effect, an independent, off-line large reservoir available to the basin water users. The Denver Basin is a north-south trending aquifer extending northward to Greeley and southward to somewhat beyond Colorado Springs. It underlies approximately 6,000 square miles of land surface. The basin consists of a number of sedimentary geologic layers overlying rock that forms the basement. Several sedimentary formations within this sequence constitute aquifers and are commonly referred to as the bedrock aquifers of the Denver Basin.

Large quantities of water, suitable in quality for almost any purpose, are stored in these aquifers, and it is being used to meet the increasing demands for water caused by the population growth along the Front Range. Some areas (e.g. the South Platte River corridor and the Strasburg-Byers-Deer Trail area) have experienced precipitous declines in water levels over the last decade.

The prudent management of these groundwaters depends on the relation between the drawdown of water levels and the volume of water recovered. Except near the outcrop areas along the edges of the basin, the bedrock aquifers are artesian. Under artesian conditions, the relationship between drawdown of water levels and the volume of water recovered is governed by the slight expansion of water and the compression of the aquifer that results from a reduction of pore-water pressure. Because both water and rocks are only slightly compressible, large and extensive drawdowns are associated with water removal from artesian aquifers.

Continued removal of water from an artesian aquifer, eventually causes the water levels to fall to the elevation of the top of the aquifer and the aquifer becomes unconfined. At this point, the relationship between the volume removed and the change in water level is modified dramatically. Typically, the total volume of water recoverable under artesian conditions is less than 0.1 percent of the volume of water stored in the aquifer. In contrast, the volume recoverable once the aquifer becomes unconfined typically ranged from 10 to perhaps 60 percent of stored volume. The salient difference between the artesian and unconfined condition is the physical drainage of pores and consequent replacement by air that occurs once the aquifer becomes unconfined.

The important bedrock aquifers of the Denver Basin are, in descending order; the Dawson, Denver, and Arapahoe formations of the Dawson Group; the Laramie-Fox Hills formations; and the Dakota, Lyons, and Fountain formations. The Dawson Arkose is the uppermost of the aquifers in the Upper Cretaceous Dawson Group. It consists of interbedded sandstone, conglomerate, shale, and clay comprising a total thickness of as much as 1,100 ft. The lowest member of the Dawson Group is the Arapahoe. It includes the Milliken sandstone of the Fox-Hills formation and the A and B sandstones of the overlying Laramie. The aquifer thickness of the Laramie-Fox Hills aquifer is 200 ft but ranges upward to about 400 ft. The Dakota aquifer consists of the upper 100 ft of the South Platte and Lytle formations of the Dakota Group. Groundwaters of usable quality are found in the Dakota only near the west boundary of the basin where the Dakota outcrops. Like the Dakota aquifer, the Fountain formation and the Lyons sandstone are useful aquifers only near the outcrop on the western side of the basin. Except near the outcrop areas, all of these aquifers are artesian. Confining beds are clay and shale strata, but are not believed to preclude vertical communication between the Dawson Arkose, the Denver, the Arapahoe, and the Laramie-Fox Hills. The piezometric head is generally greatest in the upper most aquifer (i.e., the Dawson Arkose) and decreases with depth to the Laramie-Fox Hills, at least in the undisturbed, predeveloped state. This downward gradient is thought to result in some small downward movement of water from aquifer to aquifer.

The three aquifers of the Dawson Group are the most significant from a regional perspective. It is believed that these aquifers receive recharge from precipitation on outcrop and subcrop areas, along fault zones near the Front Range, and from stream seepage in the Black Forest area. Total recharge to the Dawson Group aquifers is about 110,000 ac-ft/yr. A recent study by the USGS suggests that natural recharge to the Dawson Group aquifer may total only about 35,000 ac-ft/yr (Robson, 1984). Most of this recharge occurs in the uppermost aquifer, the Dawson Arkose, and the lower two aquifers are supplied mainly through vertical leakage. This study also suggests that the Dawson Group aquifers have the potential for discharging to streams within the basin. Under conditions prevailing prior to development, Robson (1984) suggests that all of the 35,000 ac-ft/yr were eventually discharged to streams. From the Dawson Arkose, the major recipient streams are Plum, Cherry, Box Elder, Kiowa, and Monument-Fountain.Robson indicates that the Denver and Arapahoe formations discharged, under predevelopment conditions, a total of about 11,000 ac-ft/yr. Most of the discharge from these two lower aquifers in the Dawson Group was received by Plum and Bijou Creeks and by the South Platte River.

Robson (1984) indicates recharge to the Laramie-Fox Hills aquifer at about 4,000 ac-ft/yr. Again, under predevelopment conditions, it is suggested that this quantity of water is discharged to surface streams, the major recipient being Bijou, San Arroya, and Badger Creeks. A small discharge (less than 400 ac-ft/yr) to the South Platte from the Laramie-Fox Hills is indicated.

5.5 Issues. The South Platte water system has evolved as a classic case of a complex water system. Thousands of daily actions and passive processes determine how water is mutually available between water rights owners. Its management is passive, governed by the appropriation doctrine. The only government action is reactive, to settle disputes through the courts, and to administer the system.

But the system is constantly evolving with new proposals for change initiatives for development, and demands on a limited resource. While the passive system of management is destined to continue there are some roles of government appropriate to the situation. One such role is to provide the knowledge necessary to handle the new needs about how the system will respond to specific proposals and initiatives. Essentually each one is a "reserch question," in that there are no precedents in practice to provide answers nor is empirical experience adequate. The other role is in the policy area and in leadership in stimulating collective action to solve common problems. Policy guidance is needed often so that participants use common rules and can anticipate the actions of others.

Some specific issues which have been identified to meet present or anticipated problems are enumerated. They are:

(1) Protection of Water Rights. Vigilance in protecting ones water right is often a heavy burden in legal costs and effort to assess the impact of

each proposed change to the system requiring adjudication, especially for individuals or small organizations. Is there a way to handle this problem with less expense?

(2) Policy. Alternatives for managing, developing, and administering the total water supply should be suggested as policy initiatives.

(3) Assessing Impacts of Changes. The State Engineer should have authority to evaluate water right changes (DWH insert--check)(at the expense of the proposer) for basin-wide impact to assess the proposal from a technical aspect, vis a vis a legal solution. This would use technology to protect water rights as an alternative to current litigation.

(4) Water Rights Transfers. Is state surveillance needed to monitor water rights transfers to examine basin effects!? Should there be a state managed market for sale of water rights and for rental of water?

(5) Exchanges. Put in (7) from text. (don't understand - DWH)

(6) Augmentation Plans. Augmentation plans are not decreed and hence they are not protected. They depend upon annual approvals of the State Engineer. How can they have a more permanent legal status?

(7) Conditional Decrees. A conditional water right application locks a place in the priority system, foreclosing alternatives for other development. Should there be time limits on conditional decrees?

(8) Broad Perspective. Local level managers need to broaden their leadership toward comprehensive planning and in initiatives to improve management. How can this be stimulated further?

(9) Land Treatment. The use of land treatment for secondary treated sewage effluent provides reuse benefits as well as cost advantages, but could cause water rights problems. How can these be handled?

(10) Political Pressures. Water projects have strong political aspects. How can sound technical approaches be reconciled with political exigencies?

(11) Joint Management. Some water districts and municipalities could be better off in some activities through joint ventures. How can this be accomplished?

(12) Water Conservation. What are the possibilities and the potential in agricultural water conservation? Is reduction of return flows a water saving?

(13) Domestic Use. What would be the impacts of curtaling domestic withdrawals to 80, 130, 180 gpcd on municipal demands and developments of new water supplies, social patterns, agriculture, and the environment?

(14) Storage. How can storage of flood flows and better management of supply be coordinated? (Don't understand - DWH)

(15) Drought Strategy. For a drought contingency cooperative agreements with farmers to sell water to cities during drought could be cheaper than building expensive and little used drought storage. This ought to be investigated.

(16) Water Conservation. The cost of developing new supplies ought to be balanced against the cost of implementing water conservation programs.

(17) Recharge. Sites for recharge are now in operation at several places such as at Kiowa and Bijou. Augmentation credit is given to return flow when it occurs. Determination of time and amount is an issue.

(18) Instream Flows. Requirements of fish and wildlife for instream flows ought to be addressed through an interagency plan for the lower South Platte and Platte Rivers.

(19) New Reservoirs. The benefits and costs of rehabilitation and improvement of plains reservoirs should be assessed, vis a vis construction of new main stem storage reservoirs in the mountains.

6. BASIN-WIDE COOPERATION

6.1 Transition From the Present System

6.2 Federation of Water Users - An Alternative

6.1 Transition From Present System. Historically, in the present system, each water rights holder, whether an individual, a city, or a farmer's irrigation company focuses on his own need exclusively, without much regard for others who use the same water supply. With a suitable forum for exchange of ideas and identification of agreed upon changes for the common good, selected adjustments to the present system could be identified and made for the benefit of all. Presently litigation is the only forum for initiative and all decisions must be within the present legal framework.

Four Changes. Four selected changes are identified below as examples of the kinds of ideas that might be considered in a forum of voluntary cooperation.

(1) Modify water rights administration during a "declared" drought to permit additional withdrawals of groundwater. A portion of the Denver Basin groundwater could be reserved for drought contingency.

(2) Permit a junior water rights holder to pay a senior water rights holder for use of surface water. (Bill needs to check this as I don't see the key point.)

(3) A policy of reuse should be adopted, which would encourage first use of water by municipalities, followed by downstream agricultural use. The Northglenn-FRICO and Westminster-Highline Canal and Reservoir Company agreements are the kind of system changes needed.

(4) Convert to a volumetric water rights system by permitting water rights to be sold.

None of the above would change the nature of the system. They would provide more flexibility in operation to account for present-day and future exigencies. But a most important adjustment would be to provide a forum for voluntary cooperation. A concept for this is described in the section following.

6.2 Federation of Water Users - An Alternative. The present system evolved from the last century when the system was still relatively simple. In this system, each water rights holder, whether an individual, a city, or a farmer's irrigation company focuses on his own need exclusively, without much regard for others who use the same water supply.

But the harsh realities are that the junior appropriators may be in a tenuous position, particularly during dry years. Today the same system is used for a complex system and the proposals for change are more numerous. Also, because of these complexities it is more difficult to keep track of what is happening on the river as a whole, so that daily scheduling can be done efficiently. There must be a better way to satisfy more water rights, to process the initiatives proposed, and to facilitate administration. An approach is proposed here. The focus is upon protecting and improving the status of all water rights on the river. This can be done by finding, by technical means, opportunities for improving the rights of junior appropriators without harming the rights of senior appropriators, and, at the same time, provide financial incentive for senior appropriators to release excess water. The institutional means to accomplish this must be provided also.

First, there are models being developed, described in the next chapter, which can simulate the complex South Platte water system and answer some of the critical questions, e.g. the effect of legal initiatives on existing water rights. While the use of these models may require modifications to meet the specific needs of a given question, they provide a systematic framework for addressing the questions posed by the initiatives. In other words, what may be the effect of a given initiative on existing water rights? The models provide a methodology.

Second, to utilize information available from traditional sources and also that generated by models, a South Platte Water Users Federation is proposed. The Federation would be comprised of three representatives from each of the local water users associations, such as the Cache La Poudre Water Users Association. Membership and participation would be strictly voluntary. The function of the Federation would be to facilitate tests of initiatives for change. Exchanges of water between parties could be a major area of activity. These would be tested with the basin computer model. Any of the categories of change could be tested, however, using the basin model. The burden of expense would fall upon the proposer of the initiative. Final adjudication would be for legal purposes, since agreements and contracts would be developed prior to the adjudication. The goal would be to provide a mechanism to protect existing water rights without constant vigilance.

The development of problem solving mechanisms within the Federation would have to evolve over a period of years. But the focus would be on voluntary cooperation and the use of modern information technology. To be successful the Federation would deal with specific problems. An example could be a proposal to store water in a reservoir to meet senior water rights to augment groundwater pumping from the alluvial aquifer. This illustration is used only because it is a current issue and there is familiarity.

7. MODELS

7.1 Information

7.2 CONSIM

7.3 SAMSON

7.4 Water Balance Tables

7.5 Economic Modeling

7.6 Demand Projection

7.1 Information. Procuring information and acting upon it is one of the main activities of water management. Procurement of data, its analysis, interpretation, and use is handled mostly by conventional methods. Often analysis is incomplete due to hundreds or thousands of interactions and ripple effects. Consideration of a proposed change requires, however, complete analysis, possible only by computer simulation.

Computer models can tie together the components of a system, utilizing data, processing a multitude of interactions depicted by functional relationships. Indeed, the model can simulate the behavior of the whole system. They do this by what is essentually high speed accounting in accordance with the model algorithm. The model is limited only by the data available and by knowledge of relationships within and between components.

Models have different purposes and so how they are constructed and how much resolution is built in varies with purpose, money available to construct it, adequacy of data, etc. Two computer models which have been constructed at Colorado State University are CONSIM and SAMSON. These models are the technologies for modern management. Because they are so important as management technologies they are described at some length in this chapter. They are easy to comprehend, if explained properly. Understanding these models also makes them more powerful for users.

INFORMATION CATEGORIES	Hydrologic	Water Quality	Water Rights	Economic Environmental
INFORMATION PROCESSES	Experience and Knowledge	Measurements	Records	Studies Models
EXPERTISE	Biologist Engineers	Water Districts	Federal and State Agencies	Consulting Engineers Universities
PROBLEM CATEGORIES	Infrastructures Planning	Daily Operation	Adjudication	Policy Formulation Statutes
DECISION MAKERS	Water Users	Water Commissioners	Municipalities	State Government Federal Agencies

7.2 CONSIM. The term CONSIM is an acronym for the phrase "conjunctive use simulation." It depicts a system structure in terms of "links" and "nodes." Examples of links are river reaches, canals, and pipelines, while nodes include reservoirs, cities, and irrigated lands. Its operation is simulated by programing into-each link and node capabilities, inputs, and rules. The behavior of each link and node is governed by this information. Capacities include reservoir storage, canal flows, river stage-discharge relationships, etc.; inputs are precipitation, temperature, imported water flows, etc.; and rules are water rights priorities, allowable reservoir levels, etc.

CONSIM has evolved in stages since 1970 by means of various projects in which models of local and regional water systems are constructed. It has been applied to water systems in Colorado, in California, and abroad. In relation to the South Platte CONSIM models have been constructed for the water systems of the City of Fort Collins, the Cache La Poudre River basin, and the South Platte from Sterling to Julesburg.

All or any portion of a water system can be depicted by CONSIM. The whole South Platte water system can be modeled, or just portions of it. The amount of resolution which can be incorporated in CONSIM is limited only by funding for acquiring the needed information. The resolution should be consistent with the purpose of the modeling process and the funds available. Using the large Cyber 205 computer at CSU there is virtually no limit to the size of the model.

It is important to note in this review that both CONSIM and SAMSON represent technologies which can be used as "tools" to generate information of various sorts. While both models are comprehensive and exist already as ways of obtaining information, they are not universally applicable as they stand. They must be adapted to the needs of the problem at hand. The problem governs the way the model is constructed and used.

7.3 SAMSON. The word SAMSON is an acronym for "stream aquifer model for simulation and optimization." It is a "discrete kernel" model in that all hydrologic information is stored within a grid area. The model was developed over a ten year period from about 1973 to 1983 to depict stream aquifer interactions and the effects of pumping for the reach of the South Platte River from Balzac to Julesburg. In 1983 the Colorado Legislature funded an extension of the model from Denver to Balzac.

The extended SAMSON model, as authorized by the Colorado Legislature, simulates a portion of the South Platte water system from the canyon mouths of the Front Range tributary streams to Julesburg, with emphasis on the alluvial aquifers. The components simulated include: 52 canal diversions, 150 reservoirs, 800,000 acres of irrigated land, the alluvial groundwater aquifers, and over 700 pumping wells. The model simulates hydrologic processes, including flows in streams, flows in the alluvial groundwater aquifer, deep percolation from irrigated lands, evapotranspiration from irrigated lands, moisture storage and movement in the unsaturated zone above the water table of irrigated land and canal seepage. In addition, it simulates pumping withdrawals from the alluvial aquifers of about 1,200,000 acre-feet annually.

In SAMSON the reaches are descretized into 1 mile by 1 mile grids, the areal resolution. Each of the grid squares stores all hydrologic information contained within it, such as river reaches, canal reaches, reservoirs, irrigated land, and the groundwater aquifer.

In operation, all flows to and from each grid square, plus or minus changes in surface storage and groundwater storage must balance. Since the flows from one grid square must equal the flows to the one adjacent, a water balance is necessary for the system as a whole, as well as for each grid square.

SAMSON indicates where water can be. In other words, the model is an array of "water accounts" and their relation to one another, and it also contains the data for calculating water flows within each "account" (or system component). But the "structure" of SAMSON indicates only what is possible. There is not enough water in the system to fill all of the accounts all of the time.

In SAMSON, the daily flows of water are determined by two factors: (1) the amount of water 'available, and (2) the rules for its allocation. The water available in the system is determined by the weather pattern for a given year, while the rules for water allocations are determined by the water rights system, comprised of the basic legislative doctrine, the 1969 Act, court decrees, and administration by the State Engineer. Each water right is associated with an owner, who in turn owns a ditch, reservoir, or well. All of this information is associated with the respective grid square.

To simulate a growing season, SAMSON determines the need for water by each user within each grid square for a given day. For a parcel of irrigated land the need is calculated using the Blaney-Criddle formula, which analyzes the water content of the root zone and water storage and water movement equations for the unsaturated zone, as well as losses by deep percolation to the underlying aquifer from the previous irrigation. If the root zone moisture is at or below wilting level, the need is signaled by SAMSON for water for that parcel of land, which is then signaled to the ditch supplying the land. Whether the ditch receives water from the South Platte River or not depends upon two things: (1) whether there is sufficient water in the river, and (2) whether the ditch wanting to divert has high enough priority to divert water. If other lands needing water have water rights senior to the parcel in question, they will receive water first. Determination of whether water is present in the river within a given reach is based upon virgin stream flow from the mountain snowpack.

7.4 Water Balance Tables. A network diagram showing transfers of water from one system component to another contains the kinds of information needed to understand the South Platte water system, which can facilitate decision making. But with so many components comprising the South Platte water system, e.g. cities, industries, canals, irrigated acreages, reservoirs, etc., literally thousands of components and interactions, network diagrams can become too complex to understand easily.

The idea of a water balance table was inspired by the need to provide an easy-to-understand format to display the components of a complex water system and the interactions between them. It provides the same information as a network diagram. The water balance table also is an accounting model, forcing water balances for each component and for the system as a whole. It can be used to display the findings of other computer models, or it can be used to project how the system can respond to new water demand projections. Water balance tables can be constructed for the whole South Platte water system, sub-basins, cities, or industries, etc., at any level of aggregation. Such a model can summarize flows from CONSIM or SAMSON. It gives one kind of depiction an empirical snapshot of flows between components.

7.5 Economic Modeling. Economic models are like hydrologic models in the sense that they range from the simplest concept and calculations all the way to elaborate computer-based simulation models. One category of economic model is the "input-output" scheme for demonstrating the interrelationships of economic outputs to the factors of production, one of which is water. Models of this type can be used to predict, for any defined area, the results of water exchanges or other decisions.

Robert Young, a member of this project team, has investigated the applicability of economic modeling to the South Platte Basin. One study examined the use of an economic-hydrologic-legal approach to finding the effect of various operating policies for the river. Using such a model, the hydrology and the legal rules of operation can be represented by SAMSON or CONSIM. The remainder of the model represents the economic actions of the individuals and institutions involved.

In one report, Young has discussed the formulation of a model specifically to analyze alternative water policies in the Lower South Platte. These are evaluated in terms of net economic yield, which is based on the differences between annual gross value of crop sales and the sum of fixed and variable costs of crop production and public costs. This analysis considers the regional public point of view, and would not necessarily represent the point of view of the individual farmer who will always act in his own best interest.

The hydrologic model is like SAMSON: it simulates the response of the system to the controllable and noncontrollable variables involved. The economic model representing the farmer's view simulates farm decisions seasonally and incorporates planting choices and amount or irrigated land to farm, and also daily decisions such as when and how much irrigation water to apply to crops. It computes the economic benefits and costs accruing to both surface and groundwater users. The model has been operated to study a number of alternative policy proposals and water supply situations, and could be adapted to provide information to a cooperative association of water users.

7.6 Demand Projection Model. A demand projection model for urban water utilities in the South Platte basin was developed by Ellinghouse under the supervision of team member J. Ernest Flack. This model included an assessment of current demand by municipal water users in the basin and then made projections of future demand based on population projections and various water conservation programs. The costs of implementing these conservation programs and the value of the water saved was compared over time with costs of acquiring new water supplies, both from transfers and new storage, without conservation of any kind. A benefit-cost analysis demonstrated that water conservation is cost effective, based on the assumed future costs of new water supply. It was also demonstrated that a water utility practicing water conservation, as contrasted with one that did not, would need a considerably larger drought reserve water supply to get through a drought sequence of several years for the basin.

The operation of this, or similar, models can be particularly effective in assisting urban water managers in deciding when and to what degree to adopt various water conservation methods. It also permits development of drought contingency plans for coping with unforseen but certain-to-occur deficiencies of supply.

8. RECOMMENDATIONS

Issues. The major premise of this review of the South Platte water situation has been that managing the water of the South Platte for the benefit of water right owners and the public at large can be improved by utilizing information. Computer based models would be the primary information generating tools. A federation of water users associations would provide the institutional mechanism. The development of such a federation must come from the water users themselves.

Several impending issues may stimulate the development of such a new approach to voluntary integrated decision-making. They include: the general increase in litigation and conflict over water use, problems caused by increasing urban demands, water quality maintenance, and finding the best ways to use the bedrock aquifers. Some of the specific issues that must be faced by the State and the water right owners related to the above are enumerated below.

1. Protection of individual water rights against damage from distant actions is a heavy burden of cost and vigilance for the individual or small organization. Pumping impacts are typical. How can these be handled?
2. Policy alternatives for managing, developing and administering the total water supply need to be suggested, along with constraints and impacts of each alternative.
3. The State Engineer's authority is limited in evaluating water right changes (and other actions) for basinwide impact. Technical solutions yield to "legal" solutions. What should be done?
4. A possible state role and state-of-art technology to protect individual water rights as an alternative to current litigation systems needs to be explored.
5. Water rights transfers may either help or damage basinwide efficiency. Is state surveillance needed? What would the rules be for state and/or local entities (district)? How would change of use and change of place be handled?
6. Is a state managed "water market" an option that should be considered (rental market, sale market)?
7. Relationships of exchange schemes in Colorado River basin to water supply/management options for South Platte basin should be explored (e.g.

Green Mountain exchange as alternative to Homestake II).

8. Augmentation plans are not decreed; hence not protected. They depend on annual approvals of the State Engineer. What should be done?

9. The filing of conditional applications locks-up a place in priority and forecloses other alternative possibilities for development. We need criteria for time limits on conditional applications.

10. The urgency of water problems is mobilizing local-level managers to leadership in search for comprehensive planning, evaluation of options, and general initiatives in improving management. How can this movement be encouraged?

11. Sewage effluent treatment and disposal by land treatment creates recycling advantages but introduces water rights problems. How can these be handled?

12. Can development projects be prioritized with respect to immediate action in order to satisfy political heat without risk of "wrong" decisions?

13. Augmentation plans can credit only 50% (consumptive use) of any agricultural water provided. The balance would get into the river anyway. Is there a better rule or is this justified?

14. Joint management of supplies by urban water suppliers could solve some supply shortages (e.g. Fort Collins and surrounding special service districts). How could it be accomplished?

15. Can agricultural water supply be augmented by conservation? This means to use water so efficiently that no further change could be made that would increase the net benefits to the state. What is the potential for use/management of water "saved," i.e., physical and legal availability?

16. What if all domestic use in South Platte were curtailed to 80, 130 or 180 gpcd by some means (meter, pricing, restriction, appeal)? What would be the impact on (1) municipal supply, (2) agricultural supply, (3) municipal investment, (4) environmental quality?

17. The storage of water has two purposes: to store water otherwise lost downstream; and to enable better management of the basinwide supply. How can they be coordinated?

18. The Central South Platte Conservancy District rents Aurora sewage effluent, yet may need only a fraction of the water for augmentation in a

wet year. What would be a better solution for arrangements of this kind?

19. Recharge sites are now in operation at several places in the basin (e.g., Kiowa near Wiggins; Bijou near Hudson). Augmentation credit is given to return flow at the time it occurs. Determination of time and amount is a potential issue.

20. Instream flow objections (or fish/wildlife interests) need to be addressed. An example is the interagency plan for lower South Platte and Platte Rivers. This includes "channel flushing," habitat preservation and recreation.

21. One question is plans reservoir rehabilitation/betterment versus new main stem storage in the mountains. What are the benefits and costs? The feasibility may depend on impacts of existing groundwater recharge cycle systems and associated basin efficiency. New water management procedures would be needed (maybe new institutions), exchange plans would be eliminated and junior rights would be impacted.