Denver Basin and South Platte River Basin Technical Study

Senate Bill 96-074

Prepared for the Special Water Committee

Prepared By

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April 1998
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SENATE BILL 96-74 EXECUTIVE SUMMARY

1. Introduction

Senate Bill 96-74 authorized establishment of a Special Water Committee (SWC) of nine legislators to investigate Denver Basin groundwater management and South Platte River Basin issues. To assist in the SWC's consideration of these water policy issues, the State Engineer (SEO) and the Director of the Colorado Water Conservation Board (CWCB) have administered this technical study.

The SWC approved a scope of work for the technical study in September 1996 and directed the SEO and the CWCB to proceed with the study. The study utilized the latest technical methodologies and data from previous existing studies. During its preparation, the study was subjected to peer review by qualified hydrologists, geologists, engineers, and all interested members of the general public.

South Platte River and Denver Basin Overview

The pristine South Platte River flow historically was fed from snow melt and groundwater (Figure 1). Development within the basin, initially agricultural throughout the basin and urban growth in the upper basin, resulted in the demand for water for agricultural and domestic use exceeding the natural flow of the South Platte River. Due to the increased demands on the South Platte River, the management of the water within the basin has intensified over the years. To meet the growing demand, additional water was imported into the South Platte River Basin through trans-basin diversions, primarily from the Colorado River Basin, and groundwater was pumped from the Denver Basin Aquifers. Currently, the water supply for the population along the Colorado Front Range, from the Castle Rock area in Douglas County to the Greeley area in Weld County is obtained from a variety of renewable and nonrenewable water sources.

The South Platte River annual flow at the Henderson Gage is greater under current conditions when compared to the historic flow. The increased flow is partially a result of wastewater discharge, lawn irrigation return flows from trans-basin diversions and not-tributary and nontributary ground water pumping. Municipal and industrial water use in the metro Denver area results in about 270,000 acre feet of return flow annually. The pumping of "not-tributary" and nontributary groundwater also has a depletive effect on the South Platte River. In addition, the urban development in the South Platte River basin has changed the surface runoff characteristics. The increased impervious surfaces and the storm runoff from these surfaces have increased the surface flow. Thus, the water in the South Platte River is now comprised of a number of "types" or colors of water resulting in a net effect of generally more water available for use in the river as compared to the historic flow. This net effect on the South Platte River flow due to (or stemming from) the various water management options and use is demonstrated by the illustrative tool and further discussed in chapter 12.
The overall view of the Denver Basin Aquifers also reveals a complex combination of water use and resource protection. The Denver Basin Aquifer system consists of the Dawson (upper and lower), Denver, Arapahoe (upper and lower), and Laramie-Fox Hills aquifers. The aquifers cover an area of about 6,700 square miles extending from Colorado Springs on the south to Greeley on the north, and from the foothills on the west to Limon on the east (Figure 1 and 2).

The Aquifer system contains approximately 300 million ac-ft of drainable storage. To put this quantity of water in perspective, this amounts to a reservoir 15 times greater than the active storage of Lake Powell (20 million ac-ft), and 400 times greater than the active storage of Blue Mesa Reservoir (750,000 ac-ft). The estimated total pumping of groundwater from the Denver Basin Aquifers in 1996 was 56,000 ac-ft. This is less than 2% (60,000 ac-ft) of the 1% (3,000,000 ac-ft) annual allowable pumping quantity under the 100 year aquifer life administration criteria provisions of Senate Bill 85-5.

Eventhough some localized well pumping drawdowns and loss of hydrostatic pressure are occurring, the overall Denver Basin aquifer life at this level of production (56,000 af/yr) may exceed 1000 years. Simplified projections of well development and population growth to the year 2100 result in groundwater production estimates of about 300,000 ac-ft per year which is about 10% of the annual allowable pumping from the Denver Basin aquifers under the 100 year aquifer life assumption. Depending on unknown future conditions, this amount could be significantly different.

The impacts to South Platte River flows and the potential injury to senior water rights due to depletions from ground water pumping are not currently evident due to the net increased flow in the South Platte from Denver Basin aquifer return flows and due to the delayed impacts of pumping. Therefore, water policy decisions related to the long-term use of this nonrenewable resource and the management of the South Platte River are not immediately critical. However, these water policy issues must be addressed over the next few years through the development and use of advanced computer modeling, improved data bases and a more thorough understanding of all the potential causes of injury to senior water rights on the South Platte prior to changing existing statutes.

II. Public Water Policy Issues

This study has raised a number of water policy issues that must be addressed through additional study and public meetings, and by the legislature acting in its role as “decision maker” in public water policy.

The water needs of the Denver metropolitan area and South Platte River basin are increasing as a result of population growth. Water for this increasing population will come from a combination of six sources: 1) Water conservation 2) Water reuse 3) Trans-basin imports 4) Conversion of in-basin agricultural water
rights 5) Non-tributary groundwater and 6) New South Platte water development. These six sources each have positive and negative impacts on environmental, political, social, and economic issues depending on one's perspective. No alternative entirely benefits all interests. However, the range of water supply options available to the South Platte basin and Denver Metro area provide some flexibility and possible opportunities for cooperative approaches and balancing of impacts.

A computer-based interactive tool was developed as part of the SB74 study to illustrate the interrelationships between population, water demands, water supply options and resulting effects on surface water and groundwater resources within the South Platte basin of Colorado. The illustrative tool presents the concept of net impacts to the South Platte Basin resulting from a range of surface and groundwater use and management activities. The tool allows the user to select a future water supply scenario based on population growth and water supply options for each of three regions within the South Platte basin. Relevant information on population, existing water supplies and future water supply plans is provided in the input page along with several example future scenarios.

The initial area of public water policy is based on the current and near term water resource development in the South Platte River Basin and Denver Basin aquifers. Legislative decisions regarding changing existing statutes that deal with Denver Basin aquifers and impacts on senior surface water rights do not appear to be necessary at this time. Prior to making decisions regarding the long-term impacts on existing water rights resulting from Denver Basin Aquifer use, it is recommended that additional studies be conducted to integrate the surface water and Denver Basin ground water models, obtain additional ground water use (pumping) data in the basins, refine the aquifer properties used in the models and further examine South Platte River water use and potential water right injury. The long range plans for both the Colorado Water Conservation Board and State Engineer propose extending the decision support system that was developed for the Colorado River basin (CRDSS) into the South Platte River basin. The development of a decision support system would complement and build on the results of studies proposed by the peer reviewers.

A second area of public water policy is consideration of the additional runoff in streams resulting from impervious surfaces created by population growth. The entire Front Range from Pueblo to Ft. Collins is growing in population. The increased runoff to certain streams may offset the depletions to these streams from pumping of Denver Basin aquifers. Some metropolitan water providers that use the Denver Basin aquifers believe that this additional runoff should be carefully considered as a potential offset to the depletion from groundwater use. This concept would be consistent with viewing the South Platte River flow as a whole, considering all of the increases and decreases resulting from population growth and the resulting net stream flow condition. The proposed offset discussed above is currently inconsistent with Colorado water law. The owners of senior
surface water rights along these streams may disagree with the concept of net stream flow as a measure of depletion and resulting impact, particularly as water reuse increases and during times of drought. Due to the complexity of the basin, the water use concept of net stream flow to determine impact and mitigation of impacts needs further open and thoughtful discussion as well as improved data, integrated modeling, and development of a decision support system.

A third area of public water policy is how to properly implement and fund the Platte River Cooperative Agreement. Implementation of the Cooperative Agreement is critical to the ability of Colorado water users to utilize a portion of the remaining developable flows of the South Platte River to support population growth. The Cooperative Agreement serves as a reasonable and prudent alternative for mitigation of impacts for existing water projects and new water development which, when complied with, provides a level of regulatory certainty with regard to the application of the Endangered Species Act.

Sufficient long term funding of the Platte River Cooperative Agreement is a key component to implement the agreement. The Legislative Interim Committee on Water and Land Resources has endorsed legislation (HB 98-1006) that would possibly provide a funding source. The legislature is considering the bill at the time of this writing.

The fourth area of public water policy is the role of the State of Colorado, in particular its water resources agencies, in facilitating water planning for the South Platte River Basin. It is evident from the Metropolitan Water Supply Investigation Study and this study that considerable information has been developed, and communication among water providers and users has been improved. It appears that, if additional time and resources are made available, that these studies would provide the foundation for additional studies to assist water users in meeting population growth needs while dealing with the many complex issues identified in this report.

### III. Recommendations

1. Proceed with the development of a South Platte River Decision Support System as soon as the resources become available, but not later than 1999.

2. Proceed with prioritizing studies and investigations through working cooperatively and in partnership with the peer review groups and the water community to obtain data and further refine and improve the Denver Basin Groundwater Model as the resources become available. The following studies and investigations were identified and recommended by the peer review groundwater group:
   - More accurate definition of streambed conductance factors
   - Annual stream gain-loss measurements
   - Monthly bedrock water-level measurements
More realistic calculation of stream-flow depletions
Collection/interpretation of pumping record data from each bedrock aquifer
Collection and compilation of aquifer test and core-analysis data
Analysis of core samples from bedrock wells in the basin
Expand the monitoring of declining groundwater levels in withdrawal areas.

The detailed recommendations of the peer review group are in Summary Appendix A.

3. The concept of the net impact to the South Platte River and consideration of increased stream run-off from urbanization as replacement for groundwater depletions resulting from ground water pumping requires substantial investigation and consultation within the water community prior to recommendations or decisions to change existing statutes.

4. Implementation of the Cooperative Agreement is critical to the ability of Colorado water users to utilize existing water rights and to proceed with future development of the water resources in the South Platte River Basin. The Legislature currently is considering financing for such implementation as part of HB 98-1006.

5. We recommend that the effective dates and repeal dates of SB 96-074’s amendments to Sections 37-90-137(9)(c) and (c.5) be delayed by one year (effective July 1, 1999 and repealed effective July 1, 2002).

6. The State Engineer recommends that the Division of Water Resources consider and evaluate additional public comment on a de minimis standard for depletion from the pumping of a Denver Basin “not non-tributary” aquifer based on an annual pumping volume of 3 acre-feet per year. The State Engineer would recommend to the legislature whether there is consensus to change the statutes.

STUDY CHAPTER SUMMARY

Chapter 1 - Introduction

This chapter is an identification of the Special Water Committee members and the responsibilities of the State Engineer and CWCB Director. The scope of work and work plan as approved by the Special Water Committee is presented.

Chapter 2 – Inventory of Surface Water and Groundwater Resources in the South Platte River Basin (Technical Addendum No. 1, Chapter 1)

This chapter provides an inventory of the surface water and nontributary groundwater resources of the South Platte River Basin in Colorado. The purpose
of this inventory is to provide a framework for understanding the "big picture" interrelationships between South Platte surface water and groundwater resources and various conservation, reuse, groundwater development and conjunctive use options being considered by Denver area water providers. The SB74 Study's computer-based interactive tool is helpful in understanding the numerical information presented in this chapter.

Key points:
1. Undeveloped flows or developable flows are significant in above average runoff years. Most of the developable flows occur below the metro Denver area. (Figs 1-17 to 1-19 Chapter 1, Technical Addendum No. 1)
2. Additional reservoir storage or ASR (Aquifer Storage and Recovery) would allow the use of these developable flows.
3. Platte River Three State Cooperative Agreement would need to be implemented in order to meet Endangered Species Act requirements associated with future use of the developable flows.

Chapter 3 - Estimate of the Impact on Runoff to the South Platte River from Construction of Impervious Surfaces in the Denver Metropolitan Area for the Period 1950-1995 (Technical Addendum No. 1, Chapter 4)

This chapter describes an analysis of the increase in South Platte River gains through the Denver metropolitan area over the past several decades as a result of urbanization. The approach used to estimate the increased stream flow gains assumes the gains have resulted primarily from (1) runoff from impervious surfaces (RIS), and (2) lawn irrigation return flows (LIRF).

Key points:
1. Based on preliminary research, the non-reusable increase in runoff from impervious surfaces was approximately 52,000 acre-feet and the non-reusable lawn irrigation return flows was approximately 21,000 acre-feet, or a total of approximately 72,000 acre-feet.
2. The total streamflow gain from urbanization is approximately 0.10 cfs per 1,000 persons, or 72 acre-feet/year
3. Some Peer Review Group members suggest this increase in runoff should be considered as an offset to Denver Basin aquifer pumping impacts.
4. Additional studies are needed to more accurately quantify the amount and timing of increases in runoff from impervious surfaces.

Chapter 4 – Inventory of Existing Water Efficiency Practices (Technical Addendum No. 1, Chapter 2)

Hydrosphere conducted a survey of the water conservation practices of the City
of Aurora, City of Boulder, the Denver Water Department, and the Centennial Water & Sanitation District. The conservation measures and practices employed in these communities are a good indication of trends throughout the metropolitan area. While the survey identified the conservation measures described below as practices that are currently employed by many water suppliers or are likely to be implemented in the future, the manner in which these practices are implemented varies substantially between different water suppliers.

Chapter 4 focuses on exploring water conservation and conjunctive use in terms of their long-term water supply potential and their effects on existing water rights above the Henderson Gage. Hydrosphere has approached this task through the following steps:

1. An inventory of existing water efficiency measures and practices.
2. An inventory of existing conjunctive management practices.
3. Development of quantitative estimates of the water supply effects of existing and projected future water efficiency measures and practices.
4. Development of quantitative estimates of the water supply effects of existing and estimated future conjunctive management practices.
5. An analysis of the impacts associated with efficiency and conjunctive management practices on South Platte River flows at the Henderson gage.
6. An evaluation of the combined effects of existing and future water efficiency and conjunctive management practices on existing water rights above the Henderson Gage.

Key points:
1. Water conservation is an important aspect of water supply planning. Hydrosphere's survey shows that water conservation has saved 100,800 acre-feet of water for the metro area water providers at current use levels. (see Table 2-3, Chapt. 2, Technical Addendum No. 1)
2. Little conjunctive use is practiced currently in the Denver metro area with most being done by Centennial Water and Sanitation District (654 acre-feet in 1996)
3. Future conjunctive use has significant potential to reduce Denver Basin ground water pumping through the storage above and below ground of surplus surface water flows. Douglas County water providers are more fully evaluating this potential.

Chapter 5 – Effect of Existing Water Reuse on Future Water Supply and on Existing Water Rights (Technical Addendum No. 1, Chapter 3)
This chapter examines, from a regional perspective, the effects of water reuse by metro Denver area water providers on future water supply and on existing water rights. This chapter quantifies existing and expected future amounts of reusable water available to metro Denver area water providers, and return flows resulting from those supplies, describes existing reuse activities and future reuse plans in the metro Denver area.

Key points:

1. Reuse of non-tributary and imported waters is a major component of water use in the study area.
2. Current reuse is 53,900 acre-feet per year with the potential to approach 167,900 acre-feet per year (Table 5-2).
3. Without water reuse, there would be additional pressure for development of Denver Basin groundwater, additional transbasin diversions, acquisition and dry-up of irrigated agricultural land and development of South Platte surface storage projects.
4. Water reuse implemented in accordance with water court decrees would not injure existing water rights. Water reused under exchanges and augmentation plans is foreign to the natural flow of the South Platte and, therefore, generally unavailable for appropriation under the priority system.

Chapter 6 - A Review of Distribution System Infrastructure in the Denver Metro Area to Identify Ways to Promote Maximum Utilization of Water Resources Available to the South Platte Basin above the Henderson Gage (Technical Addendum No. 1, Chapter 5)

This chapter focuses on exploring opportunities for using existing water supply and distribution facilities to enhance and promote the development and use of water resources above the Henderson Gage.

In the southern geographic sub-region, investigations are now underway to define the potential additional yield that could be cooperatively developed using Denver's existing water supply system and some of its Blue River and South Platte water rights in conjunction with water rights, storage, conveyance and delivery facilities currently or potentially available to members of the Douglas County Water Authority. These investigations will focus on the increased yield resulting from new off-stream storage, conjunctive use of surface water and ground water supplies, nontributary aquifer recharge, and borrowing/payback arrangements with Denver.

In the northeast geographic sub-region, preliminary quantitative studies are now underway to define the potential additional yield that could be cooperatively developed using water rights, storage, conveyance and delivery facilities currently or potentially available to the Northeast Provider Group in conjunction with Denver's existing water supply system and some of Denver's water rights. This study will
build upon effluent management and systems integration concepts previously identified in the MWSI Project. Specifically, the study will focus on the hydrology, water rights, operations, water quality and raw water storage aspects of potential actions.

In the northwest geographic sub-region, a study will be conducted to define the potential additional yield that could be cooperatively developed through interconnections and cooperative use of storage facilities at one or more locations in the northwest area. Northwest water supply systems, seasonal operations for wet/average/dry years, participants' relevant water rights, and major system facilities including diversion points, canals, pipelines, reservoirs, treatment plants, principal treated water distribution lines and interconnections will be examined to identify critical linkages, capacities and bottlenecks. An operational analyses will be conducted to help identify constraints and opportunities.

In conclusion, it is important to note that investigation of opportunities for the use of existing systems' infrastructure to promote maximum utilization of water resources available to the South Platte Basin above the Henderson Gage requires a high level of trust and cooperation between individual water providers and the State. The identification and investigation of the opportunities listed above has occurred as a direct result of the efforts of the members of the Technical Advisory Committee for the MWSI Project.

Chapter 7 – The Effect on Existing Water Rights of Current Recharge Technology and Practices in the Denver Basin Aquifers (Technical Addendum No. 1, Chapter 6)

Injection or recharge of reusable water into the Denver Basin aquifers for storage and later recovery and use has significant potential for the Denver Basin aquifers. Research by the Centennial Water and Sanitation District and the Willows Water and Sanitation District has proven that this concept works at its existing storage level, the Denver Basin has an estimated 500,000 acre feet of injection storage capacity.

Impact on water rights would be minimal since the water used for recharge must be fully reusable. Furthermore, the Denver Basin Artificial Recharge Extraction Rules protect existing water rights in a number of ways.

Using excess water treatment capacity of water providers during the non-irrigation season, water can be treated to drinking water standards and recharged using gravity to inject water into the Denver Basin aquifers. This ability to use surplus treatment capacity supports conjunctive use of surface water and ground water.

Chapter 8 - The Impact of De Minimis Standards for Injury Based upon an Annual Depletion Standard
This chapter examines the physical impacts to stream systems in the state, as well as possible legal and administrative implications of de minimis standards for injury based upon an annual depletions standard. In this report, de minimis means a small amount of depletion in a calendar year that could be allowed without requiring the owner of a well causing the depletion, to augment or replace the water depleted or removed from the stream and aquifer system.

The analyses included a review of types of water uses authorized by the Legislature where small amounts of un-replaced depletions to tributary water sources were deemed acceptable such as small capacity wells used for residential and livestock purposes and water stored in small reservoirs (livestock water tanks).

The State Engineer recommends that, prior to changing the current policy, the Division of Water Resources solicit and evaluate public comment on a de minimis standard for depletion from the pumping of a Denver Basin “not non-tributary” aquifer based on an annual pumping volume of 3 acre-feet per year.

Chapter 9 — The Effect of Four Percent Replacement and Two Percent Relinquishment Requirements on Future Water Supplies, Existing Water Rights and the Need for Replacement of Post Pumping Depletion Resulting from Withdrawal of Denver Basin Groundwater (Technical Addendum No. 2)

Chapter 9 summarizes Technical Addendum No. 2, which is a study conducted by staff of the State Engineer’s Office to evaluate the requirements of SB-85-5 to replace 4 percent of the pumping volumes for “not non-tributary” aquifers and 2 percent relinquishment for non-tributary aquifers.

To evaluate the effect of the current replacement (4%) and relinquishment (2%) requirements on future water supplies, water rights and need for replacement of post pumping depletions resulting from withdrawal of Denver Basin ground water, the following is required:

a) updating and improving of existing ground water models,

b) use of the model to evaluate current depletions and predict long term future depletions to the discharge areas of the South Platte River Basin drainages, and

c) evaluation of the model results and effect on existing water rights, future water supplies, and Denver Basin Aquifers.

The model developed for this study uses the USGS MODFLOW computer code. This code is well accepted in the engineering community and is considered the best groundwater modeling code currently available. In computer modeling, the assumptions and data used to calibrate the model are the most important factors. Factors such as historical pumping, recharge to the aquifer from precipitation, and the
movement of water from stream and alluvial material to the aquifer outcrop areas (river conductance) are especially important to the model development. Depending upon which value is used, this model's sensitivity to river conductance significantly impacts the model's computed depletions to the surface drainages. Surface drainages include both the river and the river alluvium. This, in turn, has a direct bearing on the replacement and relinquishment requirements.

The model achieved the best calibration with river conductance at $1 \times 10^{-4}$ per day rather than $1 \times 10^{-5}$ per day as used in previous models. This calibration resulted in a depletion to drainages of 20.7 percent for pumping "not non-tributary" non-designated areas versus 2.9 percent if the smaller river conductance is used ($1 \times 10^{-5}$ per day).

An important issue to understand is that pumping from Denver Basin wells permitted prior to SB-85-5 and wells already permitted pursuant to SB-85-5 will most likely deplete the net discharge from the Denver Basin aquifers. Additional pumping from future wells would just hasten the time when total depletion occurs.

Chapter 10 - Nontributary Groundwater Use and Long-term Impact on Water Rights

This chapter analyzes the use of non-tributary ground water and its long-term impacts on water rights. For the purposes of this analysis, we addressed impacts that result from either non-tributary or "not non-tributary" pumping of the Denver Basins Aquifers. We also looked at the impacts on surface water rights and tributary ground water rights in the South Platte and Arkansas River drainages as well as the impacts to designated ground water rights, both during Denver Basin Aquifer pumping and after such pumping ceases.

It is difficult to determine whether the current replacement requirements will be sufficient for making up stream depletions associated with new pumping. Any ability to make such a determination will depend upon obtaining accurate groundwater diversion records for both existing and new well owners. The State Engineer currently has limited resources with which to obtain these records. Although well owners are required to maintain ownership and address information in the State Engineer's records, few do. Even when the State Engineer can identify these users, not all measure their diversions or maintain records of past diversions. Without the ability to obtain diversion records by mail or other efficient method, the staff of the State Engineer would have to resort to visiting each well on a regular basis to read meters (assuming they were installed and operating) or to issuing orders to install and provide annual records from totalizing flow meters. The State Engineer would require additional staff to obtain this data.

It may be necessary to conduct additional modeling using better data that may have to be collected through additional fieldwork. In particular, data on the amount of historical pumping may have to be improved through field investigations and user
Chapter 11 - Overview of the Scope of Participation by the State of Colorado in Processes Associated with the Implementation of the Endangered Species Act of 1973 with Respect to the Water Resources of the South Platte River Basin and Denver Basin (Technical Addendum No. 3)

This chapter summarizes several options to fund actions by the State of Colorado and Colorado water users to fulfill commitments identified in the recently signed Cooperative Agreement for the Platte River Recovery Implementation Program. It also describes some options for administrative structures for managing the funds.

The successful implementation of the Platte River Basin Endangered Species Cooperative Agreement is crucial to the ability of Colorado water users to meet the increasing demands for water resulting from population growth. In turn, successful implementation is dependent upon sufficient funding to accomplish the objectives of the Agreement.

Chapter 12 - Assessment of Opportunities for Local and Regional Water Management to Enhance the Reliability and Yield of Water Resources in South Platte River Basin and Denver Basin Aquifers (Technical Addendum No. 1, Chapter 7)

This chapter assesses opportunities for the application of local and regional water use efficiency and reuse technologies and methods, in conjunction with additional water sources, to enhance the reliability and yield of water rights associated with the water resources of the South Platte River Basin and Denver Basin aquifers.

Future water demands in the metro Denver region most likely will be met from a combination of six possible water supply sources. These are listed below:

1. Water use efficiency measures
2. Reuse and exchanges
3. Water imported from other basins
4. Denver Basin ground water
5. Expanded utilization of South Platte water supplies
6. Conversion of in-basin agricultural water rights

The positive and negative impacts on competing resources resulting from using these six potential sources are shown in Table 12-2, page 12-6.

These sources have been combined to formulate two possible future scenarios (shown in Table 12-1 on page 12-2) to meet a demand of 1,014,000 acre-feet. These two scenarios underscore the importance of water use efficiency measures and water reuse.
Chapter 13 – Assessment of Surface and Groundwater Development in the Lower South Platte River in Accordance with the South Platte River Compact

This chapter summarizes current and future water development needs in the Lower South Platte area, recognized as that part of the basin below the Henderson Gage. Also outlined are the efforts of the Lower South Platte River Group (LSPRG) and others to address the water needs of the Lower South Platte region as they relate to the South Platte River Compact.

The majority of water development in the lower South Platte River in Colorado occurred prior to 1900 as flows became reliable due to return flows from upstream development. The water supply system has not changed much since that time. The area in Colorado that lies upstream of the Washington County line is unaffected by the South Platte River Compact and has developed without limitations from downstream states. The South Platte River Compact between Colorado and Nebraska has controlled water uses in the Lower Section during that time, and ditches that were junior to the Compact date of June 14, 1897 have been abandoned due to the unreliability of flows subject to the Compact.

There are new needs for water development in the lower South Platte River including water needs related to the Endangered Species Act, the need to firm augmentation supplies for existing wells, new water demands for growth in the region, and the enhancement of habitat to prevent listing of “species of concern” that exist in the South Platte River in Colorado.

Water in excess of the Compact obligations exists during periods of high flow and during the wintertime when Colorado has full use of the river pursuant to the Compact. The amount of excess water available under the Compact would be reduced under the basin-wide recovery program developed by the states of Colorado, Nebraska, and Wyoming and the Department of the Interior (USFWS and USBR). However, there should be sufficient water remaining to meet the needs of Colorado in the future.

Efficient methods exist to redistribute excess flows during more critical low flow times to meet the needs of the lower river. The South Platte Lower River Group, Inc. is a non-profit organization with widespread participation that has been initially successful in examining and resolving some of the issues on the lower South Platte River.

Chapter 14 – Economic Life of the Denver Basin Aquifers, SB 96-153 (Technical Addendum No. 4)

Chapter 14 summarizes Technical Add. No. 4, which is a study of the economic life of the Denver Basin aquifers funded by SB-96-153.
Discussions concerning the economic life of the Denver Basin aquifers have occurred for more than 20 years. Denver Basin aquifer hydrogeologists realized that production from the Denver Basin aquifer wells will decline over time due to a reduction of the aquifers' saturated thickness caused by pumping. What is not known is how water well production rates will decline and how the cost of Denver Basin aquifer groundwater production will increase over time. The study conducted under S.B. 96-153 addresses these two very important questions.

The economic life of the Denver Basin aquifers is very complicated. The study shows that, as regional water levels decline due to pumping, pumping costs increase. In some areas with greater water level declines, the number of wells necessary to produce the same volume of water will double or triple.

Model projections of regional water level declines based upon future pumping scenarios in Tech. Add. No. 2 appear to indicate that the economic life of the Denver Basin aquifers may be longer than some sources have estimated. Additional modeling studies incorporating more accurate estimates for historic and present pumping withdrawals and better projections for future pumping demands would give a better estimate of future conditions in the aquifer.
MEMORANDUM

TO: Technical Review Committee Members

FROM: Jack G. Byers, Assistant State Engineer
       Mike Serlet, Colorado Water Conservation Board

SUBJECT: SB 96-74, Denver Basin and South Platte Basin Technical Study

Enclosed is a summary of the results of a work group meeting held on February 18, 1998 at the USGS offices. The purpose of the meeting was to discuss definition of the Denver Basin ground water model parameters and brainstorm procedures to better measure or estimate those parameters.

The summary is provided for your information and review with the intent of securing your comments. Please provide any comments you may have by March 16, 1998.
March 4, 1998

Mr. Jack Byers
Colorado Division of Water Resources
1313 Sherman Street, Room 818
Denver, CO 80203

Dear Mr. Byers:

Enclosed is a summary of the results of a work-group meeting held on February 18, 1998, to discuss better definition of the Denver Basin model parameters. The meeting was the result of requests made by you and Hal Simpson at the February 11 Technical Review Committee meeting for SB96-074. The work group consisted of:

Jim Jehn - Consultant
Mark Palumbo - Consultant
Dewayne Schroeder - SEO
Brian Ahrens - SEO
Ned Banta - USGS
Ed Weeks - USGS
Stan Robson - USGS

The members of the work group hope these thoughts will provide a better understanding of the data needs of the model, and procedures that could be used to better measure or estimate these important basin characteristics.

Sincerely,

Stan Robson
Hydrologist
The model of the Denver Basin aquifer system supported by the Colorado Division of Water Resources is an important tool in the administration of State water law within the Denver Basin. The accuracy of the model is directly related to the availability and accuracy of hydrologic data used to construct the model. Most readily available hydrologic data already have been used in the construction of the model, but much of the data is either sparse, or of poor quality. The uncertainty in the data leads to uncertainty in the model results. Some of the model results have large economic and political ramifications for water users in the rapidly developing Denver Basin.

The Technical Review Committee for the Senate Bill 96-074 report "Denver Basin and South Platte River Basin Technical Study" was given the task of preparing a list of operational charges and hydrologic studies that could, if implemented, provide additional hydrologic definition of the Basin. These new data would enable the refinement of the Denver Basin model, and would allow more direct comparison of model parameters and model results to real measurements of the hydrologic conditions in the basin. To this end an informal working group met on February 18, 1998, and formulated the following list of model parameters in need of refinement, and possible procedures that could be used to better define the parameters. Costs and time shown are rough estimates only intended to indicate the general magnitude of effort required.

1. A streambed conductance factor is used in the model to simulate the cumulative effect of reduced vertical hydraulic conductivity in the geologic materials between the streambed and the center of the uppermost node in the underlying bedrock aquifer. In layman terms, this conductance factor is a restriction to water movement between the stream and the underlying bedrock aquifer that is used to account for the fact that changes in streamflow do not have an immediate effect on the water level in the underlying bedrock aquifer. Few actual data are available to define the magnitude of the streambed conductance. As a result the conductance generally has been adjusted within the model to a value that is compatible with other model parameters. The streambed conductance is a particularly important model parameter because it readily affects the rate of depletion in streamflow caused by water-level declines from pumping in the bedrock aquifer. If efforts were made to better define the streambed conductance factor, the new data could improve the simulation results of the model, and would provide a real-world measurement of this critical model parameter. One technique for measuring the streambed conductance involves running an aquifer test at a carefully chosen site where the bedrock aquifer could be pumped and water-level changes monitored in nested piezometers completed at various depths in the bedrock and overlying alluvial aquifer near a stream. Core samples could be collected during drilling of the pumped bedrock well and analyzed for lateral and vertical hydraulic conductivity. Borehole-geophysical logs would be run in the well and used with core analyses and aquifer test results to relate streambed conductance results to other sites near a stream with a suitable bedrock well and geophysical logs. As an initial effort, one test could be performed in each of the six bedrock aquifers simulated in the Denver Basin Model. Such testing might require $300,000-400,000 during a 2-year effort.

2. As discussed in item 1, the model calculates the change in bedrock-aquifer discharge to stream valleys caused by water-level changes in the bedrock aquifer. It may be possible to locate a few sites in the basin where this change in bedrock discharge can be directly
measured in streamflow. This effort would require a reconnaissance of the mid- to upper reaches of numerous small streams draining the basin to locate suitable sites for monitoring. The distribution of streamflow along a reach of a stream would be measured repeatedly over a period of years or seasons as water levels rise or decline in the bedrock aquifer. Changes in the distribution of streamflow could indicate changes in the rate and distribution of bedrock discharge to the streams. Such measurements of the effects of water levels on streamflow could be a direct confirmation of model results. Annual stream gain-loss measurements at perhaps five sites and monthly water-level measurements in nearby bedrock wells might require $10,000 per year during a multi-year monitoring program.

3. The model calculates ground-water discharge to stream valleys but these numbers may not be representative of actual streamflow in many valleys because of other factors not included in the model such as underflow in alluvium, stream diversions, pumping from alluvial aquifers, and return flows from sewage treatment plants. These other factors could be much larger than the changes in bedrock discharge to the valley and could obscure the bedrock affects. A modification could be made to the Denver Basin model to allow it to make calculations of streamflow and streamflow depletions that are more representative of actual streamflow. A more realistic calculation of streamflow depletion is needed to give the public, lawmakers, and water-law administrators a better understanding of what is happening, and potentially could happen, to streamflow in areas undergoing water-level decline in the underlying bedrock aquifers.

One method to meet this goal involves constructing a post-processor computer program that could be linked to the discharge-to-stream-valley output from the existing Denver Basin model. The post-processor would incorporate all the diversions, pumping, and return flows that affect streamflow in the various reaches of each valley and produce a calculated streamflow at various points in the valleys. Model simulations of effects of future bedrock pumping could then be run through the post-processor program to also simulate the pumping effects on future streamflow and streamflow depletions. These streamflow simulations could then be more easily compared to actual measured baseflow in streams as an additional verification of the model. Development costs for the post-processor program may require $50,000 for a 1-year effort.

4. The rate at which ground water is being withdrawn from the bedrock aquifers is another vital component in the Denver Basin model, and the model response is sensitive to this rate of withdrawal. Efforts to better measure bedrock pumping will enable better calibration of the model and more realistic simulations of future water-level changes.

Much of the pumping data needed to make better withdrawal estimates already is being collected by the larger water purveyors in the Basin. What remains to be done is to collect the pumping records, interpret the data to determine pumping from each bedrock aquifer, and publish the data perhaps as part of the Division of Water Resources’ annual Denver Basin water level report. Pumping by numerous small capacity water purveyors and individual well owners generally is not metered, and some staff time would be needed to estimate and verify (with field checking) these rates of withdrawal. Accomplishment of this task may require increased funding to support additional staff within the Division of Water Resources.

2
5. The transmissivity of the bedrock aquifer is a measure of how readily the aquifer transmits water from one area to another. Transmissivity is another important parameter in the Denver Basin model that is in need of updating and refinement. This could be done by 1) making better use of existing aquifer test data which measures transmissivity and 2) through continued support of cooperative efforts with well owners who drill core holes.

When a large capacity well is constructed it is common practice to conduct an aquifer test on the new well in order to determine transmissivity (among other factors). Currently these aquifer test data reside with the well owners or their hydrologic consultants and are not submitted to the Division of Water Resources along with other well data needed to complete the well permitting process. If submission of aquifer test results were required, much new transmissivity data could be collected. If well owners were requested to submit all historical data, a very large body of additional transmissivity data could be compiled for analyses by Division of Water Resources staff and incorporation into the Denver Basin model.

Another source of transmissivity data is laboratory analyses of rock-core samples recovered from core holes drilled into the Denver Basin aquifers. The core samples commonly are analyzed for horizontal hydraulic conductivity (which can be used to calculate transmissivity), vertical hydraulic conductivity, specific yield, and porosity. These core samples provide valuable aquifer data in areas, and in rock units, that may never be accessible from other sources. The core samples also are a valuable source of information on the specific yield of the aquifers. Collection and compilation of aquifer test and core-analyses data may require increased funding to support additional staff within the Division of Water Resources.

6. The specific yield of the bedrock aquifers is a measure of how much water can drain out of a given volume of saturated rock. Typically a 1-foot water-level decline in an aquifer will cause about 0.2 cubic feet of water to drain from each cubic foot of rock that has been dewatered. Specific yield is used to calculate the volume of recoverable ground water in storage in the bedrock aquifers, and is the basis for administration of water law within the Denver Basin. Laboratory analyses of core samples are the only means of measuring specific yield in the confined aquifers of the Denver Basin. Continued State cooperative support for analyses of core samples from bedrock wells in the Basin is vital. Previously, core analyses studies have been funded through sources managed by the Colorado Water Conservation Board.

7. Water levels are currently measured and reported annually by the Division of Water Resources for about 220 wells in the Denver Basin. These data are a vital source of information on water level changes in the basin, and are important to the Denver Basin modeling because they provide historical data used in model calibration, and can be used to verify model simulation results in future years. It is important to maintain this network of observation wells for historical continuity, and to expand the network by adding new wells as needed to begin monitoring declining water levels in areas affected by new withdrawal. Water-level monitoring previously has been undertaken by existing staff of the Division of Water Resources.
ILLUSTRATIVE TOOL

A computer-based interactive tool was developed as part of the SB74 study to illustrate the interrelationships between population, water demands, water supply options and resulting effects on surface water and groundwater resources within the South Platte basin of Colorado.

The tool allows the user to select a future water supply scenario based on population growth and water supply options for each of three regions within the South Platte basin. Relevant information on population, existing water supplies and future water supply plans is provided in the input page along with several example future scenarios.

The tool illustrates the effects of a specified scenario with respect to surface water flows; transbasin diversions, Denver Basin groundwater use and conversion of in-basin irrigated agriculture. Effects on surface water flows are shown at five gage locations on the South Platte River.

The tool can be accessed on the internet at the following URL:

http://www.dnr.state.co.us/cwcb/secb/sb74stat.htm

CAVEAT: This tool has been developed for general illustrative purposes and should not be considered as an analytical model. While the tool correctly illustrates the overall effects of various population growth/water supply scenarios, it does not allow for detailed analysis of any specific water supply plan or project.
This illustrative tool was developed as part of the SB74 study to demonstrate the interrelationships between population, water demands, water supply options and resulting effects on surface water and groundwater resources within the South Platte basin of Colorado.

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Historical and Projected Population Data

http://www.hydrosphere.com/sb74/modelinputform.asp?sb74path=d:/inetpublic\hydro\wwwroot\hrc\projects\senatebill74\&SB74User3/10/98&rs\gue
South Platte Basin Population

Population in South Platte River Basin Counties, State of Colorado 1900-2020

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### South Platte Basin Population Projections

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### South Platte Basin Population Increase

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### SB74 Illustrative Tool Input Parameters

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**Select One Scenario:**

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**Custom Scenario**

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Submit changes to SB74 Illustrative Tool

Reset

http://www.hydrosphere.com/sb74/modelinputform.asp?sb74path=d:/inetpub\hydro\wwwroot\hrc\projects\senatebill74\&SB74User3/10/98ers\gue
Average Year Flows at the Kersey Gage

Current Flow

Future Flow
### Kersey Gage

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<tr>
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<th>feb</th>
<th>mar</th>
<th>apr</th>
<th>may</th>
<th>jun</th>
<th>jul</th>
<th>aug</th>
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<tbody>
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### Effects on Flows, AF

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### Resulting Flows, AF

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<td>1,165</td>
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By cweb

http://www.hydrosphere.com/sb74/users/cweb/Kers_Avg.htm

3/19/98
Average Year Flows at the Henderson Gage

http://www.hydrosphere.com/sb74/users/cwcb/Hend_Avg.htm

3/19/98
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<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
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<td>18,394</td>
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<td>83,204</td>
<td>70,987</td>
<td>41,893</td>
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<td>19,220</td>
<td>18,239</td>
<td>16,495</td>
<td>37,875</td>
</tr>
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</table>

| Effects on Flows, AF | | | | | | | | | | | | | |
| Change at Denver | 4,736 | 4,736 | 5,121 | 7,722 | -6,082 | -5,820 | -8,222 | -274 | 3,644 | 3,514 | 5,326 | 5,078 | 19,501 |
| Additional RIS/LIRF's | 997 | 997 | 1,745 | 2,991 | 4,238 | 2,493 | 1,994 | 3,739 | 2,493 | 1,246 | 997 | 997 | 24,929 |
| Metro et. al. WWTP's | 9,679 | 9,679 | 9,679 | 9,679 | 9,679 | 9,679 | 9,679 | 9,679 | 9,679 | 9,679 | 9,679 | 9,679 | 116,151 |
| Total Effects | 15,172 | 15,211 | 15,648 | 19,014 | 5,123 | 4,494 | -2,072 | 7,622 | 13,220 | 13,056 | 15,766 | 15,514 | 137,768 |

| Resulting Flows, AF | 32,297 | 31,016 | 34,042 | 49,238 | 88,332 | 57,275 | 48,139 | 82,213 | 58,867 | 32,092 | 32,276 | 34,005 | 32,009 | 516,525 |

| Existing Flows, cfs | 279 | 285 | 299 | 509 | 1,353 | 1,193 | 681 | 459 | 317 | 313 | 307 | 268 | |
| Resulting Flows, cfs | 525 | 558 | 554 | 828 | 1,438 | 1,268 | 648 | 583 | 593 | 525 | 571 | 521 | |

*By cweb*
Average Year Flows at the Denver Gage

- Current Flow
- Future Flow

http://www.hydrosphere.com/sb74/users/cweb/Den_Avg.htm

3/19/98
### Denver Gage

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<tbody>
<tr>
<td>Existing Flows, AF</td>
<td>6,913</td>
<td>6,516</td>
<td>9,298</td>
<td>22,297</td>
<td>69,728</td>
<td>50,652</td>
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<td>10,445</td>
<td>10,053</td>
<td>10,209</td>
<td>7,731</td>
<td>255,755</td>
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### Effects on Flows, AF:

- **Change at Chatfield:** 388, 395, -984, -1,678, -17,704, -13,880, -13,753, -10,117, -4,238, -1,850, 536, 473, -62,413
- **Cherry Creek GW RF's:** 1,045, 1,040, 1,096, 1,587, 2,088, 2,142, 2,452, 2,472, 1,964, 1,850, 1,480, 1,302, 20,520
- **Reuse of GW RF's:** -268, -268, -402, -669, -2,008, -1,339, -2,945, -2,945, -1,339, -669, -268, -268, -13,388
- **Additional RIS/LIRF's:** 2,453, 2,453, 4,292, 7,359, 10,425, 6,132, 4,906, 9,198, 6,132, 3,066, 2,453, 2,453, 61,321
- **Denver Basin Interactions:** -213, -193, -213, -206, -213, -213, -206, -213, -206, -213, -213, -2,512
- **At-Cities, Marcy WWTP's:** 1,331, 1,331, 1,331, 1,331, 1,331, 1,331, 1,331, 1,331, 1,331, 1,331, 1,331, 15,973
- **Total Effects:** 4,736, 4,759, 5,121, 7,722, -6,082, -5,820, -8,222, -274, 3,644, 3,514, 5,326, 5,078, 19,501

### Resulting Flows, AF:

<table>
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<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
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<tbody>
<tr>
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<td>117</td>
<td>151</td>
<td>375</td>
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<td>529</td>
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<td>176</td>
<td>163</td>
<td>172</td>
<td>126</td>
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<td>235</td>
<td>504</td>
<td>1,035</td>
<td>753</td>
<td>395</td>
<td>311</td>
<td>237</td>
<td>221</td>
<td>261</td>
<td>208</td>
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*By cwcb*
Average Year Flows at the Chatfield Gage

Current Flow  ■  Future Flow

http://www.hydrosphere.com/sb74/users/cweb/Chat_Avg.htm

3/19/98
Chatfield Gage

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<td>2,715</td>
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Effects on Flows, AF:

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<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
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<tbody>
<tr>
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<td>0</td>
<td>0</td>
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<td>-8,949</td>
<td>-3,355</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>-22,372</td>
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<tr>
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<td>0</td>
<td>0</td>
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<td>-4,943</td>
<td>-5,438</td>
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<td>-5,438</td>
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Resulting Flows, AF

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<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
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<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Total</th>
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<tbody>
<tr>
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<td>56</td>
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By cwcb

http://www.hydrosphere.com/sb74/users/cwcb/Chat_Avg.htm

3/19/98
Average Year Flows at the South Platte Gage

- Current Flow
- Future Flow

http://www.hydrosphere.com/sb74/users/cwcb/SPlatte_Avg.htm
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<th>apr</th>
<th>may</th>
<th>jun</th>
<th>Jul</th>
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<th>oct</th>
<th>nov</th>
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<td>0</td>
<td>-7,415</td>
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<td>1,590</td>
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<td>6,722</td>
<td>4,292</td>
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<td>6,547</td>
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<td>15,700</td>
<td>9,811</td>
<td>7,459</td>
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*By cweb*
### Tables and Figures

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<td>Figure 2</td>
<td>Aquifer Map of the Denver Basin</td>
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<tr>
<td>Figure 3</td>
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<tr>
<td>Figure 4</td>
<td>Determination of Appropriation in Non-Tributary Aquifers</td>
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<td>Figure 5</td>
<td>Generalized Geologic Sections through the Denver Basin</td>
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<td>Flow from Aquifer to Stream</td>
</tr>
<tr>
<td>Figure 7</td>
<td>No Flow</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Flow from Stream to Aquifer</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Constant Leakage from Stream</td>
</tr>
</tbody>
</table>
SOUTH PLATTE RIVER BASIN
HISTORIC AVERAGE ANNUAL STREAM FLOWS
(acre feet)

Figure 1
Prepared by the Hydrographic Branch (1995)
Historic averages obtained from USGS Water-Data Report CO-93

OFFICE OF THE STATE ENGINEER
COLORADO DIVISION OF WATER RESOURCES
Aquifer Map of the Denver Basin

Legend
- Denver Basin Aquifer
- Arapahoe Aquifer
- Denver Aquifer
- Fault
- Laramie Formation
- Laramie-Fox Hills Aquifer
- Upper Dawson Aquifer
- Lower Dawson Aquifer
- Township/Range

Denver Basin Aquifer

Division Boundary

County Boundary

Laramie Formation

Arapahoe Aquifer

Denver Aquifer

Laramie-Fox Hills Aquifer

Upper Dawson Aquifer

Lower Dawson Aquifer

Figure 2
SAMPLE CALCULATION: Annual Appropriation

\[ \text{Appropriation} = \frac{\text{Area}}{\text{effective saturation}} \times \text{specific yield} \times \frac{\text{aquifer life}}{100 \text{ years}} \]

\[ = \frac{80 \text{ acres} \times 150 \text{ feet} \times 0.20}{100 \text{ years}} \]

\[ = 24 \text{ acre-feet per year} \]

DETERMINATION OF APPROPRIATION IN NON-TRIBUTARY AQUIFERS

Figure 4
GENERALIZED GEOLOGIC SECTIONS THROUGH THE DENVER BASIN

Figure 5
FLOW FROM AQUIFER TO STREAM

Figure 6
Figure 7
Figure 8
CONSTANT LEAKAGE FROM STREAM

Figure 9
1.0 INTRODUCTION AND STUDY BACKGROUND

The 1996 General Assembly in Senate Bill 96-74 authorized establishment of a Special Water Committee (SWC) of nine legislators to investigate Denver Basin ground water management and South Platte River Basin issues. The Committee's consideration of these issues will be assisted by this technical study which was administered by the State Engineer and the Director of the Colorado Water Conservation Board (CWCB Director) which was also authorized in SB 96-74.

1.1. SPECIAL WATER COMMITTEE

The Special Water Committee consists of:

Representative Jeanne Adkins
Representative Ken Gordon
Representative Marilyn Musgrave
Representative Jack Taylor
Representative Brad Young

Senator Don Ament, Chairman
Senator Joan Johnson
Senator Richard Mutzebaugh
Senator Ed Perlmutter

The specific responsibilities of the Committee as set forth in the legislation include:

1. Define the scope of a technical study of issues to be administered by the State Engineer and the CWCB Director prior to the commencement of the study.

2. Hold public hearings on the draft report submitted by the State Engineer and CWCB Director.

3. Review and comment on the draft report.

4. Review and comment on the evidence and comments received at public hearings prior to issuance of the final report.

5. Make recommendations, if deemed necessary, for legislation based on the final report and public hearings.

1.2 RESPONSIBILITIES OF THE STATE ENGINEER AND CWCB DIRECTOR

The State Engineer and CWCB Director are directed to administer a study of issues enumerated in subsection (4) of section (3) of the statute. The progression of specific responsibilities of the State Engineer and the CWCB Director is as follows:

1. Submit the scope and methodology of the study to the Committee before commencement of the study.
2. Consult with affected interests and consider existing information throughout the study.

3. Subject each phase of the study to peer review and written comments by the members of several professional disciplines.

4. Begin the study no later than August 1, 1996.

5. Use data and information from previous and existing studies.

6. Use latest methodologies, including hydrologic modeling, to develop the information for the report.

7. Report the results to the Committee no later than June 1, 1997.

Because the statute states the specific items to be studied in very broad terms, it is the judgment of the State Engineer and the CWCB Director that the technical study will be most useful to the Special Committee if the scope and methodologies are the product of a consultative process among the Committee members, state agency personnel, and interested members of the public. This Draft Preliminary Scope of Work and Workplan therefore proposes a procedure that is intended to promote such a consultative process.

1.3 PRELIMINARY SCOPE OF WORK AND WORKPLAN

The issues to be studied are set forth in SB 96-74, subsection (4) of section (3) in subparagraphs (a) through (i). These subparagraphs are excerpted from the statute and repeated below for the reader’s convenience:

(a) An inventory of surface water and groundwater resources in the South Platte River Basin;

(b) The effect of existing efficiencies and conjunctive management of surface water and groundwater resources on future supply and on local and regional existing water rights above the Henderson gauge;

(c) The effect of existing water reuse on future supply and on existing water rights;

(d) A review of distribution system infrastructure in the Denver metro area to identify ways to promote maximum utilization of the water resources available to the South Platte Basin above the Henderson gauge;
(e) The effect on existing water rights of current recharge technology and practices in Denver Basin aquifers;

(f) The impact of de minimis standards for injury based upon an annual depletion standard;

(g) The effect of the four percent replacement and the two percent relinquishment requirements of current law on future water supplies and on existing water rights and the need for placement of post pumping depletions resulting from withdrawal of Denver Basin groundwater.

(h) Use of nontributary groundwater and its long-term impact on water rights; and

(i) An assessment of:

(1) The need for and scope of participation, including financial participation, by the State of Colorado in processes associated with the implementation of the federal “Endangered Species Act of 1973” 16 U.S.C. Sec. 1531, et seq., as amended, with respect to the exercise of water rights associated with water resources and the South Platte River Basin and the Denver Basin;

(II) Opportunities for the application of local and regional water use efficiency and reuse technologies and methods, in conjunction with additional water supply sources, to enhance the reliability and yield of water rights associated with the water resources of the South Platte River Basin and Denver Basin;

(III) Surface and groundwater development in the Lower South Platte River in accordance with the South Platte River Compact.

The issues to be analyzed are broadly stated and could be approached analytically in many different ways. Since fiscal and human resources are very limited, the Committee held an initial “scoping” meeting at which the State Engineer and the CWCB Director presented options for accomplishing the study.

The State Engineer and CWCB Director developed a final scope of work and workplan, considering the guidance provided by the Committee, as well as an assessment of the time and resources available to complete the specified work.
1.4 STUDY METHODOLOGY

The methodologies employed in the study reflect the legislative direction embodied in SB 96-74, while taking into account available fiscal and human resources and time limitations. SB 96-74 contained no appropriations for conducting the technical study. Therefore, as recognized in the text of SB 96-74, it was very important to use data and information from past and existing studies and information sources to minimize study costs and reduce the time necessary to complete certain tasks.

During the discussions on the final language in SB 96-74, it was indicated that a portion of unused funds appropriated in the CWCB’s Construction Fund in 1994 for acquisition of data and information in the South Platte River Basin may be available for this related study of issues affecting water rights and water resources management in the South Platte River Basin. The State Engineer and the CWCB Director used these funds to leverage existing investments by the State of Colorado in the Metropolitan Water Supply Investigation (MWSI), which developed extensive information and modeling capability that relates very closely to the issues defined in subsections 4(a) through (e), and (l) (II).

With respect to issue (4) (f), the State Engineer and CWCB Director invited interests to present their perspectives at a public meeting concerning de minimis standards for an annual depletion. Staff reviewed case law and related policy to offer a possible de minimis standard for consideration by interested members of the public and the Committee. A recommendation and rationale concerning an appropriate de minimus standard was provided to the Committee in the draft report.

With respect to issue (4) (g), the State Engineer and the CWCB Director reviewed current law concerning the four percent replacement and two percent relinquishment requirements at public meetings where affected interests were encouraged to present their views. In particular, parties involved in the negotiations resulting in the current law (SB 85-5) presented their understanding for the basis of the current law. Staff of the State Engineer developed an improved ground water model and reviewed previous studies to evaluate the assumptions in the current law with respect to assumed aquifer conditions. The intent is to determine if the four percent replacement requirement for not non-tributary ground water pumping is appropriate.

With respect to issue (4) (h), determinations regarding the long-term impacts on water rights of Denver Basin ground water pumping likely will require the use of current ground water models and existing information to look at impacts several hundred years into the future. Considerable input from affected interests is desired with opportunities for discussion of model data and results of the models along with review of comments provided in the peer review process. It is expected that the results of a related ongoing study, known as the Economic Life of the Denver Basin Aquifers will be used to assist with completing this portion of the overall study.
The assessment required under subsection (4) (i) (I), which deals with appropriate responses to the Endangered Species Act of 1973 and its impact on current and future water resources management, will be accomplished by the various water suppliers that make up the Platte River Project.

The assessment required under subsection (4) (i) (III), which considers additional water resources development in the Lower South Platte River, will be accomplished by the Lower South Platte River Group, Inc. This organization has received a grant of $75,000 from the CWCB Construction Fund for FY 97 to evaluate water development opportunities in the Lower South Platte River. This evaluation is to be completed by July of 1997.

1.5 LIMITATIONS

The South Platte River Basin water supply, conjunctive use, efficiency, and reusable-supply data contained in this report have been assembled largely from information available in preliminary form through the Metropolitan Water Supply Investigation (MWSI). The MWSI data has been generated using simplifying assumptions. One significant assumption which should be viewed as a limitation on use of any data contained in this report is that legal and institutional constraints on use, re-use, expansion of use, and conjunctive use of imported water, from the Blue River via Denver's Dillon/Roberts Tunnel system, were not fully considered. This assumption was made by MWSI to facilitate a free exchange of ideas and the effective brainstorming of alternatives. Because legal and institutional constraints were not fully addressed by MWSI, its data and conclusions may not reflect legally available alternatives.

The "Cooperative Agreement for Platte River Research and Other Efforts Relating to Endangered Species Habitats along the Central Platte River, Nebraska," included in this report by reference and summary (Technical Addendum #3), contains a commitment by Colorado to demonstrate that additional population in the South Platte River Basin will result in increased flow at the Nebraska line. Colorado's projected ability to demonstrate such an increase may be dependent, at least in part, on larger return flows from expanded transmountain diversions. It is assumed that the increased future deliveries from transmountain sources would occur under existing and new water rights of individual water providers. These water rights are not specified, and the implications of increased transmountain deliveries upon the water needs of Colorado River Endangered Species has not been addressed in this study.
2.0. INVENTORY OF SURFACE WATER AND GROUNDWATER RESOURCES IN THE SOUTH PLATTE RIVER BASIN

This chapter provides an inventory of the surface water and nontributary groundwater resources of the South Platte River Basin in Colorado. The purpose of this inventory is to provide a framework for understanding the "big picture" interrelationships between South Platte surface water and groundwater resources and various conservation, reuse, groundwater development and conjunctive use options being considered by Denver area water providers.

2.1 SURFACE WATER RESOURCES

As part of the surface water resources inventory for the Denver Basin and South Platte River Basin Technical Study, flow data has been developed for five key gage locations in the South Platte River basin. These locations include:

- South Platte at South Platte
- South Platte Below Chatfield
- South Platte At Denver
- South Platte at Henderson
- South Platte at Kersey

For most of these locations estimates of the following have been developed:

- Natural flows
- Historical flows
- Future flows
- Reusable return flow portions of historical and future flows
- Undeveloped (free water) portions of historical and future flows

Based on the availability of data for a period common to these locations, Hydrosphere developed these estimates for the 1950 through 1980 period of hydrologic record.

2.1.1 Natural Flows
For the purposes of this study, natural flows are defined as the surface water flows that would occur without the influence of human activities.

2.1.2 Future Flows
For the purposes of this study, future flows are defined as those flows which reflect "reasonably certain" future conditions with respect to municipal and industrial water
supply system development and associated water demands within the South Platte River basin.

2.1.2.1 SOUTH PLATTE, CHATFIELD, DENVER AND HENDERSON GAGES

For the South Platte, Chatfield, Denver and Henderson gage locations Hydrosphere relied on output data from Denver Water's Platte and Colorado Simulation Model (PACSM) reflecting Denver's Near Term modeling scenario. This scenario reflects the operation of Denver's water supply system at an annual raw water demand of 390,000 acre feet. This is the demand level that Denver's system will be capable of reliably meeting with the addition of several near term future measures including additional effluent exchanges, water conservation programs, nonpotable reuse projects and other minor supply-side additions. Denver expects that its service area demands will take at least 30 years to reach this level. By comparison, Denver's current raw water demand is approximately 265,000 acre feet per year. (Denver has recently revised its Near Term scenario to reflect a slightly larger annual raw water demand of 401,000 acre feet. Due to time and budget limitations, the future flows in this report do not reflect this change in Denver's plans. We believe that any changes to future flows would be very minor.) Denver's Near Term scenario also generally reflects future water demands and water supply system operations for Aurora, Thornton, Englewood and Centennial Water & Sanitation District. Increased levels of municipal return flows as well as diversions are reflected in this scenario.

Denver's Near Term modeled stream flows do not reflect three potentially significant factors: 1) runoff from impervious surfaces and lawn irrigation return flows derived from increased urbanization of the metro Denver area beyond 1991 levels; 2) increased future wastewater flows from Cherry Creek, Plum Creek and Clear Creek; and 3) exercise of certain junior water rights on the South Platte between Metro and Strontia Springs. Each of these factors was considered in the context of Denver's Baseline Near Term model scenario.

Runoff from Impervious Surfaces and Lawn Irrigation Return Flow

As a region urbanizes, much of the land is covered with impervious surfaces (streets, buildings, parking lots, etc.), which increase the amount of precipitation that runs off to surface streams. Also, as previously dry land becomes urbanized and regularly irrigated by municipal water supplies, return flow from those irrigated areas contributes to stream flows. This is further discussed in the next chapter.

Denver's Near Term flow data for the Denver and Henderson gages were adjusted upward beyond 1991 levels using the average monthly distribution of runoff from impervious surfaces (RIS) and lawn irrigation return flow (LIRF). For the purposes of
this study it was assumed that estimated future flow increases due to metro area RIS and LIRF would be fully included in the Denver and Henderson gage flows.

Increased Future Wastewater Flows from Tributaries

Denver's PACSM model uses historical gage data to simulate inflows from Plum Creek, Cherry Creek, Bear Creek and Clear Creek to the South Platte. However, it likely that future flows from some of these tributaries will increase due to increases in wastewater discharges.

At Near Term demand levels, Douglas County water demands will probably exceed 100,000 acre feet per year, with most of this supply coming from nontributary groundwater. As a result wastewater flows in the Cherry Creek and Plum Creek basins will increase significantly. While some of this wastewater is likely to be reused through augmentation plans and direct reuse, a net increase in wastewater flows is projected, in both the Cherry Creek and Plum Creek basins. To estimate this net increase in wastewater flow, future Douglas County water demands met by nontributary groundwater, resulting wastewater flows and associated augmentation/reuse plans were estimated based on current County projections (Mulhern, 1995). The net increase in wastewater flows derived from nontributary groundwater sources was calculated taking into account average monthly municipal delivery and wastewater production patterns, augmentation plans and direct reuse plans. The resulting net increase in wastewater ranged from 1 cfs to 20 cfs and averaged 5,700 acre feet per year. These flows were added to Denver's modeled flows at the Chatfield, Denver and Henderson Gages.

Flows from Clear Creek into the South Platte have increased since 1990 by approximately 15 cfs due to wastewater discharges from the Coors/Golden plant no longer being diverted by the Croke Canal. These flow increases are not reflected in Denver's modeled Henderson gage flows. This increased Clear Creek inflow generally affects flows at the Henderson gage during all months except August through October, when intervening irrigation rights on lower Clear Creek divert most of this water. It was assumed for the purposes of this study that these wastewater flows would increase average flows at the Henderson gage by 15 cfs during November though July. Denver's modeled flows at Henderson were adjusted accordingly. Increased flows from Bear Creek and Plum Creek compared to historical gage records were assumed to be negligible.

Junior South Platte Water Rights

Denver's model does not include several junior water rights which could affect South Platte flows at the Chatfield, Denver and Henderson gages. These include: 1) Thornton's junior water rights at the Burlington Ditch and its conditional exchange rights
from Metro to the Burlington Ditch and to various locations on Clear Creek; 2) Aurora’s junior storage rights at Spinney Mountain Reservoir; and 3) Englewood’s exchange rights from the St. Vrain and from Clear Creek to Chatfield Reservoir. These rights were not included in Denver’s model because they are junior to Denver’s water rights and would not affect Denver’s system yield. They would, however, affect stream flows primarily at the Henderson gage and to lesser degrees at the Denver and Chatfield gages. These water rights would reduce future flows primarily during the months of May through August when stream flows are relatively high. However, the future exercise of these water rights will be highly variable due to constraints of stream flows, call conditions, water quality and water demands. It is therefore unlikely that these water rights would be fully utilized every year. A full analysis of the effects of these rights was beyond the scope of this study. Based on a review of the water rights and flow conditions involved it was assumed for the purposes of this study that these rights would reduce average flows at the Henderson gage by 100 cfs during May though August. Denver’s modeled flows at Henderson were adjusted accordingly.

2.1.2.2 KERSEY GAGE

To develop estimated future flows for the Kersey gage, Hydrosphere adjusted the historical Kersey gage flows to reflect the following: 1) changes in flows at the Henderson gage due to future operations of metro Denver area water supply systems as modeled by Denver Water and adjusted, described above; 2) changes in historical flows from the St. Vrain, Big Thompson and Cache La Poudre basins due to increased municipal and industrial water use in these basins, future Windy Gap project water deliveries, and to account for the fact that Colorado-Big Thompson project deliveries did not reach full levels until 1953; and 3) changes in diversions by District 2 irrigation ditches in response to future changes in supplies.

2.1.3 REUSABLE FLOWS

Reusable flows from the metro Denver area were estimated only for the Henderson gage since most reusable return flows are generated at the Metro Wastewater Reclamation District plant or at downstream locations. All metro Denver area reusable flows are assumed to accrue to the river at the Henderson gage even though a small portion of these reusable flows would actually occur slightly downstream. Reusable return flows were estimated for both existing and future conditions. Estimates were generated as part of the MWSI project through review of existing and future water supply system operations for Denver Water, Aurora, Westminster, Arvada, Thornton, major Douglas and Arapaho County water districts, Broomfield, Northglenn, Englewood and South Adams County Water & Sanitation District. Separate estimates of reusable return flows from Northern Front Range providers were also generated. In the future the gross amount of reusable return flows from all of these sources is estimated to be
approximately 292,000 acre feet per year. Current plans for reuse of these future reusable flows amount to approximately 183,000 acre feet per year.

2.8 UNDEVELOPED FLOWS

Undeveloped flows were estimated for the South Platte, Chatfield and Henderson gages using output data from Denver’s Near Term PACSM model scenario. These flows reflect excess flows at these gage locations under future demand conditions based on modeled water rights and demands. The criteria for excess flows for the South Platte and Chatfield gages were meeting a 550 cfs flow target at the Henderson gage from April through September and no shortage to water rights above the Henderson gage. The criteria for excess flows for the Henderson gage were meeting a 550 cfs flow target at the Henderson gage from April through September and a 200 cfs target from October through March.

The subject of undeveloped flows at the Kersey gage has been previously addressed in the South Platte River Basin Assessment Report (Woodward Clyde, 1982). That study reported annual historical and anticipated future undeveloped stream flows at Kersey as averaging 186,000 acre feet per year and 233,000 acre feet per year, respectively, for the 1953-1978 hydrologic period. This previous analysis was reviewed and found to be a reasonably accurate estimate of undeveloped stream flows for this location.

2.9 GROUNDWATER PRODUCTION ESTIMATES FROM THE DENVER BASIN AQUIFERS

The purpose of this sub task as described in the scope of work is to develop a 1995 groundwater production estimate from the Denver Basin aquifers, estimate groundwater return flows to the surface water system, and identify and quantify groundwater reuse. Personnel from the State Engineer’s Office (SEO), as part of their S.B. 96-74 groundwater flow modeling work, assembled 1996 municipal groundwater production information from the Denver Basin aquifers. Additionally, the SEO totaled well permit records by beneficial use category. The well permit work reflects the number of well permits in 1996. As more data is available for 1996 than 1995, 1996 production estimates from the Denver Basin aquifers were assembled instead of 1995.

2.10 GROUNDWATER SUMMARY

Total groundwater use from the Denver Basin aquifers for 1996 is summarized on Table 2-20. Total production in 1996 is estimated to be 58,474 acre feet. On a continuous annual production basis this volume represents 80.8 cubic feet per second. Information on the bottom portion of the table includes: the number of wells, average use estimate per well, total production by category, and the percentage of each use
compared to the total use estimate. The data shows that municipal production from the Denver Basin aquifers is 42.6 percent of the total use, irrigation is 21.5 percent, commercial and industrial use is 10.1 percent, domestic and livestock is 24.6 percent, and household use only is 1.1 percent of the total.

With an average accuracy of plus or minus 30 percent on the commercial-industrial, irrigation, domestic use, and household use only production estimates, total production from the Denver Basin aquifers is estimated to range from 48,406 to 68,542 acre feet in 1996. On a continuous annual production basis these volumes convert to 66.9 and 94.7 cfs, respectively.

2.11 SURFACE WATER RETURN FLOW AND REUSE ESTIMATES FROM THE DENVER BASIN AQUIFERS

A portion of the groundwater pumped from the Denver Basin aquifers for each beneficial use is returned to the surface water system. Return flow percentages are high, (90 percent), for household use only and commercial and industrial uses, and low, (20 percent), for irrigation use. The municipal and domestic and livestock return flow percentage, 50 percent, reflects a combination of in-house and irrigation use. From the estimated 1996 production from the Denver Basin aquifers of 58,474 acre feet, 28,522 acre feet is estimated to return to the surface water system. This volume of production and gross return flow represents a gross return flow percentage of 49 percent (28,522 af/58,474 af).

Return flows generated from municipal use of Denver basin groundwater are legally reusable. Some groundwater suppliers are currently reusing a portion of their groundwater return flows for augmenting alluvial well pumping and for direct irrigation purposes. Estimates of current levels of reuse of groundwater return flows were obtained from groundwater suppliers in Douglas and Arapahoe Counties. Approximately 2,400 acre feet per year of Denver Basin groundwater return flows are currently being consumed through augmentation and direct use.
3.0 ESTIMATE OF THE IMPACT ON RUNOFF TO THE SOUTH PLATTE RIVER FROM CONSTRUCTION OF IMPERVIOUS SURFACES IN THE DENVER METROPOLITAN AREA FOR THE PERIOD 1950-1995

This chapter describes an analysis of the increase in South Platte River gains through the Denver metropolitan area over the past several decades as a result of urbanization. The approach used to estimate the increased stream flow gains assumes the gains have resulted primarily from (1) runoff from impervious surfaces (RIS), and (2) lawn irrigation return flows (LIRF).

3.1 BACKGROUND

The analysis relies on previous studies which have indicated that stream flow gains have increased as the Denver area has urbanized, and that some portions of the gains are not explained by increases in precipitation.

Denver Water, as a part of its PACSM modeling studies, developed estimates of the total increase in gains through the Denver metropolitan area since 1947. The MWSI study included estimates of the current LIRF in the Denver area. The difference between the total urban gains and the LIRF is assumed to approximate the increase in RIS. The urban gain estimates were disaggregated into four reaches of the South Platte River defined by the following locations: Chatfield Reservoir, the Denver gage, the Burlington Ditch headgate and the Henderson Gage. Finally, historical daily stream flow records for Cherry Creek were reviewed to characterize daily gain variations.

It should be noted that Denver Water is in the process of revising its estimates of stream gains through the Denver metropolitan area. Denver's previous gains estimates based on Denver's virgin flow data as of 1995 and on preliminary analyses of climatic data. Denver has since refined its virgin flow data and is in the process updating and refining its estimates of stream gains, which rely in part on those virgin flow data. The results of these later studies were not available at the time of this report's publication. The results discussed in this chapter should therefore be considered provisional.

In addition, there are factors other than runoff from impervious surfaces and lawn irrigation return flows which may partially explain the increase in gains. These include as-of-yet undiscovered correlations with precipitation events, declines in agricultural water use and alluvial well pumping in the Denver area over time, and seasonal leakage into and out of regional wastewater collection systems. These uncertainties need to be further studied to ultimately derive better estimates of urban gains.
3.2 TOTAL GAINS

The total gains between the Waterton and Henderson gages were estimated from 1947 through 1991 based on virgin flow estimates. The virgin inflows to the Denver area were subtracted from the virgin outflow at the Henderson gage.

The period from 1949-1969 represents the pre-development period with an average gain of about 20,000 acre-feet per year (af/yr), The period from 1974-1991 represented the post-development period. There appears to be a generally increasing trend in the gains from the mid-1950's through the end of the study period in 1991. Therefore, it was assumed that the average gain during the last five years of the study period represented the current level of total gains through the Denver area. The average annual gain from 1987 through 1991 was 111,000 af.

3.3 PRE-DEVELOPMENT GAINS

Although Denver Water defined the 1949-1969 average gain as representative of pre-development conditions, Denver was obviously urbanized to some extent prior to and during this period. Therefore, an estimate of the runoff that would occur absent development was made to assess whether any portion of the pre-1970 gain could be considered to be due to urbanization.

Information published by the U.S. Geological Survey (USGS, 1970) indicates the average runoff from the Denver area is about 1.5 inches per year which equates to a volume of 45,000 af/yr. This exceeds the 20,000 af/yr gain for the 1949-1969 period. The results appear to indicate that the gain estimate during the 1949-1969 period would be largely comprised of gain that was present prior to urbanization. As a result, the 20,000 af/yr gain for the 1949-1969 period was assumed to represent the pre-development gain.

3.4 URBAN GAIN

The gain from urbanization of the Denver area was computed as the difference between the average 1987-1991 total gain (111,000 af/yr) and the average pre-development gain (20,000 af/yr). The result is an annual urban gain volume of 91,000 af/yr.

The data was analyzed to determine a representative monthly distribution of the post-development gain. The distribution exhibits a winter base flow component that is comprised of lawn irrigation return flows, direct snowmelt runoff and lagged underground return of runoff from impervious surfaces. During the summer months the

\[1\] Runoff from impervious surfaces to permeable areas which then infiltrates to the ground water system.
distribution exhibits a bi-modal characteristic with peaks in May and August.

The urban gain was split into incremental amounts tributary to the index gages based on the urbanized area tributary to each gage as shown in the following table.

<table>
<thead>
<tr>
<th>Location</th>
<th>Incremental Urbanized Area (square miles)</th>
<th>Incremental Urbanized Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chatfield Reservoir</td>
<td>16</td>
<td>4%</td>
</tr>
<tr>
<td>Denver Gage</td>
<td>246</td>
<td>64%</td>
</tr>
<tr>
<td>Burlington Ditch</td>
<td>21</td>
<td>6%</td>
</tr>
<tr>
<td>Henderson Gage</td>
<td>106</td>
<td>27%</td>
</tr>
<tr>
<td>Total</td>
<td>389</td>
<td>100%</td>
</tr>
</tbody>
</table>

3.5 LAWN IRRIGATION RETURN FLOWS (LIRF)

The current annual LIRF for the Denver metropolitan area are estimated at about 39,000 af/yr. It was assumed that these return flows accrue to the South Platte River and its tributaries at an approximately constant year-around rate. This is due to the relatively low transmissivity of the surface formations underlying the metro area and the relatively long return flow distances.

The reusable portion of the LIRF for the entire metro Denver area was estimated to be about 47% of the total LIRF, or 18,000 af/yr, based on the current mix of water sources used by Denver metropolitan water providers. Most of this amount, including the LIRF of Denver and Aurora, has not been adjudicated by the water court.

3.6 RUNOFF FROM IMPERVIOUS SURFACES (RIS)

The RIS was estimated as the difference between the total urban gain (91,000 af/yr) and the portion estimated to result from LIRF's (39,000 af/yr). The result is an estimated annual RIS of about 52,000 af/yr.

Unlike LIRF, RIS is assumed to be non-reusable by the water provider from whose service area the RIS originated. Instead, these gains become part of the natural river flow available for priority allocation.
3.7 NON-REUSABLE URBAN GAIN

The overall non-reusable urban gain is comprised of the RIS (52,000 af/yr) and non-reusable LIRF (approximately 21,000 af/yr), totaling about 73,000 af/yr.

3.8 URBAN GAIN USABILITY

The LIRF accrue on a relatively constant basis. However, most of the RIS occurs within a matter of days following precipitation events. In order to evaluate the gain hydrograph, it was assumed that timing of the gain in the Cherry Creek basin below Cherry Creek Reservoir is representative of the timing of the urban gain across the entire Denver area. A frequency distribution of the daily gains from 1987 through 1995 was prepared for this portion of the Cherry Creek basin. This frequency distribution was applied to the average urban gain above the Henderson gage (125 cfs) in order to compute a typical annual frequency distribution for the total urban gains upstream of Henderson as summarized below.

<table>
<thead>
<tr>
<th>Urban Gain Upstream of Henderson (cfs)</th>
<th>Percent of Annual Days with Greater Gain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>84%</td>
</tr>
<tr>
<td>100</td>
<td>37%</td>
</tr>
<tr>
<td>150</td>
<td>20%</td>
</tr>
<tr>
<td>200</td>
<td>14%</td>
</tr>
<tr>
<td>300</td>
<td>7%</td>
</tr>
<tr>
<td>400</td>
<td>4%</td>
</tr>
<tr>
<td>500</td>
<td>3%</td>
</tr>
<tr>
<td>1000</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

3.9 SUMMARY OF RESULTS

The following is a summary of the increase in gains resulting from urbanization of the Denver metropolitan area:
1. The estimated stream flow gain resulting from urbanization is summarized as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Estimated Annual Gain at Henderson (af/yr)</th>
<th>Estimated Average Gain at Henderson (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runoff from Impervious Surfaces</td>
<td>52,000</td>
<td>71</td>
</tr>
<tr>
<td>Lawn Irrigation Return Flows</td>
<td>39,000</td>
<td>54</td>
</tr>
<tr>
<td>Total Urban Gain</td>
<td>91,000</td>
<td>125</td>
</tr>
<tr>
<td>Reusable Urban Gain</td>
<td>18,000</td>
<td>25</td>
</tr>
<tr>
<td>Non-Reusable Urban Gain</td>
<td>72,000</td>
<td>100</td>
</tr>
</tbody>
</table>

The reusable portion of the urban gain represents the estimated return flows derived from initial irrigation use of totally consumable water sources. These return flows are assumed to be reusable by the water providers which are the source of the gain. The reusable gain was estimated as 47 percent of the lawn irrigation return flows. The non-reusable gain belongs to the stream and is subject to allocation under the priority system.

2. Between 1950 and 1990, the population of the Denver metropolitan area increased by 1,273,000 persons. Based on this increase, the total stream flow gain from urbanization equates to approximately 0.10 cfs, per 1,000 persons.

3. The timing of the urban gain varies depending on the gain component. Lawn irrigation return flows are assumed to accrue to the stream at a generally constant rate year-around. The runoff from impervious surfaces is highly influenced by the timing of precipitation events.

4. The usability of the urban gain by downstream water users is influenced by the rate at which the gain occurs. Much of the runoff from impervious surfaces occurs as storm runoff over a two to three day period following the precipitation event. Peak runoff flows may be partially unusable because the gain rate may exceed the capacity of the downstream diversion structures.

5. The analysis described provides estimates of urban gains at several locations in the Denver metropolitan area. These estimates should not be interpreted as water that is physically available at the various locations. Portions of the estimated gains are undoubtedly diverted and consumed within the Denver area.
6. Additional studies are needed in order to refine estimates of urban gains. Recommended areas of additional study are listed on pages 4-9 and 4-10 of Technical Addendum 1.
4.0 EFFECT OF EXISTING EFFICIENCIES AND CONJUNCTIVE MANAGEMENT 
ON FUTURE WATER SUPPLY AND WATER RIGHTS ABOVE THE 
HENDERSON GAUGE

The focus of Chapter 4 is to explore water conservation and conjunctive use in terms of 
their long-term water supply potential and their effects on existing water rights above 
the Henderson Gage. Hydrosphere’s approach to this task has consisted of the 
following steps:

1. An inventory of existing water efficiency measures and practices.
2. An inventory of existing conjunctive management practices.
3. Development of quantitative estimates of the water supply effects of 
   existing and projected future water efficiency measures and practices.
4. Development of quantitative estimates of the water supply effects of 
   existing and estimated future conjunctive management practices.
5. An analysis of the impacts associated with efficiency and conjunctive 
   management practices on South Platte River flows at the Henderson 
   gage.
6. An evaluation of the combined effects of existing and future water efficiency and 
   conjunctive management practices on existing water rights above the Henderson 
   Gage.

The results of the information gathering and analysis efforts described above are 
summarized in this chapter.

4.1 INVENTORY OF EXISTING WATER EFFICIENCY PRACTICES

Hydrosphere conducted a survey of the water conservation practices of Aurora, 
Boulder, Denver Water, and the Centennial Water & Sanitation District. The 
conservation measures and practices employed in these communities should provide a 
good indication of trends throughout the metropolitan area. While the survey identified 
the conservation measures described below as practices that are currently being 
employed by many water suppliers or are likely to be implemented in the future, the 
manner in which these practices are implemented varies substantially between different 
water suppliers.
Most of the water conservation practices currently being employed by metropolitan area water suppliers are designed primarily for the residential water use sector but are also applicable to the commercial and public sectors. These water efficiency measures are summarized below.

**Table 4-1**

Conservation Practices in Metro Denver Area

<table>
<thead>
<tr>
<th>Conservation Measures</th>
<th>Aurora</th>
<th>Boulder</th>
<th>Denver</th>
<th>Centennial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-efficient fixtures &amp; appliances:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voluntary program</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Regulatory program(^{(a)})</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Low water-use landscaping:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voluntary program</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Regulatory program(^{(b)})</td>
<td>X</td>
<td>(X)^{(b)}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation efficiency measures</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Leak detection and repair</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Education programs</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Customer water use audits</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Water use restrictions</td>
<td>(X)^{(c)}</td>
<td></td>
<td>(X)^{(d)}</td>
<td></td>
</tr>
<tr>
<td>Metering</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pricing incentives</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
(b) Landscaping code applies only to municipal rights-of-way, parks, and new industrial parks.
(c) Mandatory rationing employed during drought periods, otherwise voluntary.
(d) Voluntary guidelines for every third day outdoor watering schedule.

4.2 WATER SUPPLY EFFECTS OF EXISTING AND FUTURE EFFICIENCY PRACTICES

The effectiveness of water conservation practices varies greatly among water suppliers as a function of which program elements are adopted, how long the programs have been in place, and the level of effort associated with educational programs. Various land use, demographic and economic factors also influence the effectiveness of water conservation programs. Without a detailed evaluation of development patterns, demographics and economic factors, it is not possible to accurately isolate the impacts of existing programs, nor is it possible to definitively quantify regional levels of savings from future programs.

The results of Denver Water’s preliminary analysis of conservation savings is summarized in Table 4-2 below:

Table 4-2

<table>
<thead>
<tr>
<th>Conservation Measures</th>
<th>Years</th>
<th>Total Savings (acre-feet/yr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-efficient fixtures and appliances</td>
<td>1980 - 94</td>
<td>8,255</td>
</tr>
<tr>
<td>Leak detection and repair</td>
<td>1980 - 94</td>
<td>1,300</td>
</tr>
<tr>
<td>Customer water use audits</td>
<td>1987 - 94</td>
<td>804</td>
</tr>
<tr>
<td>Metering</td>
<td>1987 - 92</td>
<td>13,475</td>
</tr>
<tr>
<td>All other measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low water-use landscaping</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation efficiency measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education programs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pricing incentives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980 - 94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>29,500</td>
</tr>
</tbody>
</table>

Approximately 45 percent of the total estimated conservation saving for the Denver Service area is attributed to metering of about 86,000 single family residential taps that were unmetered prior to 1987. Because the practice of metering is commonly included
in water conservation programs throughout the Denver Metropolitan Area, we have assumed, for purposes of this analysis, that the effect of metering savings for all single family residential taps should be included in the estimate of overall conservation savings.

Table 4-3

Estimated Existing and Future Municipal Treated Water Use and Efficiency Savings for the Denver Metropolitan Area (acre-feet/year)

<table>
<thead>
<tr>
<th>City</th>
<th>1996 Use</th>
<th>1996 Savings(^{(a)})</th>
<th>Future Use</th>
<th>Future Savings(^{(b)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denver Water</td>
<td>235,000</td>
<td>57,100</td>
<td>333,600</td>
<td>81,000</td>
</tr>
<tr>
<td>Aurora</td>
<td>49,500</td>
<td>12,000</td>
<td>69,800</td>
<td>16,900</td>
</tr>
<tr>
<td>Westminster</td>
<td>19,500</td>
<td>4,700</td>
<td>26,000</td>
<td>6,300</td>
</tr>
<tr>
<td>Arvada</td>
<td>16,500</td>
<td>4,000</td>
<td>22,000</td>
<td>5,300</td>
</tr>
<tr>
<td>Thornton</td>
<td>18,700</td>
<td>4,500</td>
<td>82,300</td>
<td>20,000</td>
</tr>
<tr>
<td>Consolidated Mutual</td>
<td>12,600</td>
<td>3,100</td>
<td>14,900</td>
<td>3,600</td>
</tr>
<tr>
<td>Douglas Co. Water Auth.</td>
<td>32,000</td>
<td>7,800</td>
<td>128,700</td>
<td>31,200</td>
</tr>
<tr>
<td>Englewood</td>
<td>10,200</td>
<td>2,500</td>
<td>11,200</td>
<td>2,700</td>
</tr>
<tr>
<td>Golden</td>
<td>5,000</td>
<td>1,200</td>
<td>8,000</td>
<td>1,900</td>
</tr>
<tr>
<td>Broomfield(^{(c)})</td>
<td></td>
<td></td>
<td>7,500</td>
<td>1,800</td>
</tr>
<tr>
<td>Northglenn</td>
<td>4,600</td>
<td>1,100</td>
<td>6,500</td>
<td>1,600</td>
</tr>
<tr>
<td>S. Adams Co. W &amp; S Dist</td>
<td>5,500</td>
<td>1,300</td>
<td>11,000</td>
<td>2,700</td>
</tr>
<tr>
<td>Brighton</td>
<td>4,000</td>
<td>1,000</td>
<td>16,000</td>
<td>3,900</td>
</tr>
<tr>
<td>misc.</td>
<td>2,000</td>
<td>500</td>
<td>3,000</td>
<td>700</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>415,100</strong></td>
<td><strong>100,800</strong></td>
<td><strong>740,500</strong></td>
<td><strong>179,600</strong></td>
</tr>
</tbody>
</table>

(a) 12.55 percent of 1996 Use.
(b) 15.0 percent of Future Use.
(c) 1996 Treated water use of 5,300 acre-feet and Future use of 6,500 acre feet for Broomfield is included in the respective use figures for Denver.

The effectiveness of water conservation measures in terms of actual water savings may vary substantially between water suppliers as a function of which program elements are employed, the manner in which they are implemented, how long the programs have
been in place, and various land use, demographic and economic factors. Without a
detailed evaluations of these factors, it is difficult to isolate the impacts of existing
and/or future water conservation programs from the other factors that influence water
usage. For purposes of this study, because the water conservation practices employed
by Aurora, Boulder, Denver Water, and Centennial (see Table 4-1 above) appear to be
generally consistent, we assumed that the estimated water conservation savings
realized to date by Denver Water are representative of the savings being achieved by
other suppliers throughout the metropolitan area. Given this assumption, existing and
future conservation savings can be estimated, based upon current and projected levels
of demand as shown above in Table 4-3 for the Denver Metropolitan Area.

It is important to note that the future treated water use figures shown in Table 4-3 are
based upon long-term demand projections for each of the water suppliers listed. Some
metro area water providers may reach these demand levels sooner than others.

4.3 WATER SUPPLY EFFECTS OF EXISTING AND FUTURE CONJUNCTIVE
MANAGEMENT PRACTICES

Conjunctive management, for purposes of this study, refers to the joint use of surface
and nontributary groundwater systems in a manner that is designed to increase the
delivery of sustainable water supplies to the metropolitan area. In many years, there
are divertible surface water supplies in excess of the amount required to meet demands
and fill storage reservoirs. Conjunctive use systems would capture and more fully
utilize these unused surface supplies through either of the following techniques:

1. Expanded use of surface water supplies to directly meet municipal demands
during average and wet years, while reserving groundwater for use in below
average and dry years;

2. Expanded use of surface water supplies to recharge nontributary aquifers during
average and wet years, while reserving groundwater for use in below average
and dry years;

Both of these techniques could involve arrangements that would allow "borrowing" of
water when available from surface water reservoirs with repayment through the delivery
of groundwater back to the surface water supplier to meet direct demands during
periods of drought. Under this arrangement, surface reservoirs could be more fully
drawn down to meet expanded municipal demands and more effectively capture
storable flows while drought protection would be provided by groundwater supplies.
Basically, the concept of conjunctive management allows the linkage of groundwater
and surface water systems so that nontributary aquifers become functionally equivalent
to surface water storage. This allows water suppliers to more fully utilize available
surface water supplies while reducing nontributary groundwater withdrawals and
extending the life of nontributary aquifers. The MWSI Project, Phase II Conjunctive
Use Summary Report provides a more detailed discussion of conjunctive management concepts and alternative approaches.

4.4 EXISTING CONJUNCTIVE MANAGEMENT PRACTICES

Existing conjunctive management practices involve (1) limited recharge of Denver Basin aquifers by the Centennial Water and Sanitation District, and (2) experimental recharge of Denver Basin aquifers by the Willows Water District in cooperation with Denver Water and others.

The water supply effect of these existing conjunctive management practices are very limited. In the context of the water supply for Centennial, the District’s 1996 total water demand was 9,889 acre-feet, which includes 1,561 acre-feet of deliveries from nontributary groundwater. The injection of 654 acre-feet to the Arapahoe aquifer results in a net nontributary groundwater withdrawal of about 907 acre-feet and accounts for about 6.6 percent of Centennial’s 1996 water supply. Regionally, this is less than 0.3 percent of 1996 treated water deliveries.

The Willows Water District’s recharge demonstration project was concluded in 1996, and is thus not considered to be a meaningful component of their existing water supply.

4.5 FUTURE CONJUNCTIVE MANAGEMENT

Future plans for conjunctive use are actively being examined by the Douglas County Water Authority in cooperation with Denver Water, as an ongoing part of the MWSI Project, and in possible follow-up studies. Conceptual plans for conjunctive use projects at several levels are currently being developed and refined for further evaluation and discussion by interested parties. With these refinements and discussions pending it is premature to identify any specific conjunctive use project that could be characterized as likely, or even possible. However, for the purposes of this study, two hypothetical scenarios were developed to illustrate potential water supply and South Platte River impacts. These scenarios portrayed two alternative approaches to a conjunctive use arrangement between Douglas County and Denver.

4.6 ANALYSIS OF WATER SUPPLY EFFECTS

The water supply implications of the hypothetical conjunctive management Scenarios A and B are summarized below in Table 4-4.
Table 4-4
Summary of Conjunctive Use Modeling Results
(1947-91 Average Annual Acre-feet)

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Scenario A</th>
<th>Scenario B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater Pumping</td>
<td>48,000</td>
<td>33,812</td>
<td>21,447</td>
</tr>
<tr>
<td>Groundwater Recharge</td>
<td>0</td>
<td>1,853</td>
<td>20,560</td>
</tr>
<tr>
<td>Net Groundwater Withdrawal</td>
<td>48,000</td>
<td>31,958</td>
<td>916</td>
</tr>
<tr>
<td>Blue River Water Captured</td>
<td>0</td>
<td>2,277</td>
<td>21,391</td>
</tr>
<tr>
<td>% of Blue River Water Captured</td>
<td>0</td>
<td>5%</td>
<td>51%</td>
</tr>
<tr>
<td>Uncaptured Blue River Water</td>
<td>41,694</td>
<td>39,417</td>
<td>20,303</td>
</tr>
<tr>
<td>South Platte Water Captured</td>
<td>0</td>
<td>13,557</td>
<td>24,402</td>
</tr>
<tr>
<td>% of So. Platte Water Captured</td>
<td>0</td>
<td>25%</td>
<td>45%</td>
</tr>
<tr>
<td>Uncaptured So. Platte Water</td>
<td>53,761</td>
<td>40,204</td>
<td>29,359</td>
</tr>
<tr>
<td>Reusable Return Flow</td>
<td>24,000</td>
<td>17,117</td>
<td>10,559</td>
</tr>
</tbody>
</table>

The potential water supply benefits associated with these conjunctive management scenarios are represented by additional capture of unused surface waters from the Blue and South Platte Rivers and long term reductions in nontributary groundwater withdrawals which would extend the useful life of these aquifers. Scenario A results in the capture of a total of 15,834 acre-feet of Blue and South Platte unused surface supplies without the construction of additional surface water storage reservoir facilities or implementation of other measures. Scenario B results in the capture of a total 45,793 acre-feet of unused surface supplies. These additional surface supplies represent new yield to the participating water supply systems and would be a significant component of future water supply plans.

Due to the reductions in net groundwater withdrawals that occur with both Scenarios A and B, there is also a reduction the average annual volume of reusable return flows. In both scenarios, this reduction is more that offset by the amount of Blue River and South Platte water captured. Furthermore, it is unlikely that it will be physically possible to fully utilize these reusable return flows due to factors presented in the discussion of reuse in Chapter 5.

4.7 IMPACTS ON SOUTH PLATTE RIVER FLOWS AND AT THE HENDERSON GAGE AND EXISTING WATER RIGHTS
For purposes of this analysis, we have assumed that water demands in terms of underlying customer base in the metropolitan area will continue to grow to levels currently anticipated by metro area water providers. The continued use of water efficiency measures and the possible implementation of conjunctive use arrangements will affect the mix of water supply sources that would be used to meet these growing demands. Many of the water efficiency measures that will result in future demand reductions are already in place, but at this time, no specific conjunctive use plans have been identified or agreed upon by metro area water providers. The supply sources used to meet future demands will vary between individual water suppliers depending upon the sources that are practically available to their systems. (For example, Denver Water has the ability to expand utilization of its Blue River and Moffat Tunnel systems to meet higher demands.) Thus, growing demands in the metro area will be met from available supply sources combined in varying ways by water suppliers. These water supply sources and the manner in which their utilization will impact flows in the South Platte are described below.

1. **Water imported to the South Platte from other river basins and nontributary groundwater** - These sources are considered to be “new water” that does not currently contribute to South Platte River flows. Diversions of imported water and pumping of nontributary groundwater will result in return flows at wastewater treatment plants and from lawn irrigation that are new to the river and will increase flow throughout the year.

2. **Reuse and exchanges** - Generally, water suppliers have the right to reuse return flows from imported sources and nontributary groundwater to extinction through exchanges and/or direct reuse. Historically most of the return flows from these sources has not been reused, resulting in a windfall to downstream water users, particularly those with relatively junior water rights. (See Chapter 3.) Increases in reuse and exchanges will tend to reduce streamflows in the South Platte below Denver throughout the year but particularly in months during summer months when exchange opportunities and demands for nonpotable reuse are greatest.

3. **Expanded utilization of native South Platte supplies** - This supply source includes increases in diversions under existing direct flow water rights, increases in reservoir drawdowns, and development of new storage facilities or enlargement of existing facilities to capture spring and early summer flows when available. Expanded utilization of native South Platte supplies will tend to reduce streamflows primarily during the spring and early summer when existing municipal rights may be able to divert more water and when unappropriated water is most likely to be available for storage under new rights. During the remainder of the year, streamflow would tend to increase due to return flows
associated with increased use of South Platte supplies including reservoir releases.

4. **Acquisition and conversion of agricultural rights to municipal uses** - This supply source includes both new conversions of agricultural water rights and termination of leases of municipal rights to agricultural users. This source will generally result in a minor amount of increase to streamflows because the process of transferring irrigation rights to municipal uses via the water court process is rarely 100% efficient. In practice, the stream tends to benefit slightly as a result of water rights change proceedings.

5. **Efficiency Practices** - Water conservation will tend to reduce diversions and the volume of return flows to the river and will thus reduce streamflows in the South Platte below the metro area.

For purposes of evaluating the effect of existing water efficiency practices and two future conjunctive management scenarios on streamflows in the South Platte at Henderson, a spreadsheet model was developed to account for the net accretive and depletive effects of different combinations of the supply sources described above. The approach used to determine the mix of water supply sources that would be used to meet the higher level of existing demand that would occur without conservation was based upon the following assumptions:

- Denver Water would probably rely upon additional exercise of its existing absolute South Platte and Colorado Basin water rights, development of portions of its conditional South Platte and Colorado Basin water rights and additional reuse. While Denver has policies which emphasize sustainable water supplies and maximum use of its existing water rights, ultimately Denver may be required to rely on its Denver Basin groundwater at a significant level.

- Aurora would probably rely on full use of its existing absolute South Platte and transbasin water rights, additional development of South Platte, Arkansas and Colorado Basin water under new water rights or acquired water rights, and additional reuse. Aurora is currently completing its acquisition of Arkansas Basin irrigation rights and pursuing development of new supply projects in both the Eagle River Basin and the Tarryall Creek Basin. Ultimately Aurora may begin to rely on its Denver Basin groundwater at a significant level.
- Douglas County providers would probably offset loss of conservation and conjunctive use options with additional use of their nontributary groundwater rights, additional reuse efforts, and pursuit of additional South Platte and Colorado Basin supplies via new projects.

- As a group, the remaining water providers comprising the northern tier of the metro Denver area would probably rely on additional reuse, additional acquisition and change of South Platte irrigation rights and additional development of South Platte Basin water under new water rights.

The net effect of replacement of water conservation and conjunctive use with other water supply sources on stream flows in the South Platte, Colorado and Arkansas Basins would depend on the mix of "replacement" water supply sources implemented. For the purpose of this analysis, the following mix of replacement supplies was assumed:

**Table 2-5: Assumed Mix of Water Supply Sources Used For Replacement of Conservation and Conjunctive Use**

(acre feet per year)

<table>
<thead>
<tr>
<th>Replacement Supply Source</th>
<th>Existing Conservation</th>
<th>Plan A</th>
<th>Plan B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transbasin Imports</td>
<td>26,000</td>
<td>28,000</td>
<td>9,000</td>
</tr>
<tr>
<td>Nontributary Groundwater</td>
<td>5,000</td>
<td>57,000</td>
<td>86,000</td>
</tr>
<tr>
<td>Agricultural Conversion</td>
<td>15,000</td>
<td>30,000</td>
<td>30,000</td>
</tr>
<tr>
<td>Water Reuse</td>
<td>18,000</td>
<td>45,000</td>
<td>45,000</td>
</tr>
<tr>
<td>South Platte Storage</td>
<td>37,000</td>
<td>19,000</td>
<td>9,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>101,000</td>
<td>179,000</td>
<td>179,000</td>
</tr>
</tbody>
</table>

The South Platte River streamflow impacts of existing levels of water conservation and conjunctive management Scenarios A and B are shown in Figure 2-2 on the following page. With water conservation, streamflows in the South Platte tend to average about 60 cfs to 100 cfs less than would occur without conservation during the months of August through April. This effect is due to a reduction in the amount of return flows from less use of water from storage, less use of water imported from other river basins, and less use of nontributary groundwater that would have occurred without conservation. During the months of April through July, streamflows in South Platte tend to average about 25 cfs to 125 cfs more that would be the case without conservation. This effect is due to reduced municipal demands during the summer irrigation season combined with increases in reservoir spills resulting from reduced
reservoir drawdowns during the August through April period. It is also important to note that without water efficiency measures, increases in metro area water demands would result in decreases in streamflows below West Slope and possibly Arkansas River points of diversion and a possible decrease in groundwater levels. Under both Conjunctive Use Scenarios A and B, expanded use of direct flow rights and water from East and West Slope storage facilities would tend to increase average flows in the South Platte during all months of the year except for July under Scenario B. The combined effects of return flows from increases in utilization of imported water and nontributary groundwater would more than offset the effect of increased utilization of South Platte supplies.

**Figure 4-2**

**Effect of Conservation and Conjunctive Use on South Platte Stream Flows**

With regard to impacts on water rights, the water efficiency and conjunctive use practices described and quantified above have occurred and will occur in accordance with Colorado water laws under a variety of water rights decrees. Thus, by definition, these activities, if implemented in accordance with decrees, should not injure existing water rights.
Historically, junior water users on the South Platte River below Denver have benefited significantly from the return flows from transmountain diversions. Historical South Platte River flows at the Henderson Gage are presented in Chapter 1, South Platte Basin Inventory of Surface Water Resources in Table 1-9. Recorded flows at the Henderson Gage indicate a trend of increasing flows during the last 30 years associated with increases in transmountain diversions from the West Slope to meet growing water demands in the Denver Metropolitan Area. Water imported from the West Slope to the South Platte Basin has taken place primarily through the Denver’s Roberts Tunnel and Moffat Tunnel Collection Systems and Aurora’s Homestake Collection System. Increases in the use of nontributary groundwater to meet growing demands has also contributed to this trend of increasing flows at the Henderson Gage.

The historical record of flows at the Henderson Gage indicates that water efficiency measures implemented to date have been more than off set by return flows from increases in usage of imported water associated with growth in the metropolitan area. Because much of the increase in water demand has been met through increases in transmountain diversions and withdrawals of nontributary groundwater flow at the Henderson Gage have continued to increase. Future water conservation measures will serve to reduce the rate of future flow increases.

4.8 SUMMARY OF RESULTS

As a part of the SB-74 study, Hydrosphere examined the effects of water conservation measures and conjunctive management of surface water and groundwater resources by metro Denver area water providers on future water supply and on existing water rights above the Henderson Gauge. The following is a summary of the results of the analysis:

1. A variety of water efficiency practices have been effectively implemented by all major metro area water providers resulting in an estimated 100,800 acre-feet per year of existing savings.

2. Based upon current trends and projected future water conservation measures, it is estimated that future demands reductions will amount to about 179,600 acre-feet per year.

3. Water efficiency practices provide a significant component of the existing metro area water supply. Without water conservation measures, the demand for treated water would be about 24 percent greater than 1996 treated water use and currently projected future treated water demand for the metro area.

4. Without water efficiency practices, there would be additional pressure for development of Denver Basin groundwater, additional transbasin diversions,
more aggressive implementation of reuse and exchanges, acquisition and dry-up of irrigated agricultural land and development of South Platte surface storage projects.

5. Water efficiency practices generally result in reduced South Platte stream flows during the months of August through April and increased stream flows during the months of May through July. In the Colorado and Arkansas Basins, water efficiency results in an increase in streamflows in all months of the year over what would otherwise occur without conservation measures.

6. Existing conjunctive management practices consist of a small project being implemented by the Centennial Water and Sanitation District and a small demonstration project completed by the Willows Water District in cooperation with Denver Water and others. The 1996 water supply impact of Centennial's project was to reduce net nontributary groundwater withdrawals by about 654 acre-feet. Conjunctive use accounted for about 6.6 percent of Centennial's 1996 water supply.

7. Future plans for conjunctive management are currently being examined by the Douglas County Water Authority in cooperation with Denver Water, but at this time, it is premature to identify any specific conjunctive use project that could be characterized as likely, or even possible. Hypothetical conjunctive use plans examined in this report indicate potential water supply benefits ranging from about 16,000 acre-feet per year in Scenario A to 46,000 acre-feet per year in Scenario B. Either of these levels represent a potentially significant component of future water supply.

8. Existing conjunctive management practices are too small to have any meaningful impact on streamflows in the South Platte River at Henderson. Future hypothetical conjunctive use Scenario A would tend to produce a net reduction in average streamflows in the South Platte throughout the year, except in the month of July. Scenario B would tend to produce a net reduction in average streamflows in the South Platte throughout the year, except for the month of August. These streamflow changes result primarily from increased utilization of native South Platte supplies.

9. Future conjunctive management Scenarios A and B would also rely upon increased utilization of Blue River water, resulting in streamflow reductions in the Blue River below Dillon Reservoir during the spring and early summer months.

10. Conjunctive management implemented in accordance with decrees would not injure existing water rights, but would tend to reduce flows available to downstream water users that rely upon relatively junior water rights.
5.0 EFFECT OF EXISTING WATER REUSE ON FUTURE WATER SUPPLY AND ON EXISTING WATER RIGHTS

This chapter examines, from a regional perspective the effects of water reuse by metro Denver area water providers on future water supply and on existing water rights. Existing and expected future amounts of reusable water available to metro Denver area water providers, and return flows resulting from those supplies have been quantified. Existing reuse activities and future reuse plans in the metro Denver area have also been characterized.

5.1 BACKGROUND

For the purposes of this report, water reuse is defined as the use by a municipal water provider of return flow resulting from that provider's first use of water. Water reuse is any specific arrangement that utilizes return flows so that they would not otherwise be available to the stream for allocation under the priority system. From a consumptive use perspective, water reuse includes either one reuse or reuse to extinction.

Under Colorado water laws, reusable water can generally come from four sources: 1) imported transbasin water; 2) nontributary groundwater; 3) the historically consumed portion of water rights changed from one use to another, such as from irrigation to municipal use; and 4) water diverted under a water right which has been decreed to allow reuse. Reusable return flows are assumed to include both wastewater discharges and lawn irrigation return flows which originate from reusable supplies.

Broadly speaking, water reuse can be accomplished either by direct reuse or by substitution. Examples of direct reuse include irrigation of golf courses or supply of power plants with appropriated treated wastewater. Examples of substitution include water exchanges, plans of augmentation, first use agreements and water trades which allow for diversion of water at one location in substitution for water added to the stream at another location.

5.2 REUSABLE RETURN FLOWS

As part of the effluent management investigations conducted in the Metropolitan Water Supply Investigation (MWSI), the water supply portfolios of metro Denver area providers were inventoried and reusable supplies and reusable return flows were quantified using 1993 and 1994 data (Hydrosphere, 1995). In that study, existing levels of reusable supplies were quantified based on water use accounting for individual providers, surveys, and discussions with individual providers. Future levels of reusable supplies were quantified based on best available planning data; including modeling studies, decrees and individual provider’s reuse plans. Based on this
analysis, existing and estimated future reusable water supplies and reusable return flows are summarized in Table 5-1 below.

<table>
<thead>
<tr>
<th>Provider</th>
<th>Reusable supply Present</th>
<th>Present Future</th>
<th>Reusable wastewater Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denver Water</td>
<td>85,000</td>
<td>145,000</td>
<td>46,000</td>
<td>77,000</td>
</tr>
<tr>
<td>Aurora</td>
<td>49,000</td>
<td>70,000</td>
<td>26,000</td>
<td>38,000</td>
</tr>
<tr>
<td>Douglas County (1)</td>
<td>24,000</td>
<td>116,000</td>
<td>10,000</td>
<td>46,000</td>
</tr>
<tr>
<td>Thornton</td>
<td>9,000</td>
<td>45,000</td>
<td>5,000</td>
<td>24,000</td>
</tr>
<tr>
<td>Westminster</td>
<td>6,000</td>
<td>8,000</td>
<td>4,000</td>
<td>5,000</td>
</tr>
<tr>
<td>Arvada</td>
<td>4,000</td>
<td>5,000</td>
<td>1,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Other (2)</td>
<td>24,000</td>
<td>43,000</td>
<td>12,000</td>
<td>19,000</td>
</tr>
<tr>
<td>Subtotal</td>
<td>201,000</td>
<td>432,000</td>
<td>104,000</td>
<td>211,000</td>
</tr>
<tr>
<td>Reusable LRF's (3)</td>
<td></td>
<td>20,000</td>
<td></td>
<td>41,000</td>
</tr>
<tr>
<td>Total</td>
<td>201,000</td>
<td>432,000</td>
<td>124,000</td>
<td>252,000</td>
</tr>
</tbody>
</table>

(1) Includes all Douglas County Water Resource Authority
(2) Includes Brighton, Broomfield, Englewood, Golden/Coors, SACWSD and miscellaneous providers
(3) Lawn irrigation return flows

5.3 LEVELS OF REUSE

Levels of reuse vary to some degree from year to year, with higher levels of reuse occurring during average and below average years when yields from South Platte rights are relatively less and reusable supplies from transbasin and nontributary groundwater sources are relatively greater. Planned future levels of reuse were quantified based on individual providers' future reuse plans, and on provider responses to the Metro effluent reuse questionnaire. Existing and estimated future levels of reuse are summarized in Table 5-2 below.
### Table 5-2: Summary of Effluent Reuse Plan (Acre Feet Per Year)

<table>
<thead>
<tr>
<th>Provider(s)</th>
<th>Current Use</th>
<th></th>
<th>Planned Future Use</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct Subst</td>
<td>Direct Reuse</td>
<td>Total</td>
<td>Direct Subst</td>
</tr>
<tr>
<td>Denver</td>
<td>18,500</td>
<td>0</td>
<td>18,500</td>
<td>30,000</td>
</tr>
<tr>
<td>Aurora</td>
<td>6,400</td>
<td>400</td>
<td>6,800</td>
<td>12,900</td>
</tr>
<tr>
<td>Douglas County (1)</td>
<td>2,000</td>
<td>400</td>
<td>2,400</td>
<td>23,500</td>
</tr>
<tr>
<td>Thornton</td>
<td>3,000</td>
<td>0</td>
<td>3,000</td>
<td>24,500</td>
</tr>
<tr>
<td>Westminster</td>
<td>3,700</td>
<td>0</td>
<td>3,700</td>
<td>4,900</td>
</tr>
<tr>
<td>Arvada</td>
<td>1,300</td>
<td>0</td>
<td>1,300</td>
<td>1,900</td>
</tr>
<tr>
<td>Other (2)</td>
<td>18,200</td>
<td>0</td>
<td>18,200</td>
<td>30,900</td>
</tr>
<tr>
<td>Totals</td>
<td>53,100</td>
<td>800</td>
<td>53,900</td>
<td>128,600</td>
</tr>
</tbody>
</table>

(1) Includes all Douglas County Water Resource Authority
(2) Includes Brighton, Broomfield, Englewood, Golden/Coors, SACWSD and miscellaneous providers

### 5.4 EFFECTS ON FUTURE WATER SUPPLY

Water reuse has been and will continue to be a major water supply source for the metro Denver area. As previously discussed, reuse accounts for about 11% of the region's existing water supply, or about 54,000 acre feet per year. Reuse will account for approximately 20% of the region's water supply, over 167,000 acre feet per year, in the foreseeable future. If water reuse were not an option available to metro area water providers, these levels of supply deficits would have to be pursued via other means, such as additional transbasin diversions, new South Platte supply development, water conservation, nonttributary groundwater development or acquisition of irrigation water supplies.

Without reuse there would be additional pressure for development of Denver Basin groundwater, additional transbasin diversions, acquisition and dry-up of irrigated agricultural land and development of South Platte surface storage projects. Because reuse via exchanges and augmentation plans is a generally a relatively cost effective water supply source, replacement of the yield derived from reuse with other supply development options would result in significant increases in the price of water supplies. Water demand reductions, both through active water conservation programs and due to consumer price responses, would also occur.
5.5 EFFECTS ON EXISTING WATER RIGHTS

Water reuse activities described and quantified above have occurred or will occur in accordance with Colorado water laws under a variety of decrees for exchanges and plans for augmentation. Thus, by definition, water reuse activities implemented in accordance with decrees would not injure existing water rights. The water reused under these exchanges and augmentation plans is foreign to the natural flow of the South Platte and therefore generally unavailable for appropriation under the priority system.

The elimination of existing water reuse as a water supply option would decrease the metro Denver area's existing water supply by 54,000 acre feet per year, and would reduce the area's future water supplies by 168,000 acre feet per year to over 200,000 acre feet per year. Assuming that existing water demands would stay the same in terms of underlying customer base, water providers would have to resort to a combination of alternate water supply development and/or demand management measures. These would include transbasin diversions, new South Platte supply development, water conservation, nontributary groundwater development or acquisition of irrigation water supplies to make up the difference. While it is reasonable to assume that all providers would include some additional level of water conservation as a common element in their alternate water supplies, each provider or provider group would differ in their use of other supply sources.

The net effect of replacement of reuse with water conservation and other water sources on stream flows in the South Platte, Colorado and Arkansas Basins would depend on the mix of "replacement" water supply sources implemented. For the purpose of this analysis, the following mix of replacement supplies was assumed:

Table 5-3: Assumed Mix of Water Supply Sources For Replacement of (acre feet per year)

<table>
<thead>
<tr>
<th>Replacement Supply Source</th>
<th>Ultimate Potential</th>
<th>Ultimate Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Existing Reuse</td>
<td>Planned Future Reuse</td>
</tr>
<tr>
<td>Transbasin Imports</td>
<td>10,000</td>
<td>35,000</td>
</tr>
<tr>
<td>Nontributary Groundwater</td>
<td>2,000</td>
<td>35,000</td>
</tr>
<tr>
<td>Agricultural Conversion</td>
<td>10,000</td>
<td>28,000</td>
</tr>
<tr>
<td>Water Conservation</td>
<td>11,000</td>
<td>35,000</td>
</tr>
<tr>
<td>South Platte Storage</td>
<td>21,000</td>
<td>35,000</td>
</tr>
<tr>
<td>Total</td>
<td>54,000</td>
<td>168,000</td>
</tr>
</tbody>
</table>
The effects on South Platte stream flows of water reuse at existing, planned future and ultimate potential levels was quantified by comparing alternate water supply scenarios which included either reuse as a water supply source or additional amounts of replacement sources as shown above. In this analysis, the accretive and depletive effects of importations, reservoir operations, water supply diversions, consumptive uses and return flows were calculated for each alternate future based on recent historical operational data for each of these sources. The following Figure 5-1 depicts the combined net change in average year physical supply to the South Platte River and its tributaries resulting from water reuse at a region-wide level.

**Figure 5-1**

*Effect of Reuse on South Platte Stream Flows*

This analysis indicates that existing reuse generally reduces stream flows during July through April due to the depletive effect of exchanges and augmentation plans and because these reuse measures reduce the need for transbasin diversions and storage releases which would otherwise increase return flows during these months.
Reuse generally results in increased stream flows in the Colorado and Arkansas Basins. Water reuse in the metro Denver area reduces the need for transbasin diversions. Because the transbasin diversion projects operated by metro Denver area providers divert primarily during the runoff period, reuse-related flow increases in the Colorado and Arkansas Basins would occur primarily during the period of mid-May through mid-August. Based on the assumptions discussed above, existing reuse activities in the metro Denver area result in average flow increase of approximately 60 cfs during mid-May through mid-August. Planned future and ultimate potential levels of reuse would result in average flow increases of approximately 200 cfs and over 300 cfs, respectively. The distribution of these flow increases among the Colorado and Arkansas Basins and among the various tributaries within these basins would be dependent on the specific nature of the replacement supplies that would be pursued by metro Denver area providers in the absence of reuse.

5.6 SUMMARY OF RESULTS

The following is a summary of the effects of water reuse by metro Denver area water providers on future water supply and on existing water rights:

1. Water reuse accounts for about 11% of the region's existing water supply, or about 54,000 acre feet per year. Reuse will account for approximately 20% of the region's water supply, over 167,000 acre feet per year, in the foreseeable future. Ultimate levels of reuse could exceed 200,000 acre feet per year, assuming that water providers aggressively pursue full utilization of their legally reusable supplies via nonpotable and potable direct reuse.

2. Without water reuse there would be additional pressure for development of Denver Basin groundwater, additional transbasin diversions, acquisition and dry-up of irrigated agricultural land and development of South Platte surface storage projects.

3. Water reuse implemented in accordance with decrees would not injure existing water rights. Water reused under exchanges and augmentation plans is foreign to the natural flow of the South Platte and therefore generally unavailable for appropriation under the priority system.

4. Water reuse does affect the physical supply of streams in the South Platte, Colorado and Arkansas Basins by virtue of the direct depletive effects of water reuse itself and the indirect effects of reduced need for transbasin and nontributary groundwater water supply sources due to the role of reuse as a water supply source.

5. Water reuse generally results in reduced South Platte stream flows and increased stream flows in the Colorado and Arkansas Basins.
6.0 A REVIEW OF DISTRIBUTION SYSTEM INFRASTRUCTURE IN THE DENVER METRO AREA TO IDENTIFY WAYS TO PROMOTE MAXIMUM UTILIZATION OF WATER RESOURCES AVAILABLE TO THE SOUTH PLATTE BASIN ABOVE THE HENDERSON GAUGE

The focus of this chapter is to explore opportunities for using existing water supply and distribution facilities to enhance and promote the development and use of water resources above the Henderson gauge.

6.1 BACKGROUND

As a part of this report, information was reviewed and compiled from a series of regional meetings which were conducted as part of the MWSI Project to identify potential cooperative "systems integration" opportunities. These meetings included extensive mutual education between water providers and other interested parties and have resulted in the organization of three sub-regional groups. The groups have identified cooperative water supply opportunities for further investigation. The opportunities to be studied would promote maximum utilization of water resources available to the South Platte Basin above the Henderson Gauge.

6.2 SOUTHERN GEOGRAPHIC SUB-REGION

Investigations now underway will seek to define the potential additional yield that could be cooperatively developed using Denver's existing water supply system and some of its Blue River and South Platte water rights in conjunction with water rights, storage, conveyance and delivery facilities currently or potentially available to members of the Douglas County Water Authority. These investigations will focus on the increased yield resulting from new off-stream storage, conjunctive use of surface water and ground water supplies, nontributary aquifer recharge, and borrowing/payback arrangements with Denver including the following:

1. New raw water pipelines from Strontia Spring and/or Chatfield Reservoirs to one or more off-stream surface storage facilities in Douglas County.

2. Delivery of Denver's unused Blue River supplies and excess South Platte Flows as available for direct use and/or recharge.

3. Delivery of nontributary groundwater to serve Denver Water demands during dry periods based upon Denver system surface storage triggers.
6.3 NORTHEAST GEOGRAPHIC SUB-REGION

Preliminary quantitative studies are now underway to define the potential additional yield that could be cooperatively developed using water rights, storage, conveyance and delivery facilities currently or potentially available to the Northeast Provider Group in conjunction with Denver’s existing water supply system and some of Denver’s water rights. This study will build upon effluent management and systems integration concepts previously identified in the MWSI Project. Specifically, the study will focus on the hydrology, water rights, operations, water quality and raw water storage aspects of contemplated actions including the following:

1. Developing the remaining substitution opportunities using downstream reusable return flows and the participants’ upstream diversion points, subject to water rights, water quality and instream flow concerns.

2. The utility of additional storage below the Metro Wastewater Reclamation District Plant (the water quality impacts on water users located below points of substitution are items of particular mutual interest);

3. Enhancing the size, reliability and water quality of potable municipal supplies diverted from the South Platte River at or below the Burlington Ditch. Alternate sources of supply could include the Barr Lake/Beebe Draw area or the South Platte River near the Burlington Ditch. These sources could be regulated by local downstream storage.

4. Optimizing the delivery of nonpotable water from the Metro plant for appropriate uses. The utility of additional storage below Metro and the “trade potential” of participating in a nonpotable reuse plan in trade for additional potable water supplies from Denver Water are areas of particular mutual interest.

6.4 NORTHWEST GEOGRAPHIC SUB-REGION

A study is anticipated to define the potential additional yield that could be cooperatively developed through interconnections and cooperative use of storage facilities at one or more locations in the northwest area. Northwest water supply systems, seasonal operations for wet/average/dry years, participants’ relevant water rights, and major system facilities including diversion points, canals, pipelines, reservoirs, treatment plants, principal treated water distribution lines and interconnections will be examined to identify critical linkages, capacities and bottlenecks. An operational analyses will be conducted to help identify constraints and opportunities including the following:
1. Attention would be focused on identifying storage levels in major reservoirs and levels of use of major conveyance facilities. Opportunities associated with periods of unused storage and conveyance capacity within individual systems will then be identified.

2. Monthly time series estimates of unused supplies available under the participating parties' water rights will be developed including estimates of supplies from the Moffat and Gumlick Tunnels, South Boulder Creek, Coal Creek, Ralston Creek and Clear Creek. Opportunities associated with these unused supplies will be identified.

3. Opportunities associated with reusable supplies and unused Clear Creek exchange potential (which may exist due to insufficient storage or individual exchange supplies) will be identified.

4. An analyses will be conducted to look at how unused supplies could be "firmed" from a regional perspective by delivery to demand locations or to available storage capacity using existing and assumed future interconnections. Initial analyses would focus on the regional opportunities associated with existing systems.

5. The benefits of additional storage capacity at Standley, Gross, Leyden Gulch and other locations will be examined.

6.5 CHATFIELD RESERVOIR STUDIES

During the MWSI Project, numerous metro area water providers expressed interest in using storage space in the Chatfield, Cherry Creek and/or Bear Creek Reservoirs for water supply purposes. As an existing facility with a large amount of mainstem South Platte River storage capacity, reallocation of Chatfield storage could be more practicable and cost effective than the development of new storage reservoirs.

The allocation of additional storage space in Chatfield to water supply purposes could occur either through a reallocation of storage currently reserved for flood control or recreation or through the allocation of storage found to be in excess of what is needed for flood control. Under either scenario, COE regulations require extensive investigations to determine the technical, economic, and environmental feasibility of allocation or reallocation of storage for water supply. An environmental assessment or environmental impact statement (EIS), along with consultation under Section 7 of the Endangered Species Act would also be required. In addition, water users would be required to enter into a contract with the federal government for the repayment of costs associated with the storage space that would be utilized for water supply purposes.
In discussions with the Colorado Water Conservation Board and the MWSI's Chatfield Work Group, the COE has outlined their procedural requirements for the reallocation of storage from flood control to water supply purposes. The Chatfield Work Group has also facilitated the development of a detailed reallocation feasibility study scope of work, a checklist for compliance with applicable statutes and regulations, a plan for funding the feasibility study process, and a plan for the assignment of responsibilities to the State, the COE, and potential participants. Both the State and the COE have secured funding for the feasibility study and are planning to start work on the study in mid 1998.

As currently planned, the feasibility study will address the following topics:

1. The amount of flood control storage required at Chatfield and Bear Creek must be reevaluated using updated meteorological information and the new inflow design criteria;

2. Analysis of existing and proposed alternative operations of Chatfield for combined flood control and water supply purposes including potential changes to downstream flows, reservoir pool elevations, water supply consequences, flood control impacts, environmental impacts, and recreational impacts;

3. Analysis of water supply needs and alternatives for meeting those needs;

4. Analysis of alternatives and costs including an assessment of the financial capability project participants; and

5. National Environmental Policy Act (NEPA) compliance documentation (an EIS);
7.0 THE EFFECT ON EXISTING WATER RIGHTS OF CURRENT RECHARGE TECHNOLOGY AND PRACTICES IN THE DENVER BASIN AQUIFERS

This chapter examines the current injection practices in the Denver Basin Aquifers and addresses their impact on water rights.

7.1 INJECTION PRACTICES IN THE DENVER BASIN AQUIFERS

Centennial Water and Sanitation District (Centennial) and Willows Water District (Willows) are the only Front Range municipal water suppliers who have undertaken field studies to quantify the potential of injection, storage, and recovery of Arapahoe aquifer water. At current levels the injection, storage, and recovery of water has not affected existing water rights. It is estimated that at least 500,000 acre feet of injection storage capacity is currently available in the four Denver Basin aquifers.

1. **Centennial Water and Sanitation District - Aquifer Storage and Recovery Project** - Aquifer storage and recovery is an operational component of Centennial's water supply system. Injection water is brought from McLellan Reservoir, treated at the Centennial water treatment plant, and then delivered to wells for injection. In 1996 a total of 654 acre feet was injected into the Arapahoe aquifer. Injection rates at Centennial's wells approximately equal the wells' pumping rates. No adverse well hydraulic or water quality problems are reported. Centennial is currently equipping two additional wells for injection, Arapahoe well A-5 and Denver well D-10. Injection at D-10 will be the first Denver aquifer injection well.

2. **Willows Water District - Denver Basin Aquifer Recharge and Demonstration Project** - The Denver Basin Aquifer Recharge and Demonstration Project (Demonstration Project) is part of the High Plains States Ground Water Demonstration Program. This project is a cooperative including U.S. Bureau of Reclamation, Willows Water District, Denver Water, the U.S. Environmental Protection Agency, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and the Colorado State Engineer's Office.

The Demonstration Project consisted of a series of injection runs and pumping cycles. Treated surface water from Denver Water was injected into the Arapahoe aquifer. During pumping and injection, water quality and water level were monitored in the production well and a nearby monitoring well. The total volume of water injected and stored by the project is estimated to be 1,282.7 acre feet.
The EPA concludes:

"Nothing learned in the project has indicated an unacceptable risk to ground water drinking supplies from artificial recharge through injection wells at this site".

7.2 EFFECT ON EXISTING WATER RIGHTS

In 1995 the State Engineer's Office pursuant to S.B. 94-97 promulgated the Denver Basin Artificial Recharge Extraction Rules. These rules can be used to evaluate the effect of the extraction of stored water on existing wells and other water rights. The Denver Basin Artificial Recharge Extraction Rules address potential water rights injury issues and thereby address potential effects of aquifer recharge on existing water rights.

The "Rules and Regulations for the Permitting and Use of Waters Artificially Recharged Into the Dawson, Denver, Arapahoe, and Laramie-Fox Hills Aquifers" (a.k.a.: "Denver Basin Artificial Recharge Extraction Rules").

These rules and regulations are promulgated pursuant to the authority granted the State Engineer in Sections 37-80-102(1)(g) and (k), 37-90-138, C.R.S. (1990 Rep), and 37-90-137(9)(d), C.R.S. (1990 Rep, 1994 Supp).

These rules apply to the evaluation and processing of applications for permits to extract water which has been artificially recharged into one or more of the Denver Basin aquifers, identified as the Dawson, Denver, Arapahoe, or Laramie-Fox Hills aquifers located outside the boundaries of any designated ground water basin.

The naturally occurring water contained in these Denver Basin aquifers is a significant but finite resource. Artificial recharge of these aquifers by injection of surface and/or ground water for the purpose of subsequent extraction, or for maintaining water levels will extend the life of this resource. The rules promulgated herein are required to enable the State Engineer to administer the orderly withdrawal of any water artificially recharged into these aquifers.

Withdrawal of artificially recharged water may be accomplished through an existing well, or through a well specifically constructed for the purpose of extracting artificially recharged water. These rules and regulations apply to the permitting and construction of extraction wells, for the permitting of extraction through the extended use of existing wells, and for the assessment of application fees. Their purpose is to make the submission, consideration and evaluation of permit applications more uniform and certain. The granting of permits also provides the State Engineer the means to monitor and record the development and use of artificially recharged water.
These rules define the State Engineer’s authority to monitor and observe the extraction and use of artificially recharged water and to require the installation of measuring devices, to prevent injury to existing surface water rights and existing users of, and rights to water from the Denver Basin aquifers, and to provide the means for enforcing these rules.

The purpose of these rules and regulations is to enable the State Engineer to account for and administer the orderly extraction of water which has been artificially recharged into any of the Denver Basin bedrock aquifers, and to prevent injury to existing water users and water rights holders.

These rules are limited to the permitting and extraction of artificially recharged waters from existing wells or from wells constructed specifically for extraction of artificially recharged water.

The naturally occurring waters of the Denver Basin bedrock aquifers are essentially nonrenewable by natural processes. The life of this valuable resource can be prolonged by artificial recharge using surface water or other ground water available during periods of low demand or excess capacity.

Water recharged into the Denver Basin aquifers may be extracted during periods of drought, or may be left in the aquifer, resulting in lower rates of decline in local or regional water levels, thus maximizing the conjunctive use of the waters of the state.

8.0 THE IMPACT OF DE MINIMIS STANDARDS FOR INJURY BASED UPON AN ANNUAL DEPLETION STANDARD

This chapter examines the physical impacts to stream systems in the state, as well as possible legal and administrative implications, of de minimis standards for injury based upon an annual depletions standard. In this report, de minimis means a small amount of depletion in a calendar year that could be allowed without requiring the owner of a well causing the depletion to augment or replace the water depleted or removed from the stream and aquifer system. Should such a standard be deemed necessary, the analysis also suggests issues that may require further consideration.

8.1 IMPACTS OF DE MINIMIS STANDARDS FOR INJURY

The legislative requirement to examine the impact of de minimis standards under Senate Bill 96-74 is somewhat vague. The bill does not state whether the examination is to be of a physical, engineering, or philosophical perspective. There is also little assistance provided in the language as to whether the "standard" is to apply to depletions throughout the state, depletions that occur to the South Platte River system from tributary or non-tributary pumping, or depletions that result purely from Denver Basin aquifer pumping.

From a strict engineering perspective, depletion to a stream has an impact to the system no matter the source of the depletion. For example, a depletion as a result of pumping from the Denver Basin aquifer effects the South Platte and its tributaries just as pumping an alluvial well along Cherry Creek effects that same stream system. Only the relative timing and quantity of the depletion is different. Under many Denver Basin aquifer pumping scenarios, the maximum effect of the depletion may be years after pumping ceases, whereas most alluvial pumping effects are on a more immediate time frame.

8.2 PHYSICAL IMPACTS

To determine the physical impacts from an engineering or numerical standpoint would be difficult. Assuming for example, that the analysis was limited to Denver Basin non-tributary pumping, the reviewer would have to discern which augmentation plans currently exist that might have possible depletions of less than the annual depletion standard, and then discern or make assumptions as to which pieces of property overlying the not-tributary aquifer could be developed in such a manner as to have an effect less than the standard. All of these properties would then require a modeling analysis to insure that the depletion to the tributary stream is below the standard. A total depletion might then be calculated, but it would be full of assumptions concerning property size and amount of ground water available for withdrawal as a result of the property assumptions. If the study were to apply on a statewide basis, the assumptive
and predictive problems are multiplied. It has therefore been deemed impractical to attempt to determine the actual physical impacts of a de minimis standard. It is safe to assume that whatever numerical value is chosen, the effects would be cumulative for each new development falling under the standard.

8.3 LEGISLATIVE HISTORY

The legislature has not defined the term de minimis. However, in relation to Colorado law, the legislature has recognized certain types of uses as exempt from the priority system. Wells located outside the designated ground water basins as defined in section 37-92-602, C.R.S., which include small capacity wells generally used for residential and livestock uses on farms, in house use only wells, fire protection wells and very small commercial wells, may be exempt from the priority system if they meet the detailed criteria set forth in the statute. Further, small capacity wells of similar types of uses as described in 37-92-602, C.R.S., located inside of designated ground water basins are also exempt from regulation (see section 37-90-105, C.R.S.). No acre-foot amounts are associated with these types of wells, but in general, the pumping capacity is limited to a maximum of 15 gallons per minute. Some limited instances allow for up to 50 gallons per minute in designated ground water basin.

The only acre-foot limitations discussed in the relevant statutory law concerns livestock watering tanks (small dams) and erosion control dams (see sections 35-49-101 through 116, and 37-87-122, C.R.S.). Structures meeting the legislative criteria set forth under these laws are exempt from priority system. Briefly, these types of structures must be constructed on water courses which have been determined by the State Engineer to be normally dry, and are limited in the amount of water they can store. In the case of erosion control dams, 2 acre-feet is the maximum allowed and for livestock tanks, 10 acre-feet is the limit.

8.4 ADMINISTRATIVE HISTORY

Historically, the State Engineer has always maintained that “one drop” of depletion is injury to an over appropriated and on-call stream system. The State Engineer has applied this standard on all stream systems throughout the state through his permit review, consultation process, etc., regardless if the depletion results from tributary alluvial pumping, not-nontributary pumping, or as a consequence of a change of water right. From an overall water management perspective under the prior appropriation system of the state this unwritten policy of the State Engineer makes administration of the system much easier, in that it requires pumping proposals that might deplete the system to prove and insure that there is no injury, as opposed to the State Engineer making arguments to the contrary.
8.5 ADMINISTRATIVE IMPACTS AND IMPLICATIONS

Any annual depletion standard chosen, in and of itself, will be very difficult to implement. Is one acre-foot of annual depletion per project a good number? Is .5 acre-feet? Is 2 acre-feet? Whatever number is chosen, it would be difficult to develop an acceptable standard based on credible engineering analysis. And whether the number is 0.5 acre-foot or 1.5 acre-feet, the effects of such a de minimis standard become cumulative over time, presenting larger depletions to downstream senior water rights on a long term basis.

This leads to an inherent problem concerning enforcement of any particular de minimis number selected. For argument sake, assume that a 1 acre-foot per year maximum depletion as a result of pumping nontributary Denver Basin aquifer over the life of the aquifer is deemed to be de minimis. An applicant who owns property in the Denver Basin desires to adjudicate a plan for augmentation to allow for withdrawal of this nontributary water and the State Engineer’s analysis, using the current Denver Basin model, shows depletions in year 100 at 1.05 acre-feet. Would this person be allowed to pump without replacing depletions to the stream system? Many engineers might argue that the calculation in this instance is only accurate to within plus or minus 5%, and therefore, would argue that they fit under the current standard. Under this scenario, if strict enforcement of the standard was required, it may increase the State Engineer’s participation in cases he currently does not oppose.

Assuming that a number can be developed and agreed upon, and further assuming it applies to all depletions on any stream system in the state, current requirements for augmentation under the Water Rights Determination and Administration Act of 1969 to offset injury to vested senior water rights, would become a moot point in many instances. If the overall depletions from the proposed project fall under the agreed upon standard, no replacement under a plan for augmentation would be required. Under some standard depletion scenarios that can reasonably be envisioned, the need for the presumptions of non-injury in exempt well permitting requirements under section 37-92-602, C.R.S., would also become obsolete.

If one assumes that a de minimis depletive standard is to apply only to Denver Basin aquifer pumping, several concerns become apparent. Again, as stated above, depletion is depletive to the tributary stream system, whether that depletive is a result of Denver Basin aquifer pumping or alluvial aquifer ground water use. Admittedly, the issue of timing is very different. However, if the standard was applied only to depletions as a result of Denver Basin pumping, it may be difficult to constrain the ground water developer on the South Platte or Arkansas Rivers from arguing that his or her depletion is no different than the depletion allowed as a result of Denver aquifer...
pumping. This same argument might also be made for alluvial withdrawals on any other stream system in the state.

If a depletion standard is to be set for depletions that occur as a result of non-tributary pumping from the Denver basin aquifers only, at a minimum, language may need to be considered to ensure that the standard would not be applied to depletions as a result of alluvial and tributary ground water pumping in other areas of the state. Given that the effects of timing of depletions from an alluvial aquifer withdrawal are much more immediate, it may be prudent to consider some assurance to water users of protection from more immediate depletive effects.

As noted above, the adoption of a de minimis standard concerning acceptable depletion to a stream system raises some concerns. On a more positive note, it is also important to recognize possible benefits that may accrue as a result of such a standard. First, the standard may have the effect of benefiting smaller existing and future subdivisions in the state by reducing the overall engineering, legal and augmentation related costs associated with developing and maintaining sometimes complex augmentation plans that seemingly require drops of water to be sprinkled into the streams of the state. Secondly, in a somewhat related matter, it may reduce the participation of the State Engineer in these same small cases, thereby decreasing associated court costs and engineering fees of the state, allowing staff to focus on other issues of state water management. Such a standard may also be perceived by taxpayers as a more reasonable, less bureaucratic interpretation of the spirit of the law, making the government that serves them more accessible and service oriented.

8.6 CONCLUSION

Analysis of impacts of the adoption of a de minimis standard for injury from a physical, engineering standpoint would not be practical, but the impacts would be cumulative, over time. Administrative impacts of the adoption of such a policy vary, depending upon the intent and scope of the legislation. Insurance of non-applicability to non-Denver Basin aquifer pumping is suggested.

Possible benefits to the system include less legal, engineering and administrative costs for smaller subdivisions and water users in the state. The State Engineer and his staff may also see some of the same benefits, allowing for greater concentration on other water management issues in the state. Social implications between the state and the taxpayers may also be served through a more receptive taxpayer perception of government.

The State Engineer recommends that the SB-74 Special Water Committee consider and receive public comment on a de minimis standard for depletion from the pumping of a Denver Basin aquifer based on an annual pumping volume of 3 acre-feet per year. The actual stream depletion would vary depending upon the location of the well
and based upon the results of modeling as discussed in chapter 9. The depletion could vary between 20 to 30 percent of the amount pumped. This annual depletion would be similar to annual depletions caused by exempt domestic wells permitted under the criteria established in 37-92-602, C.R.S. This annual pumping volume would be for non-exempt wells issued pursuant to 37-90-137 C.R.S.
9.0 THE EFFECT OF THE FOUR PERCENT REPLACEMENT AND THE TWO PERCENT RELINQUISHMENT REQUIREMENTS ON FUTURE WATER SUPPLIES, EXISTING WATER RIGHTS AND THE NEED FOR REPLACEMENT OF POST PUMPING DEPLETION RESULTING FROM WITHDRAWAL OF DENVER BASIN GROUND WATER

An evaluation of the effect of the current replacement (4%) and relinquishment (2%) requirements on future water supplies, water rights and need for replacement of post pumping depletions resulting from withdrawal of Denver Basin ground water required; a) updating and improvement of existing ground water models, b) use of the model to evaluate current depletions and predict long term future depletions to the discharge areas of the South Platte River Basin drainages, and c) evaluation of the model results and effect on existing water rights, future water supplies, and Denver Basin Aquifers.

This portion of the study will provide a current assessment and evaluation of the requirements and definitions created by Senate Bill 85-5 (SB 85-5) which was intended to prevent injury to surface rights in the South Platte River Basin drainages based on the information and knowledge available at that time. Staff of the State Engineer have developed an improved ground water model and reviewed previous studies to evaluate the assumptions in the current law with respect to assumed aquifer conditions and depletion/replacement requirements. The intent was to determine if the two percent relinquishment requirement for non-tributary (NT) and the four percent replacement requirement for not non-tributary (NNT) ground water pumping are sufficient to replace injurious stream depletions now and in the future.

9.1 BACKGROUND

There were several assumptions and non-technical considerations which produced the SB 85-5 or post 1985 ground water use rules. A brief and simplified summary of the current rules is provided here for general background information.

The ground water in the Denver Basin Aquifers is typically described as tributary, NT, and not non-tributary, NNT. The SB 85-5 rules included full replacement of actual depletions from the NNT Dawson aquifer and tributary wells. For wells pumping in the NT areas of the basin, they are required to relinquish 2% of their pumping. Wells developed in the NNT areas of the basin are required to replace (augment) 4% of the actual quantity pumped. Replacement of actual injurious post pumping depletions is part of the requirements of SB 85-5.

The intent of SB 85-5 was to assure that the withdrawal of ground water from the Denver Basin aquifers will not materially affect vested water rights to the flow of any natural stream or tributary ground water. The authors of SB 85-5 used the information available at the time to frame what was intended to prevent injury to surface water rights due to development and use of the Denver Basin aquifers by replacement of stream depletion. However, SB 96-74 required an evaluation of the effect of current law on existing water rights and on future water supplies using the most current information available and the latest modeling technologies.
The origin of the 4% replacement value apparently evolved from the results of the "Robson Report" ("Bedrock Aquifers in the Denver Basin – A Quantitative Water Resources Appraisal"; published as USGS Professional Paper 1257). Robson estimated net discharge to drainages from all four Denver Basin Aquifers during pristine conditions was 54.7 cfs (39,600 ac-ft per year). He also estimated the total volume of drainable water in storage to be about 259 million acre-feet. The theoretical maximum allowable annual pumping rate from the bedrock aquifers using a 100 year life criterion would be 1% of the total volume of drainable water in storage or approximately 2.6 million ac-ft per year. It is however, highly unlikely and probably not economically feasible for wells to recover the entire volume of drainable storage.

During the SB 85-5 negotiations, it is believed an assumption was made that if the obligation to replace the entire amount of stream accretion (54.7 cfs) was spread uniformly over the theoretical maximum allowable annual pumping rate, the replacement obligation would be less than 1.6%. There are inaccuracies associated with these assumptions and calculations. First, and most importantly, is the fact that a significant component of stream depletion was ignored or simply under estimated; that is recharge from the drainages to the Denver Basin aquifers that will inevitably occur. Secondly, it may have been assumed that the pumping would be simultaneous and spread uniformly. It is unreasonable to assume that all of the wells could be installed and begin pumping at the theoretical maximum allowable annual pumping rate simultaneously. Also, based on the pumping estimates derived in this study, about half of the total pumping occurs in NNT (4%) areas.

9.2 MODEL OVERVIEW

After the passage of Senate Bill 96-74 in the 1996 legislative session, the State Engineer's Office undertook the tasks of evaluating the effect of four percent replacement and two percent relinquishment requirements on existing water rights and on future water supplies. The State Engineer's Office evaluated the need for replacement of post pumping depletions resulting from withdrawal of Denver Basin ground water and the use of NT and NNT ground water and its long-term impact on water rights.

To accomplish these objectives, a model of the Denver Basin aquifer system was developed using the USGS MODFLOW code, the most current and widely accepted groundwater model in use. Data for the model was obtained from previous studies by Robson, Banta, and the State Engineers Office in 1985 pursuant to SB 85-5. The model was configured with a grid consisting of 120 rows, 84 columns, and six layers. Each grid represents one square mile and was drawn to correspond to a section of land. The six layers represent the Upper Dawson, Lower Dawson, Denver, Upper Arapahoe, Lower Arapahoe, and Laramie-Fox Hills aquifers.

The modeling was completed in four phases. The first phase consisted of calibrating a steady state model to near pristine conditions. The second phase consisted of converting the steady state model to a transient model. The third phase consisted of
using the transient model to simulate historic pumping beginning in 1880 and ending in 1996.

In order to accomplish the third phase, estimates of historical pumping were derived using the SEO registered well data base and average annual well withdrawal factors. The average annual withdrawal factors were generally borrowed from Robson and appear to be reasonable. Pumping estimates using this procedure agree fairly well with Robson's and Banta's estimates for the period 1958 to 1985.

About 59,000 acre-feet of pumping from the Denver Basin bedrock aquifers was estimated for 1996. About 47% of the total pumping was used for municipal use, 26% for domestic and livestock use, 7% for industrial and commercial use, and 20% for irrigation. About 47% of the pumping was from the Arapahoe aquifer and about 17% to 18% was from each of the other three aquifers. About 52% of the pumping was from areas defined as NNT and 48% from areas defined as NT. Nearly 18% of the total pumping was from designated basins.

It is estimated that only about 12% of the total pumping for 1996 was subject to the provisions of SB 85-5 because most wells were constructed or permitted before the effective date of SB 85-5. The 12% estimate assumes small capacity domestic and livestock wells to be exempted and that the provisions of SB 85-5 apply in designated basins because the policies, rules and regulations of the Colorado Ground Water Commission closely resemble the provisions of SB 85-5.

The theoretical maximum allowable annual pumping rate from the bedrock aquifers using a 100 year life criterion would be 1% of the estimated 300 million acre-feet of drainable storage or 3 million acre-feet per year. The estimated 59,000 acre-feet of pumping for 1996 was only about 2% of the maximum allowable. It is highly unlikely and probably not economically feasible for wells to recover the entire volume of drainable storage.

The final phase consisted of using the transient model to simulate projected pumping. Pumping estimates from 1970 to 1996 indicate an average annual rate of increase in pumping of 1377 acre-feet per year. This average rate of increase was the basis for a linear BASE projection to the year 2100.

The BASE projection indicates pumping would increase from about 59,000 acre-feet per year in 1996 to about 135,000 acre-feet per year by the year 2050 and 202,000 acre-feet per year by the year 2100. Assuming a per capita water use of 175 gallons per day per person and 75% of the additional pumping would be for domestic and municipal use, BASE projections would provide water for an additional population of about 291,000 by 2050 and about 547,000 people by 2100.

Pumping was also projected using average rates of increase of 150% and 50% of the BASE rate of increase. A fourth projection was made allowing the rate of increase in pumping to decline to zero by the year 2050. This fourth projection is based on the premise that the use of Denver Basin ground water will continue to increase for nearly 50 years while other water supply sources are developed and conjunctive use technology improves.
Current population projections estimate an additional 3.2 million people in Water Division 1 (South Platte River Drainage) and an additional 1.1 million people in Water Division 2 (Arkansas River Drainage) by the year 2100. Considering where most of the increase in population might occur, the fact that the Denver Basin is only one-eighth of the total area of Water Divisions 1 and 2, that only a minor percentage of the total population has or will use ground water as it’s sole source, and that dependence on ground water will probably decrease as costs associated with lifting the water increase; it can be suggested that the BASE pumping projection reasonably coincides with estimated population projections.

The transient model was used to evaluate the effects of pumping using the four pumping projections described above. It was assumed projected pumping would be distributed the same as the 1996 level of pumping and was input to the model accordingly. Other simulations were made using the BASE projection rates to better define the separate effects of pumping NT and NNT water.

The parameters describing the extent of the aquifers and their ability to transmit and store water represent reasonable data sets. It is not expected that errors in these parameters would effect the conclusions drawn from the model results. However, predicted depletions are sensitive to river conductances. The model is probably more sensitive to river conductance than any of the other input parameters. Increasing river conductance values will shorten the period of time required for predicted depletions to drainages to reach their maximum. On the other hand, decreasing the river conductance values will prolong the period of time required for predicted depletions to drainages to reach their maximum. It is important to note that the total volume of predicted depletions to drainages will equal the volume of water pumped no matter what river conductance is input to the model, if there is no net change in storage in the aquifers.

During the steady-state calibration phase of this study, runs were made increasing and decreasing the river conductances by an order of magnitude. When river conductance values were decreased, predicted potentiometric surfaces in the aquifers were higher than expected and higher than measurement data suggested. This indicated the higher values finally selected for river conductances were more acceptable.

Due to uncertainty and concern associated with the riverbed conductances input to the original model, input parameters were modified and the model was recalibrated to steady state and transient conditions, thus providing a second model. This effectively demonstrated that the original model is non-unique and provided another estimate of incremental depletions to drainages.

Subsequent to the passage of SB 85-5, the State Engineers Office undertook the task of defining, within each of the Denver Basin aquifers, the areas of NT and NNT ground water. A provision of SB 85-5 was that all aquifers be reduced to water table conditions thereby limiting movement of ground water between aquifers to a downward direction. A river conductance sensitivity analysis performed on the SB 85-5 models indicated decreasing the river conductance two orders of magnitude moved the NT/NNT line about one mile closer to the stream. Even though it was felt that the smaller value was
too small, revising the value upward was of little consequence to fulfilling the objectives of that study. The river conductance sensitivity analysis performed in this study supports the belief that the value used in the SB 85-5 models was too low.

9.3 DEPLETIONS TO DRAINAGES

Depletions to the net discharge to drainages or simply depletions to drainages consist of two components. Ground water from the bedrock aquifers discharge to drainages. This discharge may be to springs and seeps along the drainage at points above the stream and stream alluvium and a portion of this discharge may be lost to evapotranspiration without actually entering the stream. Other discharge would be directly to the stream or stream alluvium. Depletion of the discharge to drainages is the first component of depletions to drainages. Water from streams and stream alluvium also recharge the bedrock aquifers. Pumping from the bedrock aquifers can increase the recharge from the streams representing the second component of depletions to drainages.

The model has been used to determine depletions to drainages using four projected pumping scenarios. Incremental pumping is pumping added to the 1996 level of pumping and incremental depletions to drainages are the depletions attributable to the incremental pumping. The results for the year 2100 are summarized below:

<table>
<thead>
<tr>
<th>Projection</th>
<th>Incremental Pumping (cfs)</th>
<th>Incremental Depletions to Drainages % of incremental pumping</th>
</tr>
</thead>
<tbody>
<tr>
<td>150% of BASE</td>
<td>234.2</td>
<td>16.7</td>
</tr>
<tr>
<td>BASE</td>
<td>164.5</td>
<td>17.5</td>
</tr>
<tr>
<td>50% of BASE</td>
<td>86.4</td>
<td>18.6</td>
</tr>
<tr>
<td>ZERO growth by 2050</td>
<td>45.5</td>
<td>24.8</td>
</tr>
</tbody>
</table>

Model results for the projected pumping runs indicate depletions to drainages will increase with time and will reach maximums by the year 2100. This trend is also applicable to the zero growth by 2050 projection. Depletions to drainages are predicted after 100 years of pumping and depletions will continue beyond the 100 years even if all pumping was to cease. About 25 cfs of depletion to drainages is indicated 110 years after pumping at the BASE pumping projection level ceases. Results for the 150% of BASE projection indicate net discharge to drainages would be negative 9.2 cfs by the final stress period which means recharge from stream alluvial systems to the bedrock aquifers would exceed ground water discharge to the drainages.

If it is assumed all pumping at the 1996 level is not subject to SB 85-5 requirements and all of the incremental pumping is subject to SB 85-5 requirements. The assumed pumping scenario was used because insufficient data is readily available to perform a detailed analysis of each Pre SB 85-5 wells or water rights model. Based on the pumping assumption, the model results indicate 2% relinquishment and 4% replacement is insufficient to offset depletions to drainages.
Two additional simulations were made to better define and isolate the effects of pumping NT and NNT water. In the first of these simulations, pumping was projected at the BASE rate using the BASE projection less NT pumping but including NT pumping from designated areas. Incremental depletion to drainages increased to about 3.3% of pumping in the 5th and 6th stress periods and then decreased to about 2.4% of pumping in the final stress period or about 2.9% of pumping when averaged over the 100 year simulation period. In the second simulation, pumping was projected at the BASE rate using the BASE projection less NNT pumping but including NNT pumping from designated areas and including NNT pumping from both of the Dawson aquifers. Incremental depletion to drainages increased to about 22.9% of pumping in the 100th year or about 20.7% of pumping when averaged over the 100 year simulation period. The same runs were made using river conductance values one order of magnitude lower. The results of those simulations indicated the average replacement required would be in the range of 6.2% for pumping in NNT non-designated (Dawson excluded) areas and in the range of 1.6% for the NT non-designated areas. In addition, the same runs were made using the second (recalibrated) model and the results of those simulations indicated the average replacement required would be in the range of 14.6% for pumping in NNT non-designated (Dawson excluded) areas and in the range of 2.2% for the NT non-designated areas. The comparison of these results is complicated because depletions expressed as a percentage of pumping are dependent upon the amount of pumping simulated. Also, incremental pumping input to the model was diminished depending upon the total amount of pumping and the associated dry up of model cells with minimal thickness.

Again, assuming all of the incremental pumping is subject to the provisions of SB 85-5, all of the model results suggest that 2% relinquishment of NT ground water pumping and 4% replacement (actual replacement for wells completed in the Dawson aquifer) of NNT ground water pumping is insufficient to offset depletions to drainage discharge. In reality 2% relinquishment does little to nothing to offset depletions to drainages attributable to the remaining 98% of pumping. In other words, a well pumping 100 acre-feet per year and returning 2 acre-feet per year to the uppermost bedrock aquifer would have about the same effect as a well pumping 98 acre-feet per year and returning nothing.

Predicted depletions are sensitive to river conductance. The model is probably more sensitive to river conductance than any of the other input parameters. The results of the original model and the second model suggest a range of values for incremental depletions to drainages. For NT pumping, incremental depletions to drainages may range from 2.2% to 2.9% and could be as low as 1.6%. For NNT pumping, incremental depletions to drainages may range from 14.6% to 20.7% and could be as low as 6.2%. The lower extreme values are probably not realistic because they were derived solely from a sensitivity analysis of riverbed conductances in the original model.

Mathematical models of ground water flow are at best only approximations of the real systems they are designed to represent. There is some uncertainty in all model input parameters. The model was calibrated for steady-state and historic conditions and
represents a reasonable tool for estimation of the depletions to drainages as the result of pumping from the Denver Basin aquifers.

Results and conclusions are probably not that sensitive to errors in estimating the historic pumping because the effects of historic pumping have been subtracted from the final results isolating the effects of additional pumping. Better definition of historic pumping could perhaps improve the estimation of other model parameters during the calibration process. Additional historic data could be collected from some of the major water suppliers and perhaps some type of random sampling study could be conducted to determine if some of the average annual use factors used to predict historic use are valid. The projected pumping was assumed to have the same distribution as pumping estimated for 1996 with 52% of the water being NNT and 48% NT. If greater percentages of the pumping were projected for NT areas then predicted depletions would decrease. It is also interesting to note that depletions, when expressed as a percent of pumping, decrease with increased pumping.

9.4 SUMMARY

The model indicates that the vested water rights to the flow of the South Platte River Basin drainages may be materially injured due to ground water withdrawal from wells legally developed in the Denver Basin both prior to and subsequent to the enactment of SB 85-5. The results of the model indicate that, depending on the future projection of ground water pumping, the average replacement required to protect vested surface water rights is in the range of 14.6% to 20.7% for pumping in NNT non-designated (Dawson excluded) areas of the Denver Basin Aquifers. For the NT non-designated areas, the average replacement required is in the range of 2.2% to 2.9%. In reality, the average replacement requirements may be somewhat less than the range of values derived from the model results. This is because a portion of the discharge to drainages may be to springs and seeps along the drainage at points above the stream and alluvium and a portion may be lost to evapotranspiration without actually entering the stream. In order to determine the magnitude and extent of these occurrences, extensive field surveys would be required.

Of significant concern is the fact that regardless of any changes in replacement requirements applicable to future ground water development (post 1998), depletion of the net discharge from the Denver Basin Aquifers to all of the South Platte River Basin drainages will continue due to pumping from wells developed prior to 1985 and between 1985 to 1998. Most of the developed wells are not currently pumping at their maximum allowable annual pumping rate but could do so in the not too distant future. In addition, there are numerous decrees and permits, adjudicated and approved, that have not yet been developed. If and when they are developed, they will also contribute significantly to the depletion of the net discharge from the Denver Basin Aquifers. In reality, the ground water contribution to the South Platte River Basin drainages is already as good as gone from the surface drainages, the only question is when will the full effect occur, which could be 40 years into the future.
It is estimated depletions will exceed the net discharge to the South Platte River Basin drainages around the year 2040. Depletion of the drainages will continue to increase as recharge from the drainages to the aquifers increase. Depletions will continue as long as water levels in the aquifers remain below the alluvium.

The data obtained for use in the model indicated that the estimated 59,000 acre-feet of pumping for 1996 was only about 2% of the annual maximum allowable pumping using a 100 year life criterion. The pumping projected in the BASE simulation at the year 2100 would be about 10% of the maximum allowable pumping using a 100 year life criterion.

The Denver Basin aquifers are expected to experience local and regional drawdown effects due to pumping. These areas of drawdown will face increased costs for the withdrawal of the same quantity of water currently being pumped. The water supply entities would most likely pursue alternate renewable water supplies in order to implement ASR or more cost-effective ground water development such as well fields in other areas of the Denver Basin. The latter would of course result in the reoccurring cycle of drawdown effects.
10.0 NONTRIBUTARY GROUNDWATER USE AND LONG-TERM IMPACT ON WATER RIGHTS

This chapter is an analysis of the "use of nontributary ground water and its long term impacts on water rights." For the purposes of this analysis it is assumed that we are addressing impacts that result from the pumping of the Denver Basins Aquifers, that we are considering such impacts whether they result from nontributary or not-tributary pumping, and looking at the impacts on surface water rights and tributary ground water rights in the South Platte and Arkansas River drainages as well as the impacts to designated ground water rights, both during Denver Basin Aquifer pumping and after such pumping ceases.

10.1 BACKGROUND

It is estimated that the Denver Basin Aquifers contain about 300 million acre-feet of drainable water. These aquifers are considered to be non-renewable since they receive only a small amount of natural recharge annually in comparison to the 300 million acre-feet in storage. Current law provides for a minimum aquifer life of 100 years, and allows withdrawal of one (1) percent of the water per year based on how much water is underlying the land owned or controlled by the appropriator.

Prior to 1973, ground water in the Denver Basin Aquifers was permitted or decreed in accordance with the appropriation doctrine (not limited by landownership) and there is little information concerning how decisions were made as to when to classify this groundwater as nontributary. Existing wells permitted or decreed prior to July 6, 1973, are generally referred to as PRE 213 wells which is a reference to SB 213 which was enacted on that date. SB 73-213 was the first time that the withdrawal of nontributary ground water was based on the quantity of water underlying lands owned by the applicant and a 100 year aquifer life.

Since at least the 1970's it has been recognized that pumping the Denver Basin Aquifers (whether it be nontributary or not-tributary water) does have impacts on the flow of surface streams, including their alluvium. Prior to well development, the Denver Basin Aquifers were discharging to various tributaries of the South Platte and Arkansas Rivers. Discharges may be directly to the stream or stream alluvium or may be to springs or seeps above the steam or its alluvium.

Although prior to the enactment of SB 85-5 there was not a technical definition of nontributary groundwater, groundwater in the Denver Basin Aquifers was typically described as either nontributary or tributary. Under SB 73-213 the landownership and 100 year aquifer life standards were only applied to the nontributary water. When groundwater in the Denver Basin Aquifers was tributary, its withdrawal for certain uses required water court approval of a plan for augmentation. Very little water from the Denver Basin Aquifers was appropriated as "tributary" during the period from July 6, 1973 to July 1, 1985.
During the committee work leading up to the adoption of SB 85-5, a draft of the USGS Robson Report was available and it was recognized that, based on that modeling, the contribution (discharge) of all the Denver Basin Aquifers to front range stream drainage was approximately 39,600 acre-feet annually (54.7 cfs). The committee recognized that this amount of aquifer contribution to the surface streams was a small percentage of the amount of water that could be withdrawn on an annual basis (an estimated 3 Million acre-feet), and also recognized that some stream depletions were already resulting from previous withdrawals, although this amount of depletion was not quantified. Whether or not the committee recognized that pumping of the aquifers would result in a reversal of flow at the stream/aquifer contact and cause significant additional depletions to the surface streams, or that the pumping vs depletion relationship was not linear, is unclear.

Under SB 85-5 the groundwater in the Denver Basin Aquifers was typically described as either nontributary or not-nontributary. Wells pumping in the nontributary areas were required to relinquish 2% of the annual amount pumped, meaning that they could only consumptively use 98% of the water withdrawn. Well withdrawing from the non-tributary area either had to replace actual injurious stream depletions or 4% of the amount pumped annually, depending on which aquifer they were pumping from and how far they were from the stream/aquifer contact. Not-nontributary pumping required water court approval of a plan for augmentation for their replacement and such plans were to include the replacement of actual injurious stream depletions after pumping ceased.

10.2 WELL PUMPING EFFECTS

Modeling work by the Colorado Division of Water Resources to support this SB 96-74 study estimates the pre-development stream drainage discharges to be about 60.9 cfs or about 44,000 acre-feet annually. Of these discharges about 35.8 cfs was to the South Platte River system and 7.4 cfs to the Arkansas River system. About 17.7 cfs of this discharge was to the ground water systems of drainages within the designated groundwater basins.

The pre-development groundwater discharge (flow) from the Denver Basin Aquifers (Aquifers) to the South Platte drainages (surface stream and alluvium) is represented in Figure 6. As withdrawal of water from the Aquifers increases the discharge to drainages decreases until no discharge occurs to the drainage as shown in Figure 7. As further withdrawals of water occur the direction to flow reverses and water from the drainages begins to recharge the aquifers as shown in Figure 8. The recharge increases as the water levels in the Aquifers decrease. The recharge continues to increase until the hydraulic connection between the drainages and Aquifers no longer exists, at which time the rate of recharge is at its maximum as shown in Figure 9. The extent of the hydraulic connection between the drainage and Aquifer, the resulting discharge to drainages, or recharge to aquifers will occur at different locations and times throughout the basin.

A factor to consider in determining how water rights are affected by nontributary groundwater pumping of the Denver Basin Aquifers is the current status of Denver Basin
underground water rights. There are water rights that were previously decreed or permitted whose ability to pump are likely not to be limited by future legislation, or there are inchoate rights based on the current statutory method of appropriation that can be modified by future legislation.

For purposes of discussion it helps to break the impacts of Denver Basin Aquifer ground water withdrawals on water rights into three groups. The first group may be described as decreed or permitted water rights that were established prior to July 1, 1985 (PRE 85). The second group may be described as decreed or permitted water rights established between July 1, 1985 and today (85-98). The last group are those inchoate water rights the may be decreed or permitted in the future (POST 98) and be affected by any new legislation enacted as a result of the Senate Bill 96-74 studies.

PRE 85 water rights are primarily nontributary ground water rights that are allowed to withdraw from the Denver Basin Aquifers without any obligation to relinquish or replace any portion of the depletions that may occur to the surface stream systems. The withdrawal of groundwater under these water rights has caused stream depletions and will continue to cause depletions in the future. The actual amount of the depletions due to the withdrawal of groundwater is not known.

Many 85-98 water rights have been decreed or permitted, however, very little of this water is currently being withdrawn. Under the provisions of Senate Bill 85-5, these water rights fall in to two categories; either nontributary requiring relinquishment of 2% of the water withdrawn, or not-tributary requiring replacement to surface stream system of a certain amount (generally 4%) during the pumping period and may require continuation of some amount of replacement after pumping ceases. In designated basins not-tributary replacements are generally required to the stream alluvium or the uppermost aquifer and no post-pumping replacement is required.

There is insufficient data currently available to determine how much of the groundwater that is being withdrawn is either PRE 85 or 85-98 groundwater or whether 85-98 groundwater withdrawal is subject to the 2% relinquishment or 4% replacement requirements.

### 10.3 HOW OTHER WATER RIGHTS WILL BE AFFECTED

How long term pumping of the Denver Basin Aquifers effects the tributary surface and groundwater rights will be somewhat dependent on what rate and where future pumping occurs. It is unlikely that all landowners will construct wells and it is unlikely that all the water in the aquifers will be fully withdrawn within 100 years. However, based on modeling results, it is clearly possible to cause the total reduction in discharges and maximization of recharges (hydraulic connection between aquifers and the stream system are broken), as discussed above without pumping the aquifers at a 100 year aquifer rate.
Stream depletions are not linear to and do not occur at the same rate as pumping. However, stream depletions will continue after pumping ceases for many years (even hundreds of years) until recharge returns the aquifer water levels to their original condition.

Insufficient data is readily available to accurately assess what total amount of water is associated with existing Denver Basin aquifer water rights or at what rate withdrawals under these water rights may escalate in the future. Based on the recent model results, it is likely that existing Denver Basin aquifer water rights will, within about 100 years, cause reduction in Denver Basin Aquifer discharges to the surface stream systems of the entire estimated 60.9 cfs of pre-well development discharges and that the maximum depletions due to recharge from the streams to the aquifers will occur. It is unlikely that the replacement and relinquishment requirements of SB 86-5 are sufficient to replace the future drainage depletions.

Due to the hydrologic characteristics of the Denver Basin Aquifers, reductions in discharges to the surface streams occur on a relatively constant year around basis. Therefore, in the South Platte River Basin, long term depletions resulting from pumping of the aquifers may not always impact other water rights since those water rights may not have any demand for water at the time a depletion occurs. However, it should be anticipated that development of existing conditional water rights on the South Platte River System will continue until at some point there may be a call senior to Denver Basin depletions at all times of the year. The Arkansas River System is currently considered over-appropriated throughout most of the year. Effects on drainages within the designated basins will be primarily to water levels in the alluvial ground water systems since there is generally no surface water flow in these areas. The Colorado Ground Water Commission has found that the ground water systems of Kiowa Creek, Lost Creek, and Black Squirrel Creek are already over-appropriated, but that ground water is still available for withdrawal in Big Sandy Creek.

10.4 CONCLUSION

When one considers the potential for depletions to stream drainages to occur at the maximum rate associated with PRE 85 water rights and 85-98 water rights, it appears that the operation of these existing water rights, under current decrees and well permits may themselves maximize the unreplaced surface stream depletions that can result from withdrawal of Denver Basin Aquifer water. However, it may be nearly 100 years before the operation of these existing water rights cause such effects. Until this occurs, withdrawals by new water rights will cause an increase in stream depletions.

Whether the current replacement requirements will be sufficient for making up stream depletions associated with new pumping is difficult to determine. Any ability to make such a determination will be dependent upon obtaining accurate groundwater diversion records for both existing and new well owners. The State Engineer currently has limited resources in which to obtain these records. Although well owners are required to maintain ownership and address information in the State Engineer's records, few do and even when the State
Engineer can contact these users not all measure their diversions or maintain records of past diversions. Without the ability to obtain diversion records by mail or other efficient method, the staff of the State Engineer would have to resort to visiting each well on a regular basis to read meters (assuming they were installed and operating) or to issue orders to install and provide annual records from totalizing flow meters. Additional staff to obtain this data would be required. This requirement would be costly to both the well owner and State Engineer.

The withdrawal and consumptive use of nontributary and not-nontributary groundwater does result in a depletion to the surface stream drainage and may affect surface water rights. The question as to whether this depletion is injurious and to whom is subject to debate. Certainly, if the premise that if there is less water in the stream some senior water right is potentially injured is accepted, the impact of groundwater pumping will be on surface water users.
11.0 OVERVIEW OF THE SCOPE OF PARTICIPATION BY THE STATE OF COLORADO IN PROCESSES ASSOCIATED WITH THE IMPLEMENTATION OF THE ENDANGERED SPECIES ACT OF 1973 WITH RESPECT TO THE WATER RESOURCES OF THE SOUTH PLATTE RIVER BASIN AND DENVER BASIN

This chapter summarizes several options to fund actions by the State of Colorado and Colorado water users in fulfillment of commitments identified in the recently signed Cooperative Agreement for the Platte River Recovery Implementation Program. It also describes some options for administrative structures for managing the funds.

11.1 BACKGROUND

The State of Colorado, Nebraska, Wyoming and the U.S. Department of the Interior have reached agreement in principle on the elements of a proposed program to restore and protect the habitat of listed endangered species in central Nebraska. This program will also serve as the reasonable and prudent alternative for existing and new water use and development in the North and South Platte Basins in Colorado.

The agreement, which has taken three years to negotiate, is a critical part of the effort to address water and wildlife issues within the Platte River Basin. It will lead to a $75 million dollar investment in land and water management over a 15 year period to benefit wildlife in the central Platte River Basin in Nebraska including three federally protected endangered birds - the whooping crane, least tern, piping plover - and the pallid sturgeon, an endangered fish.

The agreement is designed to leverage resources from throughout the basin to address habitat and species issues. In exchange, the U.S. Fish and Wildlife Service, the federal agency which administers the Endangered Species Act, has agreed to streamline its regulatory review of individual water projects in the Platte River Basin that could affect the endangered species' habitat. Specifically, the U.S. Fish and Wildlife Service has agreed that the basinwide, long-term investment in land and water provided for in the agreement could serve as the required mitigation for individual water supply projects in the future.

In the past, without benefit of a basinwide program, the U.S. Fish and Wildlife Service has reviewed projects for regulatory compliance with the Endangered Species Act on a case-by-case basis. Such reviews have resulted in considerable conflict, since water project operators and the three states have contended that it is impossible to accurately assess the effects of individual water management actions in the Platte River Basin in isolation from all the other actions. These conflicts have produced long delays and resulted in considerable cost to water project operators and others.
The Colorado Department of Water Resources plans to conduct public meetings regarding the pact to ensure full public understanding and discussion of the agreement. While the agreement is supported in principle a binding commitment of funding for Colorado's participation in the program requires the appropriate legislative processes.

11.2 KEY ELEMENTS OF PLATTE RIVER BASIN ENDANGERED SPECIES COOPERATIVE AGREEMENT

The Agreement provides for:

1. **A Significant Investment In Wildlife Conservation:** U.S. Department of Interior and the states of Colorado, Nebraska, and Wyoming will invest $75 million in land and water management over an approximately 15 year period to benefit three endangered birds — the whooping crane, interior least tern, and piping plover — and one endangered fish species, the pallid sturgeon. These species are protected under the federal Endangered Species Act. Specifically, timing of river flows will be improved for river-dependent wildlife by changing how some water projects in the Platte River Basin are operated and by investing in new water re-regulation capacity to benefit federally protected species. Land adjacent to the Platte River necessary to support these species will also be protected.

2. **Regulatory Certainty and Significant Savings for Water Supply Agencies Throughout the Platte River Basin:** Existing and new water projects throughout the Platte River Basin will receive expedited Endangered Species Act review when undergoing federal permitting, thereby removing a source of regulatory uncertainty that has become increasingly pronounced in recent years. Specifically, the U.S. Fish and Wildlife Service will rely on the proposed basin-wide investment in endangered species and habitat protection when determining the mitigation requirements of individual water supply projects — both existing and future projects — the Platte River Basin. The agreement could save municipal and agricultural water supply agencies in the South Platte and North Platte River Basins in Colorado millions of dollars in avoided permitting and litigation costs.

3. **Time Frames Within Which to Achieve Specific Actions:** The agreement provides for a three year initial period during which required federal review under the National Environmental Policy Act and Endangered Species Act will occur. After this required review, and assuming unacceptable changes to the agreement do not result, the agreement will be implemented in increments. The first increment will be from 10 to 13 years in duration. Milestones related to meeting the land and water management goals of the agreement will have to be met on an annual basis. After the first increment, the parties to the
agreement will negotiate terms from a second increment if necessary to address the needs of the species.

4. Specific Obligations From Each of the States and the Federal Government to Protect 10,000 Acres of Land and to Improve Flow Conditions by an Average of 130,000-150,000 Acre/Feet Per Year:

a. **Colorado's obligations include:** pay $300,000 per year during the first three years to help support the National Environmental Policy Act review process and the development of a strategy to secure water supplies from the basin program through improved water conservation and other supplies; plan and develop the Tamarack flow re-regulation plan on the Tamarack Ranch State Wildlife Area, estimated to cost $4.2 million over 15 years; contribute $9.9 million in cash over fifteen years to fund additional water conservation and supply projects and land protection in Nebraska; additional payments, currently estimated at $300,000 per year to plan and develop the Tamarack Plan re-regulation project in the lower South Platte River in Colorado between the Tamarack Ranch SWA and the Nebraska-Colorado stateline mitigate the depletive effects of future water development in the South Platte and North Platte Basins in Colorado, which mitigation requirements will be tied to population increases in Colorado.¹

b. **Nebraska's obligations include:** pay $700,000 over the first three years to help support the National Environmental Policy Act review process and the development of a strategy to secure water supplies from the basin program through improved water conservation and other sources; donate land valued at $5.3 million to the basin-wide program; establish a designated account in Lake McConaughy from which water releases can be made to improve flow conditions in the habitat critical to meeting the needs of the endangered species. The water and annual operations of the account is valued at $9 million over a fifteen year period.

c. **Wyoming's obligations include:** pay $300,000 over the first three years to help support the National Environmental Policy Act review process and the development of a strategy to secure water supplies from the basin program through improved water conservation and other sources: plan and develop an enlargement to the Pathfinder Reservoir to re-regulate flows on the North Platte River, estimated to cost $3.5 million over 15 years; contribute $4 million in cash over fifteen years to

¹ No commitments have been made as to the source of these funds. Funding discussions will occur over the next several months, and to the extent that state funds are identified, all state funds are subject to legislative appropriation.
fund additional water conservation and supply projects and land protection in Nebraska.

d. The U.S. Interior Department's obligations include: pay $2.5 million each year for fifteen years towards the goals of the program.

11.3 FUNDING ASSUMPTIONS AND CRITERIA

There are many legal, political, and policy issues inherent in each of the options presented below. The options have not been researched, but are presented here to stimulate discussions and to determine which may be most promising, and therefore warrant further research.

The options are presented with the following qualifications.

1. While we recognize that several different factors could significantly alter any future funding commitments, we assume for planning and discussion purposes that the Program will remain intact through the NEPA process and will be implemented largely as currently envisioned. To assume otherwise (i.e., to assume that we only should consider partial funding) could lock us onto a path that may be inadequate to meet the funding obligations over the entire 13 - 16 year first increment, thereby jeopardizing the benefits that the State of Colorado and Colorado water users stand to derive from the Program. With this in mind, Colorado's full funding might be assumed to be approximately $1.5 million per year in 1997 dollars, or about $20 million over the life of the Program, to provide regulatory certainty for existing water facilities, future water development and operations, maintenance, and replacement activities throughout the South Platte Basin.

2. We believe that any funding option or combination of options ought to be equitable. We recognize that some options presented will be perceived to be less equitable than others. We do not comment on the equity of any particular option, since we believe these questions are best left to public dialogue. The chart below is designed to help assess the equity of any particular option. The ultimate funding mechanism could involve a combination of options, requiring that equity be judged in terms of the entire package and not simply in terms of its individual elements.

M & I entity emphasis <----------------------> Ag irrigation entity emphasis

Funding burden spread over Funding burden limited to

11-4
all Colorado residents  <-------------------> residents within service areas of entities benefiting from the program

Funding burden spread over all water facilities in the Platte Basin  <-------------------> Funding burden limited to those facilities with a federal nexus

Funding burden confined to existing water facilities and residents in Platte Basin  <-------------------> Funding burden borne by future development

3. To the extent the State actually participates financially in the Program, the administrative structure set up to manage the funds should be as accessible and responsive as possible to the broadest possible cross-section of Colorado's citizenry. Inherently, some administrative structures will be more responsive and accessible than others. Again, we do not comment about which structures might best fit this criterion, since this question is perhaps best addressed in the course of public dialogue.

11.4 FUNDING OPTIONS

1. State General Fund

Annually, the general Assembly could appropriate such funds as are necessary to fulfill the State of Colorado's commitments to the Program.

2. Water User Fees

a. Section 7 consultation fees: Fees could be assessed by the USFWS in the course of completing section 7 consultations for projects that choose to rely upon the basin-wide program. The fee structure could be similar to that currently in use on an interim basis for the Front Range "existing facility owners." Fees assessed against "existing facility owners" on the present interim basis would continue over the life of the program. Alternatively, a different fee structure could be formulated.

b. Water use surcharge: Water supply entities in the Platte River Basin could agree to assess their customers a small use fee per quantity of water delivered. The water entities would in turn make direct payments to the program. The fee could be structured in a stratified or block-rate manner to reflect differences in water use patterns and financial capability. For example, a municipal water agency with an average annual demand of 50,000 acre-feet/year could assess its customers 1
cent/1000 gallons. This would generate $163,000 (\{(50,000 \text{ acre-feet per year} \times 326,000 \text{ gallons per acre-foot} / 1000 \text{ gallons}) \times 1 \text{ cent} = \$163,000\}). Distributed across 50,000 households, this fee would amount to $3.26 per year for each household. Similarly, a ditch company serving 25,000 acres at 2.5 acre-feet per acre could assess its shareholders 1 cent per acre-foot. This would generate $62,500. Distributed across the acreage irrigated by the ditch company, this would add a two and half cent operation cost per acre to the shareholders' annual expenses. These fees could be voluntary and limited to members of the Platte River Project as an expectation and requirement of membership, or water supply entities could be directed by state statute to establish the fees.

3. **Other Fees and Taxes**

   a. **Wildlife Cash**: Revenue from the sale of fishing and hunting licenses could be dedicated to the Program by legislative appropriation.

   b. **Development Impact Fees**: By state statute, units of local government (municipalities and counties) could be directed to collect impact fees on new development (i.e., construction permits, special use permits, etc.) for deposit into a dedicated enterprise account. Rates could be specified in the statute or certified to the local government units by a Board of Directors appointed or elected by standing local government elected officials.

   c. **Ad Valorem Tax**: By state statute, units of local government could be directed to levy ad valorem taxes on taxable real property rights, including water rights, for deposit into a dedicated enterprise account. Rates could be specified in the statute or certified to the local government units by a Board of Directors appointed or elected by standing local government elected officials to manage the account.

   d. **Water Right Change/Transfer Tax**: By statute, water courts could be directed to levy a tax on all water right changes for deposit into dedicated enterprise fund. Rates could be specified in the statute or certified to the water court by a Board of Directors appointed or elected by standing local government elected officials to manage the account.

4. **Inter-governmental Agreement**

   Through an inter-governmental agreement, public agencies could form and fund the necessary entity to achieve the goals of the program.

5. **CWCB Construction Fund**
a. **Fish and Wildlife Resources Mitigation Account:** In 1997, the General Assembly approved changes to the administration of the Fish and Wildlife Resources Mitigation Account within the CWCB Construction Fund. The changes specifically allow interest income to the account to be spent on measures that mitigate the effects of past water development activities on species and habitat protected under the federal Endangered Species Act or thought to be in decline but not yet listed under the Act.

b. **Severance tax funds:** In 1996, the General Assembly approved changes in the distribution of severance tax funds. Part of the change involved earmarking $100,000 per year for deposit into the CWCB Construction Fund to support water resource planning activities in energy impacted counties. Application is made each year to the Minerals, Energy, and Geology Advisory Board (MEGA Board).

c. **Grants:** The CWCB can award grants from the Construction Fund. It already has awarded two grants totaling $375,000 to the Lower South Platte River Group, Inc. to develop recharge capability on a pilot basis in the lower South Platte River. Grants typically are confined to planning and feasibility work.

d. **Loans:** The CWCB makes loans from the Construction Fund for water development and management activities. Repayment terms are established by the Board.

11.5 **ADMINISTRATIVE OPTIONS**

1. **State Administrative Structure**

A separate account could be established by legislation in the Executive Director’s Office of the Department of Natural Resources to receive revenue from one or more of the options identified above. Expenditures from the account for Program purposes would be subject to legislative approval annually.

2. **Regional or Local Administrative Structure**

By legislation, a regional organization, such as a Water Conservation District, could be established to administer funds derived from one or more of the options described above and deposited into a dedicated account. The regional organization could cover all or a portion of the South Platte Basin. The regional organization would be governed by a Board of Directors, which could manage and make payments from (word missing) account to fulfill Colorado’s commitments to the Program. By statute, this Board of Directors could be appointed or elected by standing local government officials from the Platte basin, thus ensuring local control. The Board could be authorized to own and manage
real property, enter into leases, and otherwise manage involvement in the Program.
12.0 ASSESSMENT OF WATER REUSE OPPORTUNITIES TO ENHANCE THE RELIABILITY AND YIELD OF WATER RESOURCES OF THE SOUTH PLATTE RIVER BASIN AND DENVER BASIN

This Chapter summarizes the results of Chapters 2 through 7 in terms of two possible alternative water supply "futures". Each "future's" ability to enhance metro area water supplies, given competing resource demands, has been assessed. Each scenario consists of a "mix" of water supply measures representative of the combined actions of metro Denver area water providers to increase the region's sustainable water supply.

12.1 ALTERNATIVE "FUTURES"

The two alternative "futures" developed in this analysis are based upon seven possible categories of water supply sources as listed below. Both "futures" have been formulated to meet the metro Denver region's aggregated long-term future water demands as currently projected by individual water providers for the longest-term planning horizons available. Because approaches to water demand projections vary between individual providers, these future demands cannot be associated with any particular date and should not be characterized as "ultimate".

The two water supply "futures" analyzed consist of a mix of water sources based upon hypothetical and alternative "moderate" and "aggressive" levels of water efficiency practices, reuse, and conjunctive management. The terms "moderate" and "aggressive" refer to the relative roles of water use efficiency and water reuse in the overall mix of water supply categories in each "future."

Under the "moderate" future, the mix of water supply sources is based upon individual water providers' current plans with respect to all sources and assumes a general continuation of current levels of water use efficiency programs into the future. Under the "aggressive" future, the roles of water use efficiency and water reuse have been substantially increased to what could be characterized as "aggressive-but-not-extreme" levels.

Representative increases in water use efficiency would include mandatory retrofit of all existing development with water efficient fixtures, increased utilization of xeriscaping, and mandatory rainfall/soil moisture sensors for all new sprinkler systems. Representative increases in water reuse would include 10,000 acre feet per year of additional effluent exchanges on the South Platte between the Metro wastewater plant and Chatfield, a 30,000 acre foot per year indirect potable reuse plant below Metro, and 12,000 acre feet per year of additional augmentation and indirect potable reuse in the Cherry Creek and Plum Creek basins. The increased roles of efficiency and reuse in the "aggressive" future would result in decreases in the need for water from other sources. These alternative "futures" are summarized in Table 12-1.
Table 12-1
Alternative Future Supply Mixes
(acre feet)

<table>
<thead>
<tr>
<th>Supply Source</th>
<th>Existing</th>
<th>Moderate Future</th>
<th>Aggressive Future</th>
<th>Moderate to Aggressive Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Use Efficiency</td>
<td>101,000</td>
<td>180,000</td>
<td>280,000</td>
<td>100,000</td>
</tr>
<tr>
<td>Water Reuse</td>
<td>54,000</td>
<td>168,000</td>
<td>220,000</td>
<td>52,000</td>
</tr>
<tr>
<td>Transbasin Imports</td>
<td>168,000</td>
<td>277,000</td>
<td>232,000</td>
<td>(45,000)</td>
</tr>
<tr>
<td>Nontributary Groundwater</td>
<td>23,000</td>
<td>81,000</td>
<td>11,000</td>
<td>(70,000)</td>
</tr>
<tr>
<td>In-Basin Agricultural</td>
<td>89,000</td>
<td>126,000</td>
<td>89,000</td>
<td>(37,000)</td>
</tr>
<tr>
<td>Transfers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Platte Sources</td>
<td>147,000</td>
<td>182,000</td>
<td>182,000</td>
<td>0</td>
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<tr>
<td>Totals</td>
<td>582,000</td>
<td>1,014,000</td>
<td>1,014,000</td>
<td>0</td>
</tr>
</tbody>
</table>

12.2 ALTERNATIVE WATER SUPPLY SOURCES

We have assumed that future water demands in the metro Denver region would be met by a combination of six possible categories of water supply sources. The specific mix of sources used will vary among water suppliers depending upon individual provider's circumstances. These water supply sources have been described in previous chapters and are listed below.

1. Water use efficiency measures
2. Reuse and exchanges
3. Water imported to the South Platte basin from other river basins
4. Nontributary groundwater
5. Expanded utilization of South Platte supplies
6. Acquisition and conversion of in-basin agricultural rights

12.3 COMPETING RESOURCE DEMANDS

Water supply planning must be sensitive to several areas of competing resource demands. For purposes of this analysis, we have provided an assessment of the two identified alternative futures in terms of their effects on several competing resource demands which are described below.
1. **Endangered Species** - Water supply alternatives that deplete South Platte River flows, particularly during the spring and summer months may impact habitat endangered species in the Platte River. Water supply alternatives that increase diversions from the West Slope may impact endangered fish in the Colorado River basin.

2. **Basin of Origin Protection** - The potential for adverse environmental and socioeconomic impacts to basins of origin from which water is diverted is a major concern. This issue has resulted in extensive litigation and will continue to generate controversy over proposals to increase transbasin diversions from existing projects and/or to build new projects.

3. **Loss of In-Basin Irrigated Agricultural Land** - During recent years, the large scale acquisition and transfer of water from South Platte irrigated agricultural land to cities has raised concerns that are similar to those associated with Colorado and Arkansas basin of origin protection, particularly in areas north of the Denver area.

4. **Groundwater Pumping** - Under Colorado law, Denver Basin groundwater users are entitled to withdraw an average of one one-hundredth of the total recoverable amount of water beneath their property or service area in any year. If demands that otherwise would be served by nontributary groundwater can be met using renewable sources of supply, the life of the aquifer can be extended.

5. **Downstream Junior Water Rights** - Diversions of imported water and pumping of nontributary groundwater have resulted in increased municipal return flows at wastewater treatment plants that are new to the river. Historically most of the return flows from these sources has not been reused, resulting in a temporary windfall to downstream junior water rights. As discussed in previous chapters, water use efficiency, reuse, and increased use of South Platte supplies under the priority system by municipalities will tend to reduce the amount of windfall water available to junior water rights.

6. **Environmental Impacts** - There are environmental issues and concerns associated with all of the currently available water supply sources. However, the water supply sources that have generated the most controversy involve large storage projects, major transbasin diversions, and major transfers of agricultural water from areas that are not in close proximity to the cities proposing the transfers. To the extent that water supply planning can be structured to rely upon sources that avoid or minimize environmental controversy, the uncertainties, risks, and costs associated with local, state and federal permitting can be reduced.
12.4 ASSESSMENT OF ALTERNATIVE FUTURES

For purposes of evaluating the comparative impacts of existing levels of development with the impacts of the “moderate” and “aggressive” futures on stream flows in the South Platte at Henderson, the spreadsheet model described in Chapter 3 was used to account for the net accretive and depletive effects of the different combinations of the supply sources shown in Table 12-1. These South Platte River stream flow changes are illustrated in Figure 12-1.

Figure 12-1
Average Flow at the Henderson Gauge Under Historical, Recent, and Alternative Future Development

It is important to note that Figure 12-1 is based upon average flows and thus does not reflect substantial variations that would occur between individual years and months. The stream flow trends illustrated by Figure 12-1 are summarized as follows:

1. Comparison of the Historical vs. Recent Averages
   a. The higher Recent Average flows of July through April have been caused primarily by return flows from substantial increases in transbasin imports and the increased use of nontributary groundwater.
b. The lower Recent Average flows of May and June have been due primarily to increased utilization of South Platte storage facilities and water rights by metro area water providers to meet growing demands.

c. The total annual volume of recent average annual flows at Henderson is about 53,000 acre-feet greater than the historical average annual flows.

2. Comparison of the Recent Average with the Moderate Future Average

a. The higher Moderate Future flows would be due primarily to greater return flows from increased transbasin diversions, increased use of nontributary groundwater, and increased urban storm water runoff.

b. The lower Moderate Future flows in June is due primarily to increased use of South Platte storage facilities and water rights and a substantial increase in reuse of return flows from imports and nontributary groundwater.

c. The total annual volume of Moderate Future flows at Henderson would be about 144,000 acre-feet greater than the recent average annual flows.

3. Comparison of the Recent Average with the Aggressive Future Average

a. The higher Aggressive Future flows during the months of September through April would be due primarily to greater return flows from increased transbasin diversions and return flows from increased urban storm water runoff.

b. The lower Aggressive Future flows of May through August would be due to the combined effects of increased utilization of South Platte storage facilities and water rights, substantial increases in efficiency, increased reuse of return flows from imports, and reductions in nontributary groundwater use.

c. Under the Aggressive Future scenario, the total volume of average annual flows at Henderson would be about 22,000 acre-feet greater than the recent average annual flows.

4. Comparison of the Moderate Future with the Aggressive Future Averages

a. The higher Moderate Future average flows during all months of the year would be due to the combined effects of additional water efficiency, additional reuse, less return flows from smaller increases in transbasin diversions and reductions in the use of nontributary groundwater.
b. Under the Aggressive Future scenario, the total volume of average annual flows at Henderson would be about 122,000 acre-feet less than under the Moderate Future. While this difference appears to be quite large, it should be noted that under the Aggressive Future, annual flows would nonetheless average 22,000 acre-feet more than the actual recent average flows.

12.5 ASSESSMENT OF COMPETING WATER RESOURCE DEMAND FACTORS

The primary purpose of this analysis is to demonstrate the tradeoffs between competing demands for water resources associated with alternative water supply sources available to the Denver metropolitan area. Different supply sources will be viewed favorably or unfavorably depending on one's perspective. For example, while West Slope interests tend to favor options that maximize use of supplies available within the South Platte Basin, water users and endangered species interests downstream from Denver may prefer options that import more water to the South Platte. The seven categories of water supply sources used to formulate the Moderate and Aggressive futures were generally assessed in terms of their relative impacts on competing resources. The results of this assessment are summarized in Table 12-2 below and are discussed in the following section.

Table 12-2: Summary of Relative Impacts of Water Supply Source Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Endangered Species</th>
<th>Basin of Origin</th>
<th>In-Basin Irrigated Agriculture</th>
<th>Nontributary Groundwater Use</th>
<th>Downstream Water Rights</th>
<th>Environmental Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Use Efficiency</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Water Reuse</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+/-</td>
</tr>
<tr>
<td>Transbasin Imports</td>
<td>+/-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Nontributary Groundwater</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>South Platte Development</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>In-Basin Agricultural Transfers</td>
<td>neutral</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>neutral</td>
<td>+</td>
</tr>
</tbody>
</table>

+ = generally positive impacts
- = generally negative impacts
+/- = mixed impacts

12-6
1. **Water Efficiency Measures**
   
a. **Endangered Species** - Reduced demands and diversions are generally beneficial to both South Platte and Colorado River endangered species, although reduced return flow to the South Platte could have negative impacts to Platte River endangered species.

b. **Basin of Origin Protection** - Reduced demands and diversions are generally beneficial to basins of origin.

c. **In-Basin Irrigated Agriculture** - Reduced demand would tend to reduce the need for agricultural transfers.

d. **Nontributary Groundwater Use** - Reduced demands would tend to reduce the rate of groundwater pumping.

e. **Downstream Junior Water Rights** - Reduced demands and associated reductions in return flows from imported sources would tend to reduce downstream flows available to junior water rights.

f. **Environmental Impacts** - Reduced demands and diversions tend to be beneficial to instream flows and may postpone or eliminate the need for new water development projects.

2. **Reuse and Exchanges**
   
a. **Endangered Species** - This supply source would tend to reduce downstream South Platte flows and offset the demand for imports from other basins. This would tend to reduce both base flows and peak flows available to South Platte endangered species and help to maintain flows for Colorado River endangered species.

b. **Basin of Origin Protection** - Reuse and exchanges tend to offset the need for diversions are thus generally beneficial to basins of origin.

c. **In-Basin Irrigated Agriculture** - Reuse and exchanges would tend to reduce the need for agricultural transfers.

d. **Nontributary Groundwater Use** - Reuse and exchanges could tend to reduce the rate of groundwater pumping to the extent that reusable supplies are available to suppliers that rely upon nontributary groundwater.

e. **Downstream Junior Water Rights** - This supply source would tend to reduce downstream flows available to junior water rights.

f. **Environmental Impacts** - South Platte stream flow depletions associated with reuse and exchanges would occur both below the upstream points of diversion for municipal water providers and downstream from the metro area. However, reduced West Slope diversions would tend to be
beneficial to instream flows. In addition, this supply source may help to postpone or eliminate the need for new water development projects.

3. Water Imported to the South Platte from other River Basins
   a. **Endangered Species** - Return flow from imported water would tend to be generally beneficial to South Platte endangered species, especially if return flow were to increase peak flows during the spring and early summer months. To the extent that imported water is diverted from the Colorado River Basin, flows to downstream habitat for endangered fish would be diminished.
   
   b. **Basin of Origin Protection** - This supply source, by definition, is generally contrary to basin or origin protection, except in cases where mitigation measures and/or cooperative development approaches result in net benefits.
   
   c. **In-Basin Irrigated Agriculture** - Imports would tend to reduce the need for agricultural transfers. This would be generally beneficial in terms of maintaining irrigated agriculture but may not be beneficial to individual farmers or irrigation companies that plan to market their water to cities.
   
   d. **Nontributary Groundwater Use** - From a regional perspective, imports would tend to offset demands that may otherwise be met with nontributary groundwater and would reduce the rate of groundwater pumping.
   
   e. **Downstream Junior Water Rights** - Water imported to the South Platte from other basins will generally result in increased return flows downstream from Denver, to the extent that return flows are not consumed through direct reuse or exchange.
   
   f. **Environmental Impacts** - Additional diversions from other basins will tend to adversely impact instream flows and water quality in the basin of origin.

4. Nontributary Groundwater
   a. **Endangered Species** - Increased reliance on nontributary groundwater tends to reduce demands for South Platte or Colorado basin water supplies. Also, return flows from the use of nontributary groundwater, to the extent they are not consumed through reuse or exchange, are generally beneficial to Platte River endangered species.
   
   b. **Basin of Origin Protection** - From a regional perspective, increased reliance on nontributary groundwater tends to reduce demands for additional transbasin imports.
   
   c. **In-Basin Irrigated Agriculture** - Use of nontributary groundwater may tend to reduce the need for agricultural transfers.
d. **Nontributary Groundwater Use** - Increased reliance on nontributary groundwater, by definition, will increase the rate of groundwater pumping.

e. **Downstream Junior Water Rights** - Return flows from nontributary groundwater, to the extent they are not consumed through reuse or exchange, would be generally beneficial to downstream flows available for diversion under junior water rights.

f. **Environmental Impacts** - This supply source tends to be generally beneficial to instream flows in the South Platte below the metro area and may tend to temporarily postpone the need for new surface water development projects.

5. **Expanded Utilization of Native South Platte Supplies**

a. **Endangered Species** - Increased utilization of South Platte surface water supplies would tend to reduce South Platte peak flows available to endangered species, but would tend to reduce increase supplies available to Colorado River endangered fish species.

b. **Basin of Origin Protection** - Increased utilization of native South Platte surface water supplies would generally tend to offset the need for increased diversions from other basins.

c. **In-Basin Irrigated Agriculture** - Increased utilization of South Platte surface water supplies could tend to reduce the need for agricultural transfers. This would be generally beneficial in terms of maintaining irrigated agriculture but may not be beneficial to individual farmers or irrigation companies that plan to market their water to cities.

d. **Nontributary Groundwater Use** - Increased utilization of South Platte surface water supplies if used for conjunctive management would reduce the rate of groundwater pumping and could extend the life of nontributary aquifers.

e. **Downstream Junior Water Rights** - Increased utilization of South Platte surface water supplies would tend to reduce downstream flows available to junior water rights.

f. **Environmental Impacts** - Increased utilization of South Platte supplies would tend to reduce both peak and base instream flows. However, if used for conjunctive management, could also reduce or eliminate the need for development of new large surface water development and storage projects.
6. **Acquisition and Conversion of In-Basin Agricultural Rights**

a. **Endangered Species** - This supply source generally results in somewhat greater return flows and thus may be generally beneficial to South Platte endangered species.

b. **Basin of Origin Protection** - To the extent that metro area demands are met through the transfer of South Platte agricultural water rights, this source could offset the need for imported water.

c. **In-Basin Irrigated Agriculture** - This supply source, by definition, would increase agricultural transfers.

d. **Nontributary Groundwater Use** - Agricultural transfers could offset or reduce the need for groundwater pumping and could extend the life of nontributary aquifers.

e. **Downstream Junior Water Rights** - This supply source generally results in somewhat greater downstream return flows and thus may be generally beneficial to downstream junior water rights.

f. **Environmental Impacts** - This supply source generally results in somewhat greater return flows and thus may be generally beneficial to instream flows and to South Platte endangered species. Agricultural conversions may postpone or eliminate the need for new water development projects.

There are no alternatives that are entirely beneficial to all involved interests. However, this assessment demonstrates that the range of water supply options available to the metro Denver area provides some flexibility and possible opportunities for cooperative approaches and balancing of impacts.

Water use efficiency and water reuse already play a major role in the metro Denver region’s water supply systems, currently meeting over 25% of the region’s water demands. The relative importance of water use efficiency and water reuse could potentially increase significantly in the future. This could result in reduced future reliance on nontributary groundwater, smaller increases in transbasin diversions and less dry-up of irrigated agricultural land.

**12.6 INTERACTIVE TOOL**

A computer-based interactive tool was developed as part of the SB74 study to illustrate the interrelationships between population, water demands, water supply options and resulting effects on surface water and groundwater resources within the South Platte basin of Colorado.
The tool allows the user to select a future water supply scenario based on population growth and water supply options for each of three regions within the South Platte basin. Relevant information on population, existing water supplies and future water supply plans is provided in the input page along with several example future scenarios.

The tool illustrates the effects of a specified scenario with respect to surface water flows; transbasin diversions, Denver Basin groundwater use and conversion of in-basin irrigated agriculture. Effects on surface water flows are shown at five gage locations on the South Platte River.

The tool can be accessed on the internet at the following URL:

http://www.dnr.state.co.us/cwcb/secb/sb74stat.htm

CAVEAT: This tool has been developed for general illustrative purposes and should not be considered as an analytical model. While the tool correctly illustrates the overall effects of various population growth/water supply scenarios, it does not allow for detailed analysis of any specific water supply plan or project.
13.0 ASSESSMENT OF SURFACE AND GROUNDWATER DEVELOPMENT IN THE LOWER SOUTH PLATTE RIVER IN ACCORDANCE WITH THE SOUTH PLATTE RIVER COMPACT

This Chapter summarizes the current and future water development needs in the Lower South Platte area, recognized as that part of the basin below the Henderson Gauge. Also outlined is the Lower South Platte River Group's (LSPRG) and others efforts to address the water needs of the Lower South Platte region as they relate to the South Platte River Compact.

13.1 BACKGROUND

Water development in the South Platte River commenced in the upper reaches of the basin in 1859 and proceeded to progress downstream within the basin as seepage waters and return flows from the earlier surface diversions transformed the "disappearing river" into a constant flow that was reliably available to those diverters located downstream. Irrigators in the area considered to be the lower South Platte River began diverting flows in 1872 and, before 1900, had essentially developed the canal systems that remain in place today. The lower South Platte River, also known as former water district 64, is considered to extend from the west boundary of Washington County eastward to the Colorado-Nebraska state line as shown in Figure 1.

After the turn of the century, water usage in the lower South Platte River in Colorado was and continues to be regulated by provisions of the South Platte River Compact that was signed by representatives of the states of Colorado and Nebraska on April 27, 1923. The background and details of the compact and a report by the Colorado Compact Commissioner, Delph Carpenter, are included as Appendix 1. The salient provisions of the South Platte River Compact are:

The river was divided into an "Upper Section" and a "Lower Section." The Upper Section is the South Platte River in Colorado that is upstream of the west boundary of the Washington County line, and this part of the basin is not impacted by the provisions of the Compact. The Lower Section is the part of the South Platte River in Colorado between the west boundary of the Washington County line and the common line between the states (the same description as former water district 64), and is impacted by the provisions of the Compact.

The "Flow of the River" is the flow at the interstate station (Julesburg) plus inflows accruing between the station and the Western Canal.
Between October 15 and April 1 of each year, Colorado has the uninterrupted use of the flow of the river subject to Article VI of the Compact.

Article VI of the Compact allows Nebraska the right to construct the Perkins County Canal to divert up to 500 cfs under a December 17, 1921 priority date, subject to the following constraints:

a) Colorado appropriations, existing and future, are not affected in the upper section.
b) Colorado appropriations in the Lower Section senior to 12/17/1921 are not affected.
c) Colorado is allowed 35,000 AF of storage senior to the Perkins County canal regardless of the timing of perfection of this amount.

Between April 1 and October 15 of each year, Colorado must curtail diversions that are junior to June 14, 1897 if the flow at the interstate station is less than 120 cubic feet per second (cfs). (The 1897 date and the 120 cfs flow rate correspond to the water right attributed to the Western Canal in Nebraska)

The South Platte River Compact has allowed the development of water in Colorado upstream of the Washington County line to continue without impact from water rights in Nebraska. However, direct flow water rights in the Lower Section of the river did not continue to be developed after the Compact because the flow at the state line is frequently less than the 120 cfs required during the irrigation season making those water rights unreliable. Colorado continues to have approximately 1600 cfs of direct flow water rights located in the Lower Section of the river that are senior to the June 14, 1897 compact date. Those rights are diverted through 19 major canals or through wells that pump those rights as alternate points of diversion. In addition, there are about 900 irrigation and M & I wells located in the Lower Section and one major reservoir, Julesburg, that divert its water in this reach. Total irrigated acreage in the area is about 130,000 acres.

The historical amount of flow coming into the Lower Section of the river at the Washington County line has been historically measured by the Balzac gage, which has kept flow records since 1917. The average annual inflow to the Lower Section has been about 325,000 acre feet per year. The gaging station located at Julesburg has kept records since 1902. The average annual outflow from Colorado to Nebraska has been about 374,000 acre feet per year. Of interest is the fact that since records were kept at the Julesburg station, the average trend in flow at the state line has been steady, if not slowly increasing over time as shown in Figure 2. This is
largely due to transmountain diversions that have been brought into the South Platte River basin and have been available to Colorado water users, leaving steady streamflows at the state line. The annual average amount of water imported into the basin is about 410,000 acre feet per year.

Water continues to be available to Colorado that is in excess of the amounts required by the Compact as shown in Figure 3. That analysis shows that an average of about 313,000 acre feet of water is excess to the Compact requirements in the form of inflows to and river gains within the Lower Section.

13.2 FUTURE WATER DEVELOPMENT NEEDS IN THE LOWER SOUTH PLATTE RIVER

With the exception of groundwater, the South Platte River Compact has largely limited the development of water in the lower South Platte River since its implementation. In fact, several ditches that were junior to the Compact have been abandoned due to unreliable water supplies. However, today there are new needs to develop available flows that are in excess to the Compact in order to maintain existing uses in Colorado and meet future water needs.

The Endangered Species Act has created new and increased needs for water in Colorado. In the Big Bend reach of the Platte River in central Nebraska, there are three bird species and one fish species that are listed as threatened and endangered pursuant to the Endangered Species Act. This listing has already impacted several existing water projects within Colorado, and has the potential to impact many more in the future as water projects that need federal permits, including renewals, are reviewed. Reviews by the U.S. Fish and Wildlife Service require that such projects must not increase depletions to the Platte River system. Existing projects are evaluated as though they were new to the river system, and they are required to replace their depletions that affect the species’ critical habitat. Because of the problems and high costs that are encountered with individual reviews of projects subject to the Endangered Species Act, the states of Colorado, Nebraska, and Wyoming and the Department of Interior have worked on and have reached preliminary agreement on a basin-wide recovery plan that would address the listed species problems. The agreement essentially provides that the impacts of existing projects will be offset by the development of water and habitat for the species, and that any new water related project will not create additional depletions to flows needed for the critical habitat of the affected species. For Colorado, the agreement would require the state to develop at least 10,000 acre feet of water annually for their contribution to offset existing uses. Also, the requirement to offset depletive effects of new projects on the critical habitat will require the reregulation of additional water in
Colorado and will reduce the amount of flows that can be used by Colorado for new uses.

Another paramount need for water users located in the lower river is to protect their existing uses of water. Since wells were incorporated into the priority system along with the more senior ditches and reservoirs by the 1969 Water Right Determination and Administration Act, augmentation of those existing wells has been necessary. Continuing to maintain and improve the reliability of these augmentation supplies is an important future need, especially with the results of the Colorado v. Kansas litigation on the Arkansas River in mind.

As the towns along the lower South Platte River in Colorado grow, it is also important for them to be able to develop additional supplies of water for municipal and industrial needs that are reliable and of acceptable quality. While these needs are not large, the limited availability of water in the summer months makes such development difficult. The towns of Sterling and Julesburg currently face the problems of getting reliable water supplies for their anticipated needs.

There are species in Colorado known as "species of concern" which are candidates for listing as threatened and endangered by the USFWS. Included in this category are several species of minnows that reside in the South Platte River system in eastern Colorado. If these species were to become listed in the future, similar problems would face water users in Colorado as brought about by the Nebraska threatened and endangered species, but the impacts would be located within Colorado. In order to avoid the consequences associated with the federal listing, there is an effort to improve habitat for these species and keep them from becoming listed as threatened and endangered by the USFWS. This effort also involves water, and those needs are currently under study by the Colorado Division of Wildlife and others.

There are several ways to meet the water demands that exist in the Lower South Platte River using the flows that are in excess to the Compact and the proposed basin-wide recovery plan. The most effective method is to divert flows that are physically and legally available in the wintertime or water available during high flow conditions and reregulate or store those flows so they can be used during the irrigation season. The most efficient way to control this water is to increase storage within the lower river system, including the enlargement of existing reservoirs. However, development of reservoir storage can be relatively expensive. Another method that can be less expensive than reservoir development is to reregulate the available flows through groundwater recharge projects. This process involves the diversion of flows through existing ditches or through wells, delivering the water to locations away from the river, and causing those flows to infiltrate into the alluvial aquifer through ponds or the bottoms of canals so that the recharged water will
migrate back to the river at a time of need. Groundwater recharge is less efficient at controlling water supplies, but this process has been developed and used successfully along the South Platte River for the past 20 years. Again, these methods would tap available wintertime and/or high flows and store them for use at more critical times of the year.

13.3 EFFORTS TO ADDRESS NEEDS IN THE LOWER SOUTH PLATTE RIVER

There have been efforts to address water supply needs in the lower river over the years. With the implementation of the 1969 Act, augmentation supplies to offset well usage over the entire lower river were developed by Groundwater Appropriators of the South Platte (GASP). Some individual projects to augment wells were also implemented. Over the last few years, the Lower South Platte Water Conservancy District (LSPWCD) has initiated development of a plan to augment wells located in the eastern end of the river in Colorado. The most recent effort to address water needs in the Lower South Platte River is managed by the South Platte Lower River Group, Inc. (SPLRG). This effort grew out of a recognition that there were new demands for water supplies on the lower river that have come about relatively recently, i.e. Endangered Species Act, issues related to the Arkansas River litigation, and species of concern. A coalition of entities including GASP, LSPWCD, Northern Colorado Water Conservancy District (NCWCD), the Platte River Project (PRP, an extension of the Colorado Water Congress created to deal with South Platte River endangered species issues), the Colorado Department of Natural Resources (CWCB, SEO, and DOW), and water users in the lower river formed a non-profit organization to evaluate needs and implement projects to meet those needs.

Since their inception last year, the group has been very active, and they have combined funding ($40,000) and in-kind services (estimated to be over $150,000) from members along with grants from the Colorado Water Conservation Board ($375,000) to promote the development of needed projects in the lower river. SPLRG, Inc. has already initiated or assisted ditch companies on several groundwater recharge projects in the lower river to reregulate excess flows into the irrigation season to benefit wells. Several filings have been made in Water Court for such water rights. In addition the group has helped design the concept for the Tamarack Plan, a plan to develop Colorado’s 10,000 acre feet of water for the basin-wide recovery effort. Lastly, SPLRG has worked with Colorado State University and other entities to develop a user-friendly computer tool for data verification and analysis that can be used in water development and augmentation projects on the South Platte River. The SPLRG continues to look at additional projects to meet the multiple needs of the lower river for the future.
13.4 CONCLUSIONS

The majority of water development in the lower South Platte River in Colorado occurred prior to 1900 as flows became reliable due to return flows from upstream development, and the water supply system has not changed much since that time. The area in Colorado that lies upstream of the Washington County line is unaffected by the South Platte River Compact and has developed without limitations from downstream states. The South Platte River Compact between Colorado and Nebraska has controlled water uses in the Lower Section during that time, and ditches that were junior to the Compact date of June 14, 1897 have been abandoned due to the unreliability of flows subject to the Compact.

There are new needs for water development in the lower South Platte River including issues related to the Endangered Species Act, the need to firm augmentation supplies for existing wells, new water demands for growth in the region, and the enhancement of habitat to prevent listing of "species of concern" that exist in the South Platte River in Colorado.

Water in excess of the Compact exists during periods of high flow and during the wintertime when Colorado has full use of the river pursuant to the Compact. The amount of excess water available under the Compact would be reduced under the basin-wide recovery program developed by the states of Colorado, Nebraska, and Wyoming and the Department of the Interior (USFWS and USBR), but there should be sufficient water remaining to meet the needs of Colorado in the future.

Efficient methods exist that can reregulate excess flows into more critical times to meet the needs of the lower river. The South Platte Lower River Group, Inc. is a non-profit organization with widespread participation that has initially been successful at examining and resolving some of the issues on the lower South Platte River.
14.0 ECONOMIC LIFE OF THE DENVER BASIN AQUIFERS

This Chapter is a study of the economic life of the Denver Basin aquifers. This project was funded by the Colorado Legislature through the Colorado Water Conservation Board and in cooperation with the Office of the Colorado State Engineer. HRS Water Consultants, Inc. (HRS) was awarded the contract to perform the work.

14.1 BACKGROUND AND INTRODUCTION

Discussions concerning the economic life of the Denver Basin aquifers have occurred for more than 20 years. Denver Basin aquifer hydrogeologists realized that production from the Denver Basin aquifer wells will decline over time due to a reduction of the aquifer's saturated thickness caused by pumping. What is not known is how water well production rates will decline and how the cost of Denver Basin aquifer groundwater production will increase over time. Work authorized by S.B. 96-153 is meant to address these two very important questions.

Determining the economic life of the Denver Basin aquifers is a complicated problem. The analysis of production and drawdown in a Denver Basin aquifer well is complicated by the fact that aquifers are composed of interbedded layers of sandstone, siltstone and shale. Denver Basin aquifer water wells are constructed such that well screens are placed adjacent to the saturated sandstone/siltstone layers. Standard methods used to determine drawdown in a pumping well do not address the layered nature of the Denver Basin aquifers.

Phase 1 of the study concluded that the problem should be analyzed as an aquifer drawdown problem where the relationships among aquifer drawdown, pumping water level in a well, and production from a Denver Basin aquifer well are investigated. The problem can be stated as follows: How does water well production from the Denver Basin aquifers change in response to reduced saturated thickness and lower pumping water levels? Water well production rate is important because it is the measure of an aquifer's production. The costs of well installation, operation, and maintenance over time to meet demands is the basis of the economic analysis.

This Phase 2 study is intended to provide insight into the costs of ground water production from the Dawson, Denver, and Arapahoe aquifers which supply water in the Denver Basin of Colorado. Due to funding limitations and the lithology of the Laramie-Fox Hills aquifer, which is not similar to the Dawson, Denver, and Arapahoe aquifers, the decision was made not to include the Laramie-Fox Hills aquifer in this analysis. This initial effort is meant to:

- develop methods to more accurately analyze pumping water level and production from Denver Basin aquifer wells
- calculate the cost of ground water production at well locations to the year 2050.
The results of a well production analyses cannot be applied on an aquifer wide basis. The study results show significantly different results for wells located in different areas of the Denver and Arapahoe aquifers. However, the results have some applicability to other wells located with the same local aquifer area. Additional work should be performed on more wells in each aquifer including the Laramie-Fox Hills to determine the production characteristics and costs in additional aquifer areas.

Development of the ground water stored in the Denver Basin aquifers has resulted in regional declines in water level and increased pumping costs within some areas of the aquifers. In other aquifer areas water levels have risen. At some time, costs to produce the ground water may exceed the costs of other possible water supplies, making the other supplies more attractive or groundwater production costs may be similar to sources of water. The goal of this project is to estimate the relationship between ground water production and cost to the year 2050 at several well sites in the Denver Basin.

Previous work by the United States Geological Survey has provided estimates of regional water levels in the Denver Basin aquifers under several possible development scenarios. These modeling studies provide a description of the probable future water levels in the aquifers but do not address the problem of water levels in the pumping wells which are needed for this study. Methods to estimate pumping water levels based on simulated regional water levels exist for certain aquifer conditions, but do not properly account for changing aquifer thickness as the aquifers are drained. HRS has developed a method (Multi-Completion Well (MCW) Module) of simulating pumping water levels in the type of wells found in the Denver Basin and applied this methodology to this problem. With this approach, a more accurate analysis of future Denver Basin aquifer well production rates is possible. Ground water production cost analyses are performed based on the results of the well production analysis.

This study analyzed the pumping water level, production rate, and cost of production from the following seven well locations.

Arapahoe Aquifer - See Figure 5.1 of Technical Addendum 4 for well locations

1. North Metro Area - South Adams County Water & Sanitation District - Well 13R
2. South Metro Area - Castle Pines - Well A3

Denver Aquifer - See Figure 10.1 of Technical Addendum 4 for well locations

4. North Metro Area - Unconfined Well, Section 32, Township 2 South, Range 67 West
5. South Metro Area - Confined Well, Section 29, Township 5 South, Range 66 West
6. South of the Palmer Divide - Confined Well, Section 13, Township 11 South, Range 67 West

Dawson Aquifer - See Figure 10.1 of Technical Addendum 4 for the well location

7. South Metro Area - Unconfined Well, Section 13, Township 5 South, Range 66 West
14.2 CONCLUSIONS

For the groundwater production, pumping water level, and economic analysis performed to the year 2045, the following conclusions can be drawn.

Denver and Arapahoe aquifer well sites in the central portion of the basin may be able to operate for a long period at high pumping rates without requiring additional wells to meet projected demands. The analyses show that at these locations additional wells are not required in the Arapahoe aquifer before 2085 and that additional wells are not required in the Denver aquifer until 2075.

At Denver and Arapahoe aquifer sites toward the edges of the basin, additional wells would be required to meet demand in the next 30 to 40 years. Some Denver aquifer sites near the edge of the Basin may require many wells (approximately 10) to maintain future production levels. Arapahoe aquifer sites toward the edge of the basin may only require one additional well to meet expected demands through the year 2085.

This project evaluated existing numerical well production and drawdown methods (confined Trescott approximation) and developed a new method to analyze drawdown and production for wells constructed in the Denver Basin aquifers. The results of the study show that existing methods provide a very good estimate of expected water level in a well under confined conditions. Additionally, for situations where the aquifer converts from confined to unconfined conditions, the existing Trescott approximation method gives usable results when more than half of the original saturated thickness remains at the pumping well. Although a drawdown approximation exists for strictly unconfined conditions, this method was not evaluated, and it is not clear how this would be applied in a situation where the aquifer changes from confined to unconfined conditions in the course of the simulation.

As saturated thickness decreases below one-half of the original saturated thickness, for an Arapahoe aquifer well located near the edge of the aquifer, the pumping water level in the well becomes very sensitive to regional water levels and pumping rate. In the simulations of Woodmen Water & Sanitation District Well No. 7 in the Arapahoe aquifer located south of the Palmer Divide, a single well was required in 2015, but two wells were required in 2025. An increase in steady pumping rate of 11 gpm (5%) together with a drop in regional water level of 29 feet (23 feet of artesian head and 6 feet or a mere 1% reduction saturated thickness) caused water level in the well to drop to the bottom of the screen indicating that another well would be required to meet demand. This extreme sensitivity to pumping rate with decreasing saturated thickness has been observed in the Denver Basin aquifers and is supported by anecdotal evidence.

Pumping water levels in a well are based in part on regional water levels. The comparison of observed and simulated water levels at the Castle Pines Arapahoe Well A3 (Site 1, Figure 7.7) indicates that if the regional water level is incorrect, the pumping water level at the well will also be incorrect. However, if the regional water level can be accurately projected, the radial flow modeling methodology should allow the calculation
of pumping water level at a given discharge rate. Simulations of regional water levels contained in this report are based on a particular pumping scenario, and if actual pumping differs significantly from anticipated pumping rates, future projections calculated in this report will also be inaccurate.

The ability of the Multi-Completion Well module to closely match observed water levels in pumping wells, monitoring wells, and individual aquifer layers during simulation of aquifer tests indicates that the module is working correctly.

The future cost of groundwater production in the Denver and Arapahoe aquifers is closely related to the number of additional wells required to meet a demand schedule. Well production costs increase in years when additional wells are needed to maintain anticipated demands. Long term operational costs in the Arapahoe aquifer are in the range of $500 to $1,000 per acre foot and operational costs in the Denver aquifer are less than $500 to more than $2,000 per acre foot of production depending on the well's location. Operational and maintenance costs of more than $2,000 per acre foot represent a Denver aquifer well south of the Palmer Divide on the edge of the aquifer and includes the installation of three production rate wells by the year 2035 to meet anticipated demands. The installation of three wells to meet demands may or may not be a reasonable water supply scenario. The reasonable nature of future water supply costs are relative to the cost and availability of other water supplies.

This study analyzed municipal well production with pumping rates that approach maximum aquifer production rates. Individual domestic, municipal, commercial, and irrigation wells pumping at lower rates would create a smaller drawdown effect which would results in lower production costs.

14.3 RECOMMENDATIONS

Since pumping water levels are a strong function of regional water levels, one of the best ways to derive better pumping water levels is to develop a better future estimate of regional water levels in the aquifers. Additional modeling studies incorporating more accurate estimates for historic and present withdrawals and better projections for future water demand should give a better estimate of future conditions in the aquifer. The State's S.B. 96-74 modeling work should provide more accurate estimates of regional groundwater level declines.

An existing method called the Trescott approximation used to determine the pumping water level in a well appears to be remarkably accurate for long-term pumping under confined conditions and also works quite well as the aquifers start to convert to unconfined conditions over large areas. As the aquifer's saturated thickness declines, the accuracy of this approximation decreases. It is not clear how a new approximation for calculation of pumping water level in a well would work for an aquifer which changes from confined to unconfined conditions during pumping. With the Multi-Completion Well (MCW) module a confined-unconfined relationship should be developed for the
Denver Basin aquifers which would allow much easier estimation of pumping water levels as aquifer saturated thickness decreases.

A similar Trescott approximation specific to conditions where the aquifer is initially unconfined has been applied to one Denver aquifer site and one Dawson aquifer site in this study. However, the results of the unconfined approximation analysis were not compared to MCW module results. The results from the unconfined Trescott approximation should be compared to MCW radial flow model results to see if the Trescott approximation is good for initially unconfined aquifer conditions.

Results of the Trescott approximation for the Denver aquifer in the North Metro area indicate quite low production rates from individual wells due to the low transmissivity in the cells. Additional review of well records, aquifer test data, and production history from existing wells may allow a determination of whether these results are reasonable.

One of this study's results is that the Trescott confined approximation for pumping water level in a well appear to work well. As discussed above, additional work should be performed on the unconfined approximation to confirm this result. Additional analyses should be performed to address the cost of production from the Denver Basin aquifers over the entire area of the aquifers including the Laramie-Fox Hills aquifer. This could be done by using the Trescott unconfined and confined approximations and by developing a new approximation for a well during the transition from confined to unconfined conditions using the Multi-Completion Well module. The three approximations could then each be applied to their appropriate aquifer areas. More than one unconfined-confined approximation per aquifer may be necessary. These approximations to calculated pumping water level in a well would be applied to regional water levels developed from a regional ground water model. The State Engineer's S.B. 74 hydraulic head model of the Denver Basin aquifers may be appropriate for this purpose. The results of this analysis would then be used to determine the cost of ground water production for each aquifer over the entire basin.
GLOSSARY

Abandonment of a Conditional Water Right - means the termination of a conditional water right as a result of the failure to develop with reasonable diligence the proposed appropriation upon which such water right is based.

Abandonment of a Water Right - means the termination of a water right in whole or in part as a result of the intent of the owner thereof to discontinue permanently the use of all or part of the water available thereunder.

Absolute Water Right - A decree that has been perfected (diverted or stored) by beneficially using the appropriated water.

Acre-foot (ac-ft) - Quantity of water that would cover 1 acre, 1 foot deep. An acre-foot contains 43,560 cubic feet or 325,851 gallons.

Adjudication - A judicial proceeding in which an appropriation is assigned a priority and a decree defining the water right is issued.

Adjudication Date - the date of the court action on which the right to use of the water is legally acknowledged.

Alluvium - an aquifer which is directly connected hydraulically to a stream or lake. The gravels, sands, and fines deposited by a water body over the historical course of its flow.

Alternate Point of Diversion - any diversion point used in addition to the original point of diversion.

Appropriation - the application of a specified portion of the waters of the state to a beneficial use pursuant the procedures prescribed by law; but no appropriation of water, either absolute or conditional, shall be held to occur when the proposed appropriation is based upon the speculative sale or transfer of the appropriation rights to persons not parties to the proposed appropriation, as evidence by either of the following:

1. The purported appropriator of record does not have either a legally vested interest or a reasonable expectation of procuring such interest in the lands or facilities to be served by such appropriation, unless such appropriator is a governmental agency or an agent in fact for the persons-proposed-to be benefited by such appropriation.

2. The purported appropriator of record does not have a specific plan and intent to divert, store, or to otherwise capture, possess, and control a specific quantity of water for specific beneficial uses. (CRS 37-92-103)

Aquifer - An underground, water bearing formation (includes alluvium).

Aquifer Constant (alpha) - A number characteristic of an aquifer that denotes the speed with which transient changes will take place within the aquifer.
Artesian Well - A well which flows freely at the land surface because it taps a confined aquifer with sufficient hydrostatic pressure to push water to the surface.

Bank Storage - The water contained in the upper portions of an alluvium. It usually flows to the stream or lake following a lowering of the free water surface. It is usually filled by water flowing from the stream or lake with a rise of the free water surface.

Beneficial Use - The use of an amount of water that is reasonable and appropriate under reasonably efficient practices to accomplish without waste the purpose for which the appropriation is lawfully made and, without limiting the generality of the foregoing, shall include the impoundment of water for recreational purposes, including fishery or wildlife (CRS 37-92-103). For the benefit and enjoyment of present and future generations, "beneficial use" shall also include the appropriation by the State of Colorado in the manner prescribed by law of such minimum flows between specific points or levels for and on natural streams and lakes as are required to preserve the natural environment to a reasonable degree.

Border Irrigation - An open field method of flood irrigation between controlling ridges or borders.

Call - Placing a demand by a senior priority with the administrative official to shut down junior priorities so that the senior is able to divert its full entitlement. In such cases, junior priorities are curtailed or "called out."

Canal - An open conduit for the conveyance of water, distinguished from a ditch or lateral by its larger size, usually excavated in natural ground.

Cell - A block in a three dimensional mathematical mesh used to subdivide an aquifer system.

Change in Water Right - a change in the type, place or time of use, a change in the point of diversion, a change from a fixed point of diversion to alternate or supplemental points of diversion to a fixed point of diversion, a change in the means of diversion, a change in the place of storage, a change from direct application to storage and subsequent application, a change from storage and subsequent application to direct application, a change from a fixed place of storage to alternate places of storage, a change of alternate places of storage to a fixed place of storage, or any combination of such changes. The term "change of water right" includes changes of conditional water rights as well as changes of water rights (see Transfer).

Check Irrigation - A method of field irrigation where the field is divided into compartments or checks. The field is irrigated by successively pooling water into the checks.

Condition of Continuity - The requirement that water volumes must be strictly accounted through the free body.

Conditional Water Right - A right to perfect a water right with a certain priority upon the completion with reasonable diligence of the appropriation upon which such water right is to be based. No claim for a conditional water right may be recognized or a decree granted except to the extent that it is established that the waters can be and will be diverted, stored, or otherwise captured, possessed, and controlled and will be beneficially used and
that the project can and will be completed with diligence and within a reasonable time (CRS 37-92-103).

**Conductance** – The product of hydraulic conductivity and cross sectional area divided by the length of the flow path.

**Confining Unit** – A body of “impermeable” material stratigraphically adjacent to one or more aquifers. Although a confining unit may have very small permeability, it may store substantial volumes of water, which may flow to adjacent aquifers under a sufficiently large hydraulic gradient.

**Compact** – A contract between states of the union, entered into with the consent of the National Government, and in water, defining the relative rights of two (2) or more states on an interstate stream to use the waters of that stream.

**Conduit** - A closed duct or pipe for transporting water, a pipeline, or aqueduct.

**Cone of Depression** - The resulting top of the water table reflecting the gradient towards a well caused by withdrawals from the aquifer. In homogenous aquifers, the form of the top of the water table is a cone.

**Confined Aquifer** - An aquifer sandwiched between impermeable formations. The water level in a well completed in a confined aquifer will be above the top surface of the aquifer.

**Conjunctive Use** – The coordinated use of ground water and surface water to complete an appropriation and maximize the beneficial use of available water.

**Consistent Units** - A system which allows only one unit for each variable. The system can be used to derive explicit relationships.

When data are expressed in units other than those of a chosen system, the first task is to convert the data to the chosen system. Factors for making this conversion for some common units are given below:

<table>
<thead>
<tr>
<th>To Convert</th>
<th>To</th>
<th>Multiply by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gallons per Minute</td>
<td>Cubic Feet per Second</td>
<td>0.002228</td>
</tr>
<tr>
<td>Meinzer Unit (Permeability)</td>
<td>Feet per Second</td>
<td>1.5472(10) ^-6</td>
</tr>
<tr>
<td>Meinzer Unit (Transmissivity)</td>
<td>Feet Squared per Second</td>
<td>1.5472(10) ^-6</td>
</tr>
<tr>
<td>Acre Feet</td>
<td>Cubic Feet</td>
<td>43560</td>
</tr>
<tr>
<td>Cubic Feet per Second</td>
<td>Gallons per Minute</td>
<td>448.8</td>
</tr>
</tbody>
</table>

A township has an area of 23,040 acres or 1003.62(10) 6 square feet. A section has an area of 640 acres or 27.8784(10) 6 square feet. An acre contains 43,560 square feet. One cubic foot per second running for one day will deliver 1.983471 acre feet. Note that while a year of 365 days is usually assumed for computation purposes, a year is 365.2422
days (Smithsonian Physical Tables). This is 31,556,930 seconds. A cubic foot per second running for one year will deliver 724,447 acre feet.

Consumptive Use - The amount of water consumed during use and no longer available to the stream system. For irrigation, consumptive use is water used by crops in transpiration (building of plant tissue) and evaporation (process is termed evapotranspiration). The typical consumptive use assumed for in-house domestic use served by a central wastewater treatment plant is five percent.

Critical Year - A year in which the annual precipitation is considerably less than the average and the runoff in the stream is low. The critical year is used to test the dependability of water rights under "worst-case" conditions. Yield to a water system during this condition is termed dependable.

Cubic Feet Per Second (cfs or ft³/s) – The rate of discharge representing a volume of one cubic foot passing a given point during one second (equivalent to 7.48 gallons per second, 448.8 gallons per minute, or 1.98 acre-feet per day).

Cusec - A measurement of flow in cubic foot per second.

Darcy's Law - A law discovered by Henry Gaspard Darcy (1803-1858). His experiment showed that the velocity of flow through the porous media is proportional to the first power of the water table gradient.

Decree - An official document issued by the court defining the claimants, the priority, amount, use, and location of a water right or plan for augmentation. When issued, the decree serves as a mandate to the State Engineer to administer the water rights involved in accordance with the decree.

Deep Percolation – The volume of water from precipitation or irrigation that infiltrates the soil and moves by the force of gravity to the water table.

Depletion - Net rate of water use from a stream or ground water aquifer for beneficial and non-beneficial uses. For irrigation or municipal uses, the depletion is the headgate or well-head diversion less return flow to the stream or ground water aquifer during the same period.

Direct Flow Right - A right defined in terms of discharge which must be put to use more or less promptly following diversion from the source.

Discharge - The rate of flow which is the volume of water passing a particular point in a unit of time. Units of discharge commonly used are cubic feet per second (cfs) or gallons per minute (gpm).

Discharge Curve - A rating curve showing the relation between stage and discharge of a stream. The curve is defined by equation for properly constructed, standard measuring devices. It is defined by measuring the discharge for varying stages for non-standard measuring devices.

Designated Ground Water Basin – An area that has been designated by the Colorado Ground Water Commission wherein ground water is the primary source of supply.
Ditch - A narrow, artificial trench cut into the surface of the ground to transport water. A diversion ditch transports water from a stream to a point of use away from the stream. A drainage ditch transports water to a stream.

Divert - Removing water from its natural course or location, or controlling water in its natural course or location, by means of a ditch, canal, flume, reservoir, bypass, pipeline, conduit, well, pump, or other structure or device.

Diversion Records - Record of the daily, monthly, or annual flow for a ditch or other diversion structure during the irrigation season, usually compiled by the District Water Commissioner. Diversion records are on file and available for review by the public at the State Engineer's office or at the Division Engineer's office in each Division.

Division Engineer - The State of Colorado is divided into seven water divisions under the State Engineer. Each water division is administered by a Division Engineer, who is responsible for administering the water rights in that division.

Drainable Depth - A depth of ground water above the level of a system of drains or above the level of a river in an alluvium.

Drainage - 1) The process of removing surplus ground or surface water by artificial means. 2) The manner in which the waters of an area are removed. 3) The area from which waters are drained; a drainage basin.

Drawdown – The difference between the original water level and the water level after a period of pumping.

Drift - A term used to describe a flow of ground water under the action of a naturally existing regional gradient.

Due Diligence - the holder of a conditional water right must prove to the water court once every six years that they are working with reasonable diligence toward the appropriation of that right; for example, work toward the construction of the system, reservoir, or canal, required to regulate the water.

Dupuit-Forchheimer Idealization - An idealization whose use was pioneered by Arsene Jules Emile Juvenal Dupuit (1804-1866) and Philipp Forchheimer (1852-1933). Under this idealization, the gradient of the water table is assumed to be effective throughout the saturated thickness of the aquifer. When the water table gradient is small compared to unity, the postulated conditions are substantially realized.

Duty of Water - The total volume of irrigation water required to mature a particular type of crop. It includes consumptive use, evaporation, and seepage from ditches and canals, and the water eventually returned to streams by percolation and surface runoff, usually expressed in acre feet per acre.

Effective Precipitation - The amount of rain that falls during the growing season and is available for growth of vegetation. Effective precipitation is a portion of the total rain that falls during the growing season and is a function of the type of soil, the time period in which each rain falls, and its intensity. Thus, effective precipitation usually is less than precipitation measured at a given point.
Enlargement - A subsequent right awarded to a ditch or structure in addition to the amount granted originally. More than one enlargement may be awarded to a ditch or structure and each enlargement will have a priority related to the date it was appropriated and applied to beneficial use. Enlargements may be absolute or conditional.

Entire Water - A term used to describe water which occupies volume to the exclusion of everything else. Water flowing in a canal or a river is entire water. Interstitial water occupies only the interstices between grains in an aquifer.

Evaporation - The physical process by which a liquid or solid is transformed to the gaseous state. In irrigation, it is usually restricted to the change of water from liquid to gas.

Evapotranspiration - The combined processes by which water is transferred from the earth surface to the atmosphere; evaporation of liquid or solid water plus transpiration from plants. (See consumptive use)

Exchange – Diverting water at one place and replacing it at another without causing injury to other water rights.

Exempt Well – A well, usually domestic or stock watering, that is presumed to be exempt from administration as a result of statutory provisions assuming non-injury to other water users.

Fee Well – A well that is not exempt and requires a finding by the State Engineer of non-injury to other water rights before a permit can be issued. The permit number will generally have a “F” at the end.

Free River - A term used to describe a conditions where the flow of the river is sufficient to satisfy the demand from all vested water rights, and diversions from the river can be made without possibility of injury to any senior right.

Futile Call - If, in the opinion of the Division Engineer, there is no possibility that water called by a downstream, senior right will reach the headgate of that right, the Division Engineer has the discretion (on the basis of CRS 37-92-502(2)) of not honoring the call and allowing the upstream junior right to continue diversion.

Gaging Station - A selected section in a stream channel equipped with a gage and facilities for measuring the flow of water; a place on a stream where data are gathered from which continuous discharge record may be developed.

GPM (gpm) – Gallons per minute; the amount of water in gallons flowing by a given point in one minute; 448.8 gpm equals 1 cubic foot per second.

Gradient - A slope of the water table tending to cause the flow of ground water.

Ground Water - Any water not visible on the surface of the ground under natural conditions. (CRS 37-90-103)

Growing Season - That portion of the year in which the plants are consuming water and nutrients.
Head – Hydraulic head. Head is used generally to express a water level.

Headgate - A physical structure on a stream through which water is diverted into a ditch or on a ditch through which water is diverted into a lateral or onto a field (the latter is also termed takeout).

Historical Use - The evidenced diversion and use of water by a water right holder in a structure over a period of years.

Hydraulic Conductivity – The volume of water at existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow through a porous material.

Hydraulic Gradient – The change in static or hydraulic head per unit of distance in a given direction.

Hydrology - The science treating of the waters of the earth in their various forms - precipitation, evaporation, runoff and groundwater.

Irrigable Area - The area under an irrigation system capable of being irrigated principally as regards quality and irrigation of land. It generally includes roads, farm lots, building sites, and miscellaneous areas not actually irrigated.

Junior Right - A relative term describing a water right with a priority less than that of a "senior right." Usually diverts only during the runoff and tailing hydrograph periods.

Image - A hypothetical well, source, or sink used as a mathematical device to satisfy a boundary condition.

Impermeable - Not permeable

Inch - A Colorado statutory inch is defined as follows: "Every inch shall be considered equal to an inch square orifice under a five inch pressure, and a five inch pressure shall be from the top of the orifice of the box put into the banks of the ditch, to the surface of the water; said boxes, or any slot or aperture through which such water may be measured, shall in all cases be six inches perpendicular, inside measurement, except boxes delivering less than twelve inches, which may be square and said box put into the banks of ditch shall have a descending grade from the water in the ditch or not less than one-eighth of an in to the foot." Generally defined as the "Colorado, or "statutory" inch; 1 cfs = 38.4 inches. Other definitions of inch can be determined by a particular user and typically are rounded versions of the statutory inch such as 1 cfs = 40 inches.

Infiltration – Water moving downward into the ground from a surface supply such as precipitation or irrigation.

Initial Conditions - The conditions that prevail at the time of initiation of the transient.

Insolation - (Contracted from incoming solar radiation.) Solar radiation received at the earth's surface.

Intermittent Flows/Streams – Streams that do not have a continuous flow throughout the year.
**Interstitial Water** - Water which occupies the interstices between grains in a permeable bed.  
(See entire water)

**Irrigation** - The application of water to crops and lawns and gardens by artificial means to supplement natural precipitation. Water can be applied by spreading over the ground, by sprinkling, or by drip.

**Irrigation Efficiency** - The ratio of the volume of water required for a specific beneficial use as compared to the volume of water delivered. It is commonly interpreted as the volume of water that can be stored in the soil for evapotranspiration compared to the volume of water delivered, but may be defined and used in different ways.

**Irrigation Water Requirement** - The quantity of water, exclusive of effective precipitation, required for growing crops.

**Lateral** - A minor ditch headgating off the main ditch used to direct water onto the land. A ditch may have many laterals, depending on the amount of acreage irrigated, the slope of the land, and the rate of the seepage losses.

**Leach** - To attempt to remove alkali from soils by abundant irrigation combined with drainage.

**Left Bank of a Stream** - The left-hand bank when one is looking downstream.

**Linearization** - Many of the differential equations representing physical relationships are inherently nonlinear in form. Such relationships are generally difficult to solve and it is often desirable to replace them with approximations which have a more tractable linear form. This may be done in specific cases, by neglect of small quantities, by replacing a curve with its tangent in a range of interest or by other means. The process is called linearization.

**Line Source** - A source uniformly distributed along a line.

**Livestock Water Tanks** - includes all reservoirs created by dams constructed after April 17, 1941, on water courses, the channels of which are normally dry as determined by the State Engineer, having a capacity not exceeding ten acre feet and a vertical height not exceeding fifteen feet from the bottom of the channel to the bottom of the spillway to be used for stock watering purposes.

**Local Convergence** - A convergence of flow of ground water as to a drain tile.

**Loss** - The difference between the amount of water that is actually placed on the land and the amount of water that was physically diverted at the headgate. Losses are usually from seepage and evaporation.

**Made Whole** - To leave the river in the condition it would have been had the exchange, reservoir release, or other action not taken place. (Robert Jesse, Colorado Water Division Engineer, written commun., August 23, 1984)
Mass Diagram - A graphical representation of cumulative quantities, such as the integral of a time-flow curve; an integral curve; each point on the curve is the sum of all preceding quantities considered. The diagram is used extensively in storage analysis.

Material Injury - A reduction of water available to a water user as the result of diversions by other water users.

Meinzer Unit - A unit of permeability used in the older publications of the U.S. Geological Survey. It is defined as the flow of water in gallons per day through a crosssectional area of one square foot under a gradient of one foot head of water per foot of length, measured in the direction of flow, at a temperature of 60°F.

Miners Inch - The discharge from an orifice one inch square under a definite head. The value of a miner's inch has been fixed by statute in various states as follows: Colorado 1 cfs = 38.4 inches; Arizona, California, Montana, and Oregon - 1 cfs = 40 inches; Idaho, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, Utah - 1 cfs = 50 inches; British Columbia - 1 cfs = 35.7 inches. In the southern part of California 1 cfs = 50 inches regardless of the legal definition.

Mitigation – To moderate or reduce the impact of injury.

Native Water - water naturally occurring in the basin in which it is found; not imported from outside the basin.

Natural Stream – A channel on the surface of the earth that has been formed by flowing water.

Node – The point in the model cell at which the head is calculated.

Nontributary-ground water - Water that is not part of a natural stream as established through geological and hydrologic facts. The factual determination of nontributary usually involves the length of time the impact of withdrawal would take to reach the stream and the amount of impact relative to the total volume of surface flow impacted. In Colorado, the withdrawals from nontributary wells require stream augmentation of two percent of withdrawal during the well life. See CRS 1973, 37-90-103(10.5) as amended.

Not-nontributary groundwater - Water withdrawn from the Denver aquifer which does not meet the definition of tributary or nontributary. If a well is located within one mile of the contact between an aquifer's outcrop and a natural stream, full augmentation of the injurious effects of the well's withdrawals is required. This condition applies to all Dawson aquifer wells. In the Denver, Arapahoe, or Laramie/Fox Hills aquifers, wells located more than one mile from any point of contact between the aquifer's contact and any natural stream on which water rights would be injuriously affected by the well's stream depletion, the replacement of four percent of the annual withdrawal is required during the well's life. Additionally, the well's injurious effects on the stream must be replaced after the well's life.

Original Adjudication – The court proceeding that was the first to be held in a water district.

Original Right - The first right awarded to a ditch or storage structure.
Over-Appropriated Stream — A stream system that during certain times of the year does not have adequate water to satisfy all of the water rights demanding water.

Parallel Drains - Drains of the type installed for drainage of agricultural land. They can be in the form of open ditches or buried tile lines.

Parshall Measuring Flume - (formerly termed the "improved Venturi flume") A calibrated device developed by engineers of the U.S. Department of Agriculture, of whom Ralph L. Parshall, a professor of hydraulic engineering at Colorado State University was principal experimenter. Its purpose is to measure the flow of water in open conduits. It consists essentially of a contracting length, a throat, an expanding length. At the throat is a sill over which the water is intended to flow at Belanger's critical depth. The upper head is measured a definite distance upstream and the lower head a definite distance downstream from the sill. The lower head need not be observed except where the sill is submerged more than about 67%. A special form of control flume.

Percolation – The infiltration or absorption of water into soil, or the migration of water through a geologic formation.

Permeability - A term used to describe the ability of water or other liquid to move through a porous formation under the action of a gradient. The ease with which a fluid will move through a formation is greater for some than for others. For a given head, the permeability is expressed by a constant K representing the flow through unit area in unit time under the influence of a unit gradient. The flow is expressed in terms of entire water.

Phreatophyte – A plant that has its root system in shallow ground water and is often found along streams, rivers and canals.

Piezometer - A instrument for measuring pressure head, usually consisting of a small pipe tapped into the side of a closed or open conduit and flush with the inside, connected with a pressure gage, mercury, water column, or other device for indicating pressure head. Usually used on earthen dams to determine the elevation of the piezometric line of water infiltrating from the reservoir. Also a slotted pipe drilled into the ground to determine the water table level.

Plan for Augmentation - A detailed program to increase the supply of water available for beneficial use in a diversion or portion thereof by the development of new or alternate means or points of diversion, by a pooling of water resources, by water exchange projects, by providing substitute supplies of water, by the development of new sources of water, or by any other appropriate means. "Plan for Augmentation" does not include the salvage of tributary waters by the eradication of phreatophytes, nor does it include the use of tributary water collected from land surfaces which have been made impermeable, thereby increasing the runoff but not adding to the existing supply of tributary water.

Potential Evapotranspiration - The rate at which water, if available, would be removed from the soil and plant surface expressed as the rate of latent heat transfer per square centimeter or depth of water.
Potentiometric Surface - A surface to which water will rise in a well with perforated casing installed below the top of a confined aquifer.

Previous Adjudication Date - A date that is significant, in that, regardless of the priority date assigned, all rights adjudicated on a given date are junior to all rights adjudicated at an earlier date. The opportunity to adjudicate is taken into consideration in establishing basin-wide priorities.

Primary Storage Coefficient – A model term that is equal to specific yield if the aquifer is unconfined or is otherwise equal to the storage coefficient. The term is only used in a transient simulation.

Priority - The relative seniority of a water right as determined by its adjudication date and appropriation date. In some cases, other factors are also involved in determining priority. The priority of a water right determines its ability to divert in relation to other rights in periods of limited supply. Three dates are important in the determination of a basin priority of a water right: (1) The water appropriation date when the initial work toward utilizing the water was begun; (2) the adjudication date, when the decree was granted by the court; and (3) the date of the previous adjudication. Consideration of the last date is necessary, as all rights in each of the former districts must have an equal opportunity to adjudicate.

Pristine – The original condition of an early period or earliest period; still pure; unspoiled; uncorrupted.

Production (Well) - The total volume of well flow counted from the time of initiation of flow.

Promulgate – To place a rule or law into effect by formal public declaration or announcement.

Radial Flow - Flow converging toward a center.

Raw Water - Untreated water supply.

Recharge – To enhance an aquifer by placing additional water into it through percolation of surface water, or injection wells.

Recovery – A rise of the potentiometric surface or water table due to decreased discharge from, or increased recharge to, the ground water reservoir.

Refill – A term used when a reservoir is given the right for a second filling.

Replacement Storage - Storage used to store water during times when all downstream rights are satisfied. Water is released later to meet the demands of senior rights downstream in order to allow diversion by more junior project rights located upstream of the storage facility. This is a common feature of conservancy transmountain diversion projects in Colorado.

Reserved Rights – Water rights established by reservation of lands by federal government for given purposes such as Indian Reservations.

Return Flows – Water which returns to a stream or aquifer system after it has been used for a beneficial purpose.
Reuse - A term that often applies to the use of transbasin water, non-tributary water, or transmountain water, where the owners have the right of successive use as long as they maintain identification and control of their water.

Right Bank of a Stream - The right-hand bank when looking downstream.

Riparian - Pertaining to the banks of a body of water; a riparian owner is one who owns the banks; a riparian right is the right to control and use water by virtue of the ownership of the bank or banks.

Riparian Doctrine - A form of water law that gives the owners of the land adjacent to the stream equal rights to the use of water.

River Call - At any time, the river call date is the priority date of the most junior right diverting from the river. A request by a water user to have the Division Engineer curtail junior appropriators to provide water to a senior right.

Root Zone - the part of the soil occupied by the roots of the plant.

Rotation - A system or irrigation through which the irrigator receives his allotted quantity of water, not at a continuous rate, but as a larger flow at stated intervals; for example, a number of irrigators receiving water from the same lateral may agree among themselves to rotate the water, each taking the entire flow in turn for a limited period. (Also called sectioning)

Saturated Thickness – The thickness of water bearing materials in a geological formation.

Second Foot, cfs or Cubic Foot Per Second -- A rate of flow of water passing a given point so as to amount to a volume of 1 cubic foot for each second of time.

Secondary Storage Coefficient – A model term that is always equal to specific yield. The term is used instead of the primary storage coefficient when an aquifer converts to unconfined conditions. The term is only used in a transient simulation.

Sectioning - (see rotation)

Seepage - The percolation of water through the soil; infiltration.

Senate Bill 5 (SB 5) – Enacted in 1985, amongst other things, defined non-tributary (NT) and not-non-tributary (NNT) ground water terms. It provided the requirement to replace 4% of the amount of water withdrawn on an annual basis for wells withdrawing NNT ground water and relinquish 2% of the amount of water withdrawn on an annual basis for wells withdrawing NT ground water. It also provided the requirement to replace actual depletions for wells withdrawing NNT ground water from the Dawson aquifer.

Senior Right - a relative term referring to a right with an earlier priority.

Shrink - Term used to describe the decrease of an entity’s water supply by any one of a number of causes. It has been used in reference to: 1) transpiration loss charged in routing a reservoir release down a river channel; 2) the decrease of reservoir storage accounts by evaporation.
Siphon - A closed conduit, a part of which rises above the hydraulic grade line. It utilizes atmospheric pressure to effect or control the flow of water through it. An inverted siphon has none of the properties of a siphon.

Sluice - As most commonly used, this term refers to the act of washing sand and other sediments from canals back to the stream from which they came.

Solar Radiation - The total electromagnetic radiation emitted by the sun. (See insolation)

Specific Yield – The amount of ground water that can be recovered from a given volume of saturated aquifer (usually expressed as a percentage).

Steady State – Equilibrium conditions when hydraulic heads and the volume of water in storage do not change significantly with time.

Steady State Cases - Ground or surface water conditions which do not change with time

Storage Coefficient – The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Storage Right - A right defined in terms of the volume of the water which may be diverted from the flow of the stream each year and stored in a reservoir or lake to be released and used at a later time either within the same year or a subsequent year. Usually the diversion under a storage right is limited to one "fill" per year. The fill is determined by the state water officials as the decreed amount less the amount in storage at the beginning of the administrative year.

Stream-Aquifer System – A stream and alluvial aquifer in hydraulic connection such that there may be an interchange of surface and ground water.

Stress Period – A period of time represented in the model during which stresses input to the model such as pumping and precipitation recharge are held constant.

Subirrigation 1) Watering plants by applying water below the ground surface, 2) Irrigation by the water table rising within or near the root zone, often under control. 3) Colloquially, "subbing".

Tailwater - Excess surface water draining from an irrigated field or returning to natural channels from the downgradient end of an irrigation ditch. It is also the water in a channel immediately downstream from dam, mill, or power plant.

Total Consumptive Use - The amount of water, regardless of its source, used by the crops during the growing season. It is the amount of water that is physically removed from the system and is not available for other users.

Transfer - The process of moving a water right originally decreed to one ditch to another ditch by court decree. A transferred water right generally retains its priority in the stream system and may or may not retain its right to divert its entire decreed amount. Additional terms and conditions may be imposed on a transferred right to limit its burden of the stream to that historically felt.
**Transit Loss** - Water lost to the owner of a right as it is transported to the place of use in the natural stream.

**Transient State** – Non-equilibrium conditions when hydraulic heads and the volume of water in storage do change significantly with time.

**Trans-Basin** -- The removal of the water of a natural stream from its natural basin into the natural basin of another stream.

**Transmountain Diversions** - The importation of water originating in one river basin to another basin. The diversion is by means of a ditch through a topographic saddle in a divide between the basins or by a tunnel through the basin divide. A water right is required from the basin of diversion. This term is often used when water is transported across the continental divide.

**Transpiration** - The process by which water in plants is transferred as water vapor to the atmosphere.

**Tributary** – Water that is hydrologically connected to a stream system either by surface or underground flows.

**Tributary Ground Water** - Seepage, underflow, and percolating water that will become part of a natural stream within 100 years. A natural stream's water include water in the unconsolidated alluvial aquifer of sand, gravel and other sedimentary materials, and all other water hydraulically connected thereto, which can influence the rate or direction of movement of the water in that alluvial aquifer or natural stream. In Colorado, all ground water is presumed to be tributary unless proved otherwise.

**Unconfined Aquifer** - An aquifer in which the water table serves as the upper surface of the zone of saturation.

**Unit Consumptive Use** - The amount of water used by crops for growth, less effective precipitation, expressed in acre feet per acre or feet of water. Unit consumptive use is considered synonymous with consumptive use and is less than total consumptive use. Water for consumptive use may be supplied from surface water diverted by a ditch and ground water occurring naturally beneath the crops (subirrigation).

**Vapor Pressure** - The partial pressure of water vapor in the atmosphere.

**Virgin Flow** – The natural flow of a stream which would occur if man had not affected or used water from the stream.

**Void Ratio** - The ratio of the volume of drainable or fillable voids to the gross volume.

**Volume** - A specific quantity of water generally expressed in terms of acre feet or million gallons.

**Water Right** - A right to use, in accordance with its priority, a certain portion of the waters of the State by reason of appropriation of the same (CRS 37-92-103).

**Water Table** - The upper limit of the completely saturated material in an aquifer. The surface in an unconfined water body at which the pressure is atmospheric.
Yield - The volume of water diverted by a water right. Yield may be expressed as an average for a period of years (average yield) or as the yield of one selected year representing the lowest or critical amount of water provided (critical or dependable year yield). Yield also may refer to diversion at the river (river headgate yield) or at the farm turnout where it is applied to irrigation (farm headgate yield). The difference between headgate yield and farm yield is the amount of water loss to seepage and other causes related to conveyance of water through the ditch.