PLANNING WATER REUSE: DEVELOPMENT OF REUSE THEORY AND THE INPUT-OUTPUT MODEL
VOL. I: FUNDAMENTALS

by

Charles D. Turner
David W. Hendricks

September 1980

COLORADO WATER RESOURCES
RESEARCH INSTITUTE

Colorado State University
Fort Collins, Colorado

Completion Report No. 114

Planning Water Reuse--Development of Reuse Theory and the Input-Output Model

Volume I: Fundamentals

Completion Report
OWRT Project No. 78-270450-145

by

Charles D. Turner
David W. Hendricks

Department of Civil Engineering
Colorado State University

submitted to

Office of Water Research and Technology
U.S. Department of the Interior
Washington, D.C. 20240

September 1980

The work upon which this report is based was supported (in part) by funds provided by the U.S. Department of the Interior, Office of Water Research and Technology, as authorized by the Water Resources Research Act of 1978.

Colorado Water Resources Research Institute
Colorado State University
Fort Collins, Colorado
Norman A. Evans, Director

APPLICATION SUMMARY

The stability of irrigated agriculture in Colorado is being endangered due to the high rate of water transfers from agriculture to municipalities. Very little undeveloped raw water remains and new water developments are costly and extremely controversial. Therefore, many municipalities have turned to the acquisition of agricultural water rights as a source of supply.

The transfer of Colorado Big Thompson Project (CBT) water units from agriculture to municipalities typifies the trend along Colorado's Front Range. For example, since 1957, 51,340 units of CBT water have been purchased by municipalities from agriculture and the price per unit has increased from less than $20 to $2,000 per unit during the same time period.

An alternative to acquiring agricultural water for municipal purposes is sequential reuse exchange between agriculture and municipalities. High quality raw mountain water that is currently receiving first use for agricultural irrigation can be rerouted to municipalities for first use. After use, the treated municipal wastewater plus makeup water for consumptive use losses within the municipality is then transported to agricultural lands for a second use. Since municipalities typically consume between 30 and 50 percent of the water used, the demand for water from other sources such as agriculture is reduced by 20 to 50 percent.

This research develops a theory of water reuse planning for developing water reuse exchange alternatives and comparing those alternatives with conventional approaches to water supply. A water balance matrix (also known as the input-output water balance model) that can be used to model any size water system is developed and demonstrated for developing and displaying water reuse alternatives. The demonstration is done for the Cache la Poudre River Basin along the Front Range of Colorado. Use of the water balance matrix allows the water planner to see alternatives that might otherwise be overlooked. The matrix is a tool for presenting alternatives to decision makers that shows how each alternative relates to the water system of the planning area.

The research provides a theory of water reuse planning applicable to complex already developed agro-urban regions along the Front Range in Colorado. Application of the theory to the South Platte River Basin shows that a projected year 2020 municipal water shortfall of 430,000 acre-feet can be met using a combination of water reuse types. These projections are made using a water reuse theory that brings together facets from appropriative water law, water quality legislation and economic principles to form a comprehensive reuse planning methodology. Application of the methodology and the water balance matrix demonstrates that water reuse exchanges between municipalities and agriculture can solve a significant part of the water problems in Colorado. The water reuse planning methodology and water balance matrix should prove to be useful to water resource planners developing alternatives to meet increasing municipal water demands.

ABSTRACT OF REPORT

PLANNING WATER REUSE

Municipalities in the west are searching for new sources of water at a time when very little undeveloped water remains. An increasing number of communities are planning to meet growing water needs through water reuse. In Denver, for example, a potable water reuse facility of 100 mgd is being planned for construction during the 1990's.

An alternative to potable water reuse is the exchange of treated municipal wastewater for unused high quality agricultural water. This type of water reuse promises to be less expensive than potable reuse and it can be implemented today. In order to facilitate the exploration of municipal water reuse alternatives, a water reuse methodology is developed in the research. Two case study demonstrations are used to document the application of the methodology.

The water reuse planning methodology is developed using: (1) a synthesis of reuse definitions from the literature, (2) an analysis of proposed and existing water reuse projects to discover new directions in reuse development, (3) identification of financial and regulatory incentives contained in the water quality laws, and (4) the identification of mechanisms in appropriative water law that influence water reuse. The resulting methodology is designed to aid in the formulation of water reuse alternatives. An economic methodology is also developed for the evaluation and comparison of dual purpose water reuse alternatives with other water supply and wastewater treatment alternatives.

The South Platte River Basin and the cities of Fort Collins and Greeley are used to demonstrate the alternative development methodology. The demonstration shows that water reuse exchange with agriculture has the potential to meet all but the very highest municipal water projections for the next 40 years in the basin.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ACRONYMS

AF, ac-ft	acre-feet
CBT	Colorado Big Thompson
CLPRB	Cache la Poudre River Basin
DWD	Denver Water Department
EPA	Environmental Protection Agency
FRICO	Farmer's Reservoir and Irrigation Company
gpcd	gallons per capita per day
MDSDD No. 1	Metropolitan Denver Sewage Disposal District Number 1
mgd	million gallons per day
mg/ℓ	milligrams per liter
ml	milliliters
NPDES	National Pollutant Discharge Elimination System
NPICo	North Poudre Irrigation Company
OWRT	Office of Water Research and Technology
PRPA	Platte River Power Authority
PVLCCo	Pleasant Valley and Lake Canal Company
SPRB	South Platte River Basin
SS	suspended solids
STP	sewage treatment plant
TDS	total dissolved solids
WS&SCo	Water Supply and Storage Company
WTP	water treatment plant
WWTP	wastewater treatment plant

CHAPTER 1

INTRODUCTION

Water reuse projects have appeared in the water resources literature for decades. Most professionals in the water resources field recognize the names of water reuse projects such as Water Factory 21 and Whittier Narrows in Los Angeles, Windhoek in Southwest Africa, and the sewage farm in Muskegon, Michigan. Yet, until relatively recently, water reuse has not been viewed as a viable water supply alternative. Why the change?

For most of history, sewage has been regarded as an offensive commodity that should be disposed of as cheaply and inostensibly as possible. Several events have taken place over the last decade to change this negative attitude. One of the most important was the passage of the Water Pollution Control Act of 1972. Regulatory measures resulting from the Act have meant much higher quality municipal and industrial discharges. At the same time, arid western urban areas have been growing rapidly and most have exhausted readily available raw water supplies. As a consequence, treated sewage is now called wastewater and is being thought of as a resource that can be used to meet at least part of the water needs of urban and agricultural users.

1.1 Background

The challenges of water reuse planning are distinctly different from those faced in the traditional development of raw water supplies. Reuse planning is more complex and coordination with other water users is more critical. Water reuse planning requires an understanding of the basin-wide water system while, by contrast, the traditional approach (i.e., raw water resources that are unused or available for transfer from one use to another) focuses on a limited portion of the system.

The development of water reuse alternatives demands an approach where all water resources, including raw water and wastewater resources currently being used or disposed of by others, are examined in a systematic fashion. Reuse alternative development should include sequential reuse schemes as well as the more common recycle reuse options. A systematic approach allows for the evaluation of sequential reuse exchange alternatives that might otherwise go undetected.

This research utilizes a two-part system for water reuse alternative development and display. The first part, Volume I, contains the methodology of water reuse alternative development. It establishes a definitional base, reviews and evaluates water and water quality laws that serve as reuse incentives and constraints, establishes economic evaluation criteria, and lays out a step-by-step reuse planning procedural methodology. The second part, Volume II, develops the input-output water balance model as it is adapted to water reuse planning. Case study demonstrations using the planning methodology and the input-output model are presented for the South Platte River Basin in Colorado.

1.2 Objectives

The overall objective of this research is to develop a methodology for water reuse planning within the context of a complex, man-developed water system. The specific research objectives are: (1) to develop a planning theory of water reuse, (2) to adapt the input-output model to water reuse planning, and (3) to demonstrate how the reuse theory and the input-output model are applied through case studies.

The theory includes the explanation of water reuse forms, basin water resource planning characteristics, and water reuse evaluation criteria. The input-output model development presents new approaches for using the model in water reuse planning. The demonstrations apply the theory and the input-output model to real world situations.

1.3 Research Procedure

The theory of water reuse is developed in Volume I by linking the historical evolution of water reuse forms and terminology with water laws and water quality regulations of today. The procedure is outlined below. It includes the following elements:

1. Water reuse terminology from the literature is used to establish a definitional base for the water reuse forms that are evolving in the western United States and the South Platte River Basin.
2. The water reuse "fits" are delineated between the variety of reuse "forms" for the context of a river basin. The contexts include physical, legal, organizational, economic, and water quality.
3. An economic methodology is set forth for comparing dual purpose water reuse alternatives with single purpose alternatives accomplishing the same purposes.

The input-output water balance model theory is developed in Volume II by adapting the basic input-output principles to the context of reuse in a water resources system. The procedure used has the following elements:

1. Review of input-output principles that have been applied to model water transfers in various river basins.

2. Develop a methodology for applying the water transfer principles to a water reuse exchange input-output model.

In Volume I the demonstration of the theory is accomplished on two levels. First, the water reuse potential of the entire South Platte River Basin (SPRB) is quantified using the water reuse methodology theory developed in the first part of the research. The reuse potential of each of the water resources of the basin is determined by categorization under legal and water quality constraints. The gross reuse potential is then matched with the projected water demands for the basin. The first level of reuse potential evaluation does not include specific reuse alternatives. The reuse potential is an evaluation of what is possible in terms of ultimate reuse development.

The second level is the demonstration of water reuse theory for the Cache la Poudre River Basin (CLPRB), a sub-basin of the South Platte River. The ultimate reuse potential of the CLPRB is determined at a much higher level of resolution than for the SPRB. A detailed analysis is made of native and foreign water supplies, water storage and distribution, water ownership, water quality, and the legal reuse status of each water resource. Specific water reuse alternatives are developed for both Fort Collins and Greeley. The water resources of the cities and the neighboring agricultural water users are examined with an eye towards the development of mutually beneficial symbiotic reuse alternatives.

In Volume II, the input-output water balance model is demonstrated for the Cache la Poudre River drainage in Northern Colorado. Two models are constructed: one for the year 1979 for documentary purposes and the other for the year 2020 under assumed drought conditions to document the planning potential of the input-output model.

1.4 Scope

The research takes a rapidly expanding area of water resources, i.e., water reuse, and provides a planning methodology for developing and evaluating water reuse alternatives. The research clarifies the concepts and applications of reuse by placing them into a comprehensive unified format. The end product is an engineering planning tool that can be readily applied to evaluate water reuse as a water supply alternative.

The concepts of water reuse are universal in nature but the water reuse forms that evolve are shaped by the context of the region. This research places special emphasis on water reuse in the western United States with specific case studies from the South Platte River Basin in Colorado.

CHAPTER 2

FORMS OF WATER REUSE

Water reuse may well be the next phase of water resource development in the United States. As such, interest in water reuse has expanded rapidly during the last ten years as evidenced by the profusion of reuse articles, conferences, research, and scattered reuse projects. Water reuse is similar to other rapidly developing areas in that there is no uniformity or consensus on the exact meaning of frequently used terminology. Each article or report defines reuse terminology within the contextual framework of the reuse program being discussed. No commonly accepted definitions that are precise in meaning yet universal in their coverage exist for the water reuse field.

The first part of this chapter is an attempt to fill the terminology void in the water reuse area. First, the term "water reuse" is defined based on current definitions of reuse. Then, specific reuse terms and their definitions are taken from the literature and critically evaluated for their precision and universality. A set of water reuse terms is then selected and redefined in accordance with the meanings established in the literature. The terms are modified as necessary to make the definitions fit a broader range of applications. The water reuse terms are then categorized using branch and set theory systems to show their areas of application.

The last half of the chapter discusses the development of water reuse forms in the western United States. Water reuse forms evolving on the West Coast are compared with the water reuse forms evolving in the South Platte River Basin of Colorado. An exchange system is developing in the South Platte River Basin that is based on using water for the highest quality uses first and lower quality uses next. These sequential reuse exchange forms are separated into three distinct forms and described. The final section provides a summary of the chapter.

2.1 Defining Water Reuse

What are the limiting factors associated with a definition of water reuse? Looked at from the global perspective, the hydrologic cycle itself is the ultimate recycling mechanism. In order to be useful, however, reuse must be precisely defined in narrower terms. At the same time, the reuse definition must be broad enough to encompass all subcategories of reuse.

In order to accomplish this resolution, the various physical states of water in the hydrologic cycle can be examined. Water is commonly found in all three physical states, i.e., liquid, solid, and gaseous. Water is considered to be "consumptively" used when water in its liquid form is transformed into its gaseous state. Water as an unconfined gas is extremely difficult to control in that water lost to the atmosphere is out of man's control. No property or usufructuary rights exist for water vapor although cloud seeding may be an intrusion into this previously untouched area. As an example, the portion of water that is lost through evapotranspiration when used for crop irrigation is considered a consumptive use loss. The transformation of water from the liquid to the gaseous state can then be considered the first limiting factor of reuse.

Water can be considered reusable only as long as it remains in either the liquid or solid phases between uses.

Water in either the liquid or solid state can serve functions in nature without being used by man. Snowfall high in the mountains may first be used as an insulating ground cover during the winter to protect plants from wind and low temperature damages. In the spring, the snow will melt and be partially consumed by the same terrestrial plants as a water source. Subsequently, the snowmelt runoff will flow into a channel carrying erosional materials and dissolved minerals. Water while in the stream is used as a life support medium for aquatic flora and fauna. The erosional materials carried by the water are eventually deposited at some downstream location. All of these "natural" functions of water can occur without man having used the water. In order for reuse to occur, a first use and then a subsequent use by man must take place. Natural functions of water that occur without man's intervention are not included as part of the water reuse definition developed herein.

Uses by man can be divided into consumptive and nonconsumptive categories. In the literature, consumptive uses generally connote a loss of water to the vapor state. The meaning of consumptive use can also include significant changes in water quality that limit the usefulness of the water for beneficial purposes. Therefore, consumptive uses in this paper include all uses that significantly alter either the quantity or quality of the water. Before water can be reused, it must be first consumptively used by man.

Up to this point, the term water reuse has been narrowed considerably from the natural form of water reuse: the hydrologic cycle. Several constraints have been imposed on the definition of water reuse. Water reuse has been limited to mean a series of two or more consumptive uses by man in which the water does not pass through an unconfined gaseous state.

Several definitions of water reuse are contained in the water resources literature. Four of them are given in Table 2-1 and then depicted in Figure 2-1. The following subsections review these reuse definitions.

2.1.1 Culp, Wesner, and Culp Reuse Definition

Reuse is defined by Culp, Wesner and Culp (1979) as being applied to "wastewaters that are discharged and then withdrawn by a user other than the discharger." Severe limits are placed on the term reuse by the fact that the wastewater must be discharged first from the system and then withdrawn by another user as shown in (2) of Figure 2-1(a). The first user cannot "reuse" the wastewater via loops (1) or (3). This defnition of reuse seems very restrictive until viewed in combination with OWRT's definition of "recycling". Recycling is defined as "the internal use of water by the original user prior to discharge to a treatment system or other point of disposal." This definition of recycle partially fills the gap left by the definition of reuse as shown in loop (1). Wastewater that is discharged to a treatment system and then put to use once more by the original discharger is not defined and is shown in loop (3) of Figure 2-1(a).

Table 2-1. Definitions of Water Reuse from the Literature

	Water Reuse Definitions
A	The term reuse is applied to wastewaters that are discharged and then withdrawn by a user other than the discharger (Culp, Wesner, Culp and Hughes, 1979).
B	Reuse is the subsequent use of imported water for the same purpose as the original use (Colorado Supreme Court, 1973).
C	The recycling of a substantial portion of the effluent stream through the production of agricultural, silvicultural, or aquacultural products, through irrigation or public areas such as open space or recreation sites or through industrial or domestic reuse, which results in substantial and effective upgrading of the effluent prior to discharge into a natural watercourse. Reuse can include discharge to an irrigation reservoir (Colorado Department of Health, 1979).
D	Reuse is the subsequent use of water for the same purposes as the original use (Denver Regional Council of Governments, 1977).

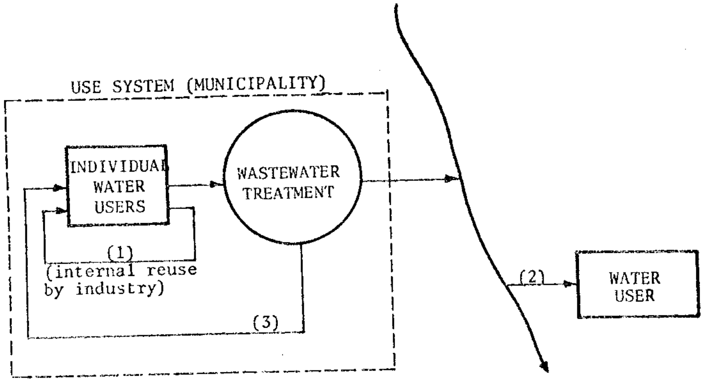


Figure 2-1(a). Reuse terminology as defined by Culp, Wesner, Culp for OWRT.

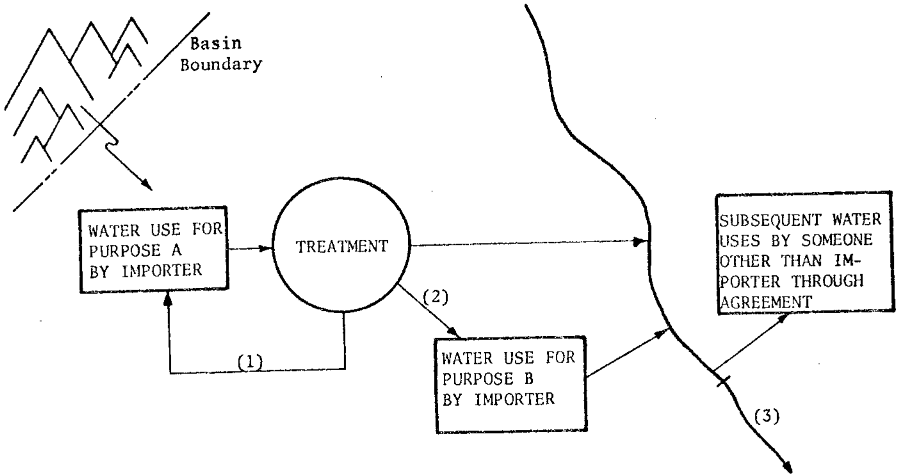


Figure 2-1(b). Colorado Supreme Court.

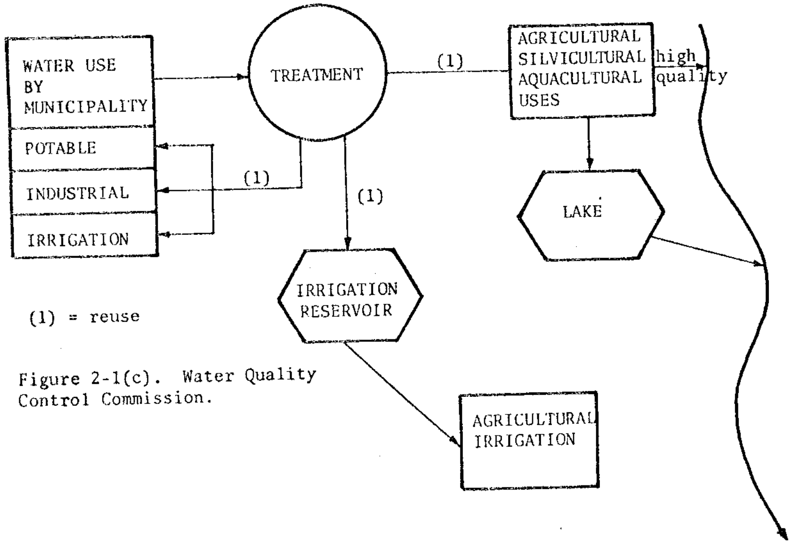


Figure 2-1(c). Water Quality Control Commission.

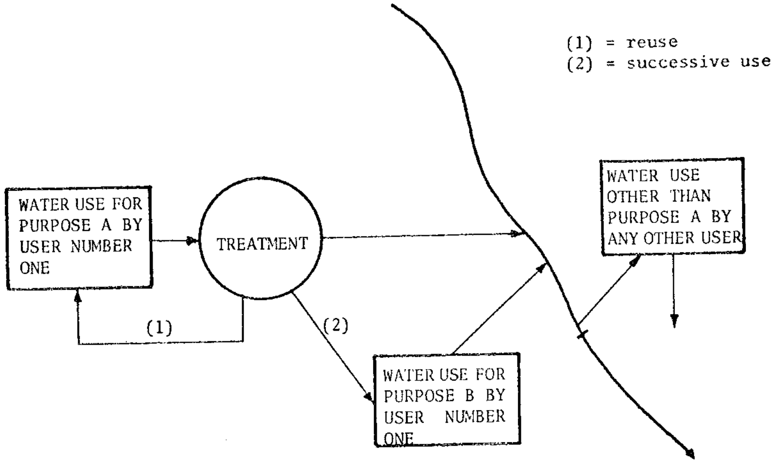


Figure 2-1(d). Denver Regional Council of Governments.

2.1.2 Colorado Supreme Court Reuse Definition

The Colorado Supreme Court has handed down a definition of reuse specific to the case of Denver vs Fulton. Water reuse is defined as the "subsequent use of imported water for the same purpose as the original use." This definition is rather narrow because of its legal context. Constraints imposed by the words "imported" and "same purposes as the original use" severely limit the meaning of reuse. Loop (1) of Figure 2-1(b) depicts the Court's definition of reuse. The Court's definition of successive reuse as "a subsequent use by the water importer for a different purpose" is braoder but still defines reuse only in terms of foreign water and the original user. Cycle (2) of Figure 2-1(b) depicts successive reuse. The Court's definitions of reuse and successive use do not include second or subsequent uses by someone other than the importer. Uses that involve agreements between the importer and another party have been defined as "rights of disposition" and are shown in cycle (3) of Figure 2-1(b). The importer has the right to "sell, lease, exchange, or otherwise dispose of effluent containing foreign water." Subsequent use of imported water that does not occur fortuitously and is not covered by an agreement between the importer and the subsequent user is not defined by the Court.

2.1.3 DRCOG Reuse Definition

The definitions used by the Denver Regional Council of Governments (DRCOG) are derived from the Colorado Supreme Court's definitions. DRCOG's definitions of reuse and successive use delete the word "imported" and "by the importer" in order to give broader applicability. Reuse is defined as the "subsequent use of water for the same purpose as the original use." Loop (1) of Figure 2-1(d) depicts this cycle. Successive use is defined as "the subsequent use of water for different purposes than the original use" and is shown for two cases as cycle (2) in Figure 2-1(d). The definition used by DRCOG for successive use is much broader than that of the Colorado Supreme Court and includes the right of disposition plus other unplanned fortuitous uses.

2.1.4 Colorado Water Quality Control Commission Reuse Definitions

Definition C of water reuse in Table 2-1 is taken from the Water Quality Control Commission of Colorado. This definition is used in the Federal Construction Grant Priority System for awarding grants to municipalities for the construction of wastewater treatment facilities. Although the definition is relatively broad, it is limited by the qualification that the reuse must be for a "substantial portion of the effluent stream" and must result in "substantial and effective upgrading of the effluent prior to discharge." Figure 2-1(c) graphically depicts the Commission's reuse definition. The Commission has not subdivided its broad classification of reuse into subcategories.

2.1.5 Water Reuse Defined

The definitions of reuse examined in the previous sections serve as guides to current thinking in the concepts of water reuse. All four reuse definitions were developed for specific purposes that necessarily limited the breadth of their meaning. The ideas contained in these definitions can be combined with the constraints imposed earlier on a reuse definition. Three basic constraints must be met:

1. The water that is to be reused must not pass through an unconfined gaseous state between uses.
2. The water reuse must be the result of an act of man.
3. The water uses must be a series of two or more consumptive uses in which the water incurs a significant change in either quantity or quality.

Based on these constraints, water reuse can be broadly defined as: *A series of two or more consumptive uses that occur due to the acts of man in which a portion or all of the water originating from the first use and then used a second time has not passed through an unconfined gaseous state between uses.*

When this reuse definition is compared with those in Table 2-1, all four of those definitions can be included within the definition set forth above.

2.2 Development of a Reuse Vocabulary

A large number of reuse terms that are subcategories of water reuse can be found in the literature. Thirteen of these terms, with their definitions, are given in Table 2-2. These reuse terms constitute a reuse vocabulary that has come about without any organizational framework. Each term was defined to meet the needs of the author. In this section, the concepts common to all of the water reuse terms are identified and then used to define a reuse vocabulary devised to systematically include all water reuse concepts.

In Table 2-2 the terms direct reuse, successive reuse, and indirect reuse each have two definitions. The two definitions for indirect use have similar meanings, but slight differences dependent on the author's

Table 2-2. Water Reuse Terms Defined in the Literature

Term	Definition
Agricultural Reuse	The reuse of effluent for agricultural purposes after a certain degree of wastewater treatment (DRCOG, 1977).
Agricultural Reuse System	Occurs when an agency discharges a unit volume of effluent directly into an irrigation ditch, and in return, the irrigator allows a unit of raw water in the stream to bypass the irrigation ditch headgates and continue in the stream. An exchange of water is involved, but the agency does not remove the water from the stream (DRCOG, 1977).
Direct Potable Reuse	The planned addition of treated wastewater to the headworks of a potable water treatment plant or directly into a potable water distribution system (Middleton, 1975).
Direct Reuse	1. Direct reuse is made by the first user, who recycles the water through the same system after suitable treatment (National Water Commission, 1973). 2. The planned and deliberate use of treated wastewater for some beneficial purpose such as irrigation, recreation, industry, prevention of salt water intrusion of recharging of underground aquifers, and potable reuse (Middleton, 1975).
Exchange System	An exchange system is the exchange of a unit volume of wastewater effluent discharged into an irrigation ditch for a unit volume of the irrigator's stream water diverted into the headgate of a domestic water supply at an upstream point. In some cases the system can involve unequal volumes of water being exchanged (DRCOG, 1977).
Indirect Potable Reuse	The planned addition of treated wastewater to a drinking water reservoir, underground aquifer, or other body of water designed for potable use that provides a significant dilution factor (Middleton, 1975).
Indirect Reuse	1. Indirect reuse occurs when effluent is discharged into a body of water by the first user, diluted by natural forces, and then withdrawn, treated (if necessary), and used by others (National Water Commission, 1973).

Table 2-2. Continued.

Term	Definition
Indirect Reuse (cont.)	2. Indirect reuse of wastewater occurs when water already used one or more times for domestic or industrial purposes is discharged into fresh surface or underground waters and is used again in its diluted form (Middleton, 1975).
Planned Reuse	A deliberate second or repetitive use of water by the same or another user with or without treatment, after either: (1) direct transfer of the used water from one use (or user) to the next, so that the water is not returned to the stream system for another allocation according to the existing water rights doctrine; or (2) groundwater recharge of used water (i.e. treated wastewater) under controlled conditions for delivery by the aquifer to groundwater users in a specific region (Milliken, 1979).
Potable Reuse	The direct reuse of wastewater effluent after special treatment for domestic purposes, including human consumption (DRCOG, 1977).
Recycle Reuse	Recycle reuse is a recirculation of water through a given use entity (Hendricks and Bagley, 1969).
Recycling	Recycling is defined in this report as the internal use of water by the original user prior to discharge to a treatment system or other point of disposal (Culp et al., 1979).
Right of Disposition	Right to sell, lease, exchange or otherwise dispose of effluent containing foreign water (Colorado Supreme Court, 1973).
Sequential Reuse	Sequential reuse is use of effluent from one use entity by another use entity. The use may be on any scale desired--a river basin, a municipality, or a process (Hendricks and Bagley, 1969).
Successive Reuse	1. Repetitive use of water by a succession of water users, with the water used and returned to the stream system for allocation to the next user according to the existing water rights doctrine (Milliken, 1979). 2. The subsequent use of water for a different purpose than the original use (DRCOG, 1977).

use of the term. The National Water Commission's definition of indirect use requires discharge by a first user into a water body and use again by a second user after withdrawal. Middletown's (1975) definition of indirect use makes no distinction concerning use but does require once used water to be discharged into a body of water prior to its second use. The second use, unlike the National Water Commission's definition, could be made by the first user or a second user. The difference between the two terms is due to distinction between uses and users.

The same type of distinctions can be made for the term direct reuse. the National Water Commission's (NWC) definition of direct use states that "reuse is made by the first user who recycles the water through the same system after suitable treatment." The NWC has limited direct reuse to same use and user. Middletown, on the other hand, makes no distinction concerning either use or users. The water may be reused "for some beneficial purpose" as long as the use is "planned and deliberate". The NWC implied that the reuse must be planned but made the distinction that the second use must be in the same use system as the first.

The two definitions for the term successive use reveal a similar categorization by use and user. Milliken (1979) defines successive use as "repetitive use of water by a succession of water users." The Denver Regional Council of Governments (1977) has defined successive use as "the subsequent use of water for a different purpose than the original use."

Definitions of reuse subcategories are based on differences between uses, users and intent. The water can be used for the same purpose or different purposes. The use refers to the different purposes for which the water can be used. Distinctions about who is using the water are made between the first water use and the second water use. Different users can put the same water to the same use in different use systems. Intent distinguishes between planned reuse and unplanned reuse that occurs fortuitously. Planned reuse is implied in many of the definitions and specifically mentioned in four of them. Table 2-3 classifies the reuse terms from Table 2-2 by divisions made according to use, user, and intent.

The foundation is now in place to select a limited number of water reuse terms that encompass the water reuse field and define them. The definitions are derivative of the definitions in Table 2-2 and are based on the use-user-intent breakdown in Table 2-3. The terms selected for definition are: (1) unplanned reuse, (2) planned reuse, (3) sequential reuse, (4) successive reuse, (5) recycle reuse, and (6) potable reuse. The definitions are explained using the South Platte River Basin but the resulting definitions are applicable throughout the West.

2.2.1 Unplanned Reuse

In the South Platte River Basin, unplanned reuse has existed since the 1860's. Agricultural development in the basin is limited by water supply rather than by irrigable land. Most crops must be irrigated to be profitable. Return flows to streams from irrigation and municipal discharges can be diverted and reused by downstream appropriators. The appropriative water law doctrine recognizes this by allowing downstream water users to establish water rights on return flows from upstream users. Active coordination typically does not take place between the first water user and the second. Yet, reuse occurs because of the nature of the

Table 2-3. Division of Water Reuse Terminology by Use, User and Intent

Use:	Reuse for same purpose or different purposes
	Direct Reuse (EPA)
	Direct Reuse (NWC)*
	Indirect Reuse (EPA)
	Successive Reuse (Colorado Supreme Court)*
	Successive Reuse (DRCOG)
	Agricultural Reuse
	Agricultural Reuse System
	Potable Reuse
	Direct Potable Reuse
	Indirect Potable Reuse
	Planned Reuse*
User:	Reuse by same user or a second user
	Direct Reuse (NWC)*
	Indirect Reuse (NWC)
	Successive Reuse (Colorado Supreme Court)*
	Successive Reuse (Milliken)
	Sequential Reuse
	Recycling
	Recycle Reuse
	Right of Disposition
	Exchange System*
	Planned Reuse*
Intent:	Definition specifically mentions words "planned" or "deliberate"
	Planned Reuse
	Direct Reuse (EPA)
	Indirect Potable Reuse
	Direct Potable Reuse

*Definitions of these terms specifically mention both use and users.

physical system. The law, in recognizing the existence of unplanned reuse, has been designed to protect the investments of junior appropriators dependent on return flows from senior appropriators. Any purchase or movement of the point of diversion of the senior water right must allow for the continuance of flows equal to the historical return flows. This provision protects unplanned reuse.

The unplanned reuse definition used in this paper is given below: *Unplanned reuse occurs when water after a first use is discharged to either a surface or groundwater body and the water is subsequently captured and put to use by a second or subsequent user without coordination or planning between the first and second or subsequent users.*

2.2.2 Planned Reuse

Planned reuse has become important to South Platte River Basin water users in recent years. The first major reuse incentive came from the Blue River Decree in 1955 in which the United States District Court of Colorado required Denver and Colorado Springs to minimize foreign water imports from the Blue River through reuse of their foreign waters (U.S. District Court, 1955). Reuse incentives are now a part of both federal and state water quality laws. In addition, reuse of foreign water is specifically encouraged in Colorado water law. Planned reuse is the main form of reuse addressed in this report. Because existing water supplies are fully utilized, reuse is being viewed as an alternative for supplementing water supplies.

Reuse proposals involve active planning by those intending to reuse the water. Milliken's definition of planned reuse given in Table 2-2 is very specific. Direct transfer and storage in the groundwater aquifer between uses are the only two mechanisms allowed for planned reuse. The definition used in this research must include all forms of planned reuse. Many tranfers between the first and second use can involve transport of used water through irrigation canals, reservoirs, or natural streams. Milliken's definition excludes these transfer mechanisms between uses.

The definition set forth below deletes Milliken's two conditional statements in order to broaden its applicability: *Planned reuse is a deliberate second or repetitive use of water by the same or another user that involves planning to coordinage the transfer of water between the first and second or subsequent users.*

2.2.3 Sequential Reuse

Hendricks and Bagley (1969) define sequential reuse as the "use of effluent from one use entity by another use entity." The key is the distinction between users and not uses. A similar distinction between users is contained in the NWC's indirect reuse definition: "effluent is discharged into a body of water by the first user, diluted by natural forces, and then withdrawn, treated, and used by others." Middleton's definition of indirect reuse limits the first use to domestic and industrial purposes.

Sequential reuse must include: (1) a series of uses by different users, and (2) use by the same user for a different purpose. If sequential reuse is not defined in this manner a gap in the reuse terminology will exist for situations where the first user, such as a city, uses water for a different purpose.

Sequential reuse occurs when water is put to a second or subsequent use by another user or a different use by the first user.

2.2.4 Successive Reuse

The term successive reuse is widely used within the State of Colorado and particularly in the South Platte River Basin. The Colorado Supreme Court defined the term in Denver vs Fulton in 1973. Since that time, the term successive reuse has become popular due in large part to continued use of the phrase by water agencies and attorneys in the area. Because extensive use of the phrase and its basis in law, the Court's definition is used verbatim in this study.

Successive use is a subsequent use (of foreign water) by the water importer for a different purpose.

2.2.5 Recycle Reuse

Recycle reuse is defined by Hendricks and Bagley (1969) in Table 2-2 as the "recirculation of water through a given use entity." The definitions of two other terms in Table 2-2 are closely parallel to the recycle reuse definition. These terms are direct reuse and recycling.

Direct reuse is defined by both the NWC and Middleton. NWC's definition is more specific in its applicability. NWC defined direct reuse as reuse of the wastewater by the same user. The words "same system" imply that the second use is the same as the first use. Middleton chose to define direct reuse as a "planned and deliberate use of treated wastewater for some beneficial purpose." This definition is broad and parallels the definition of planned reuse given earlier. NWC's definition of direct reuse is much closer to the definition of recycling and recycle reuse given in Table 2-2.

Recycling was defined by Culp et al. for OWRT as the "internal use of water by the original user prior to discharge to a treatment system."

This definition is oriented towards internal industrial reuse because of the words "prior to discharge to a treatment system." In this paper, the term will be defined broadly enough to include reuse within a municipal or agricultural system. Either the NWC definition of direct use or Hendricks' definition of recycle reuse could be used in this paper. The term recycle reuse is more descriptive than the term direct reuse, therefore, a slightly modified version of Hendricks' definition is used: *Recycle reuse is the recirculation of water through a given use entity for the same purpose.*

2.2.6 Potable Reuse

Potable reuse is actually a special case of direct reuse. Although potable reuse is the least used reuse form, it is the most commonly discussed form. The DRCOG definition of potable reuse limits the second or subsequent uses of the wastewater effluent to use in a potable water supply. EPA's definitions of potable reuse separate direct and indirect reuse. Indirect potable reuse adds an intermediate step in the reuse chain by adding the wastewater to be reused to a reservoir or groundwater aquifer for dilution and subsequent use as a potable water source. DRCOG's definition of potable reuse is adequate for use after deletion of the word "direct". The resulting definition given below includes both the EPA and DRCOG versions: *Potable reuse is the reuse of wastewater effluent after special treatment for domestic purposes, including human consumption.*

2.3 Categorization of Reuse Terms

Water reuse and six subcategories of water reuse were defined in the preceeding two sections. The term water reuse was defined so that all six subcategories would be included within the water reuse definitions. Defining water reuse in this manner simplifies the discussion of water reuse and establishes water reuse as a comprehensive form.

Figure 2-2 displays the categorization of the reuse terms. The figure is a schematic of the subcategories and illustrates how the various reuse definitions are subparts of the larger water reuse definition. Since planned reuse is a rapidly evolving form of water reuse, a greater resolution of the reuse forms under planned reuse is necessary. Sequential reuse can be either planned or unplanned and is included under both categories.

Figure 2-3 uses set theory to show the nesting of the various subcategories of water reuse within the larger reuse definition. Planned reuse and unplanned reuse do not intersect but are both in union with the larger water reuse set. The union of sequential reuse includes both planned reuse and unplanned reuse. Since sequential reuse can be both planned and unplanned, the sequential reuse subset intersects both of these subsets. Successive reuse is a subset of sequential reuse and planned reuse. The intersection of the sequential reuse and the planned reuse subsets is shown by the single crosshatched area. The successive reuse subset is double crosshatched to show its intersection with sequential reuse and planned reuse.

The use of sets illustrates the inclusion of sequential reuse in both the planned and unplanned categories better than the chart in Figure 2-2. Both potable reuse and recycle reuse are subsets of planned

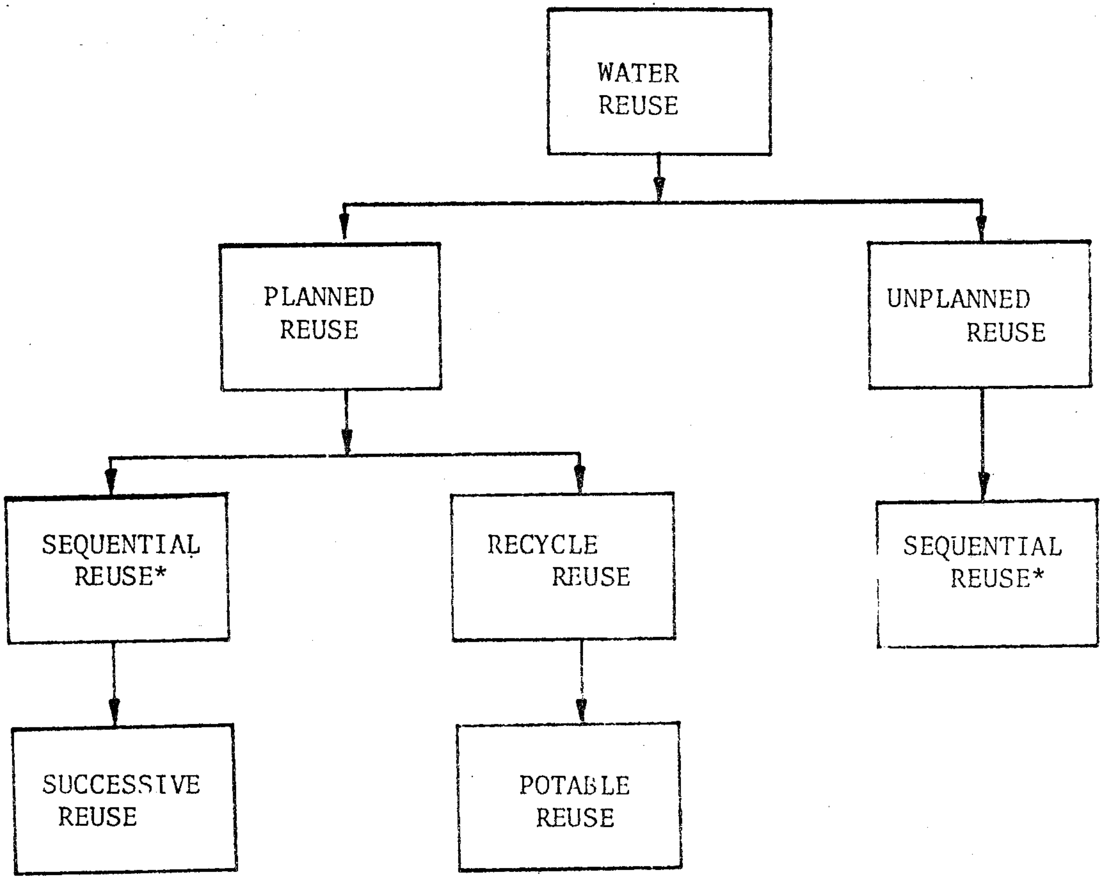


Figure 2-2. Reuse terminology tree.

---

*Sequential reuse can be either planned or unplanned.

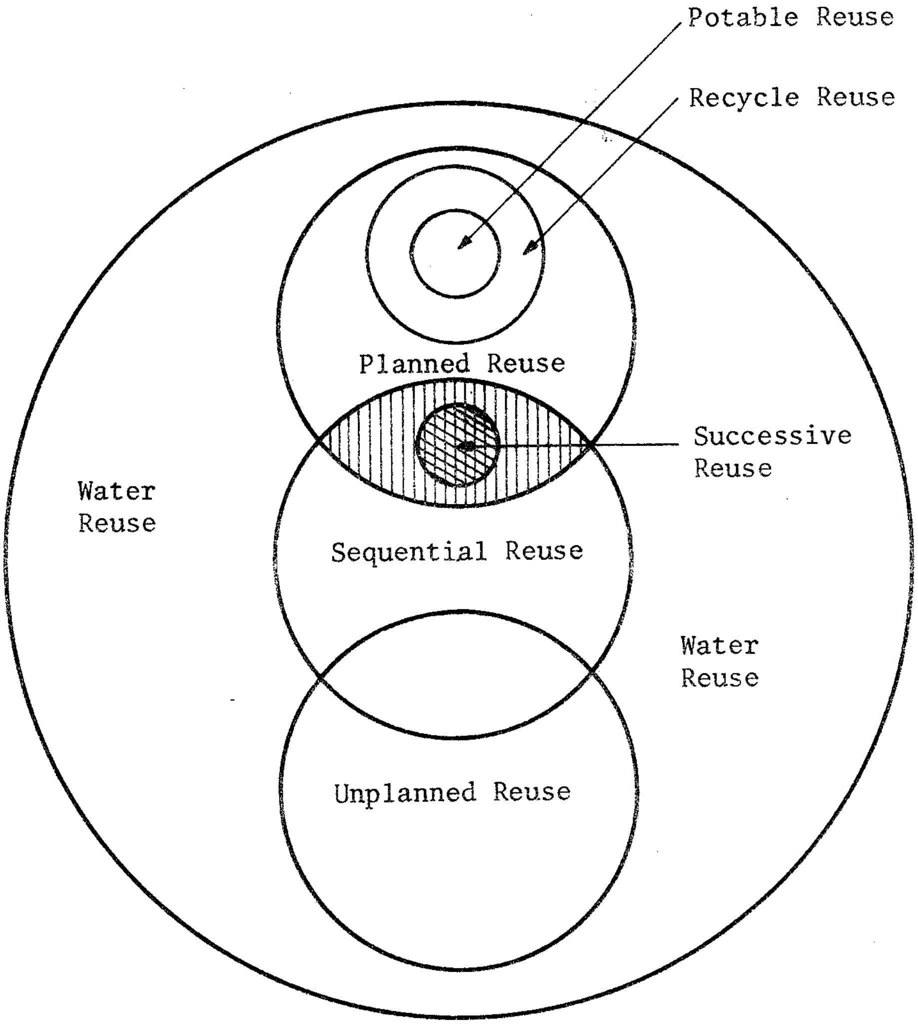


Figure 2-3. Water reuse definitional sets and subsets.

reuse. Potable reuse is also a subset of recycle reuse. The definition specifies domestic use. Therefore, recycle reuse is more inclusive than potable reuse. One possible exception would be if wastewater from one system was treated and reused for domestic consumption in another system. The potable reuse subset would extend outside the recycle reuse subset. Potable reuse would no longer be a subset of recycle reuse. This situation is not likely to occur because potable reuse projects involve close physical proximity between first and second users. Even if two separate political systems were involved in a potable reuse project, the high level of management needed for proper operation would serve to integrate the two politically separate systems into one for practical purposes.

2.4 Evolution of Water Reuse Forms

Several definitions of reuse, direct reuse, indirect reuse, recycling and other reuse terms were reviewed in Sections 2.1 and 2.2. Many of these definitions had different and/or overlapping meanings. The differences are in part due to dissimilar water reuse forms that develop in diverse geographic areas. Reuse forms evolve within the physical, legal, and organizational contexts of the area in which they are applied. Water reuse on the California coast takes on distinctly different forms than water reuse in the South Platte River Basin of Colorado. Within each geographic region, water reuse forms emerge that are unique to the needs and uses found within the regions. As water reuse forms continue to evolve within geographic regions, the water supply system is reshaped for that region. Management of a water supply system using reuse implies understanding, planning and applying water reuse forms within the context of the region. The potential for reuse in terms of the quantities of water made available and changes in current use patterns must be known if the water resources of a given region are to be well-managed.

2.4.1 Growth and Reuse

As the population of the United States has grown and as its municipalities have expanded, the highest quality, least cost raw water supply sources have been developed first. Each additional increment of water resource development has, in general, utilized more remote or lower quality sources of supply that require sophisticated and technologically advanced treatment and distribution systems. Each additional water supply increment is more expensive than the last. In some areas, new sources of raw water are not readily available, and transfers of previously developed water are occurring from lower to higher valued uses. An example of this type of transfer is the purchase of agricultural water by municipalities for domestic and industrial uses. The acquisition of agricultural water is often less expensive than developing remote or low quality water sources. This type of situation can be ideal for the development of reuse exchange schemes.

2.4.2 Effect of Stringent Wastewater Effluent Criteria on Water Reuse

Since the passage of the Water Pollution Control Act Amendments of 1972 (PL92-500), effluent quality criteria have been adopted for point source discharges of wastewater. Initially, these criteria made it necessary for municipalities to use secondary wastewater treatment methods. As the goal of attaining fishable and swimmable waters by 1983 is pursued, many wastewater dischargers are faced with more stringent discharge criteria. These criteria often times require the use of tertiary treatment. In many cases the quality of the wastewater discharge is very close to the quality of water needed as a water supply source for many uses. As the quality of treated wastewater approaches that of local raw water sources, the treated wastewater itself becomes a water supply resource. Municipalities have already reused treated wastewater as a supply source for industry, lawn watering, recreational lakes, groundwater recharge, and salt water intrusion barriers to protect freshwater aquifers in coastal areas. Potable reuse of treated wastewater is currently prohibited by the EPA. The effect of water quality laws on water reuse is discussed in Chapter 3.

2.4.3 Shaping of Reuse Forms by Water Law

Sequential reuse in the western United States is strengthened in an ad hoc fashion by the appropriative system of water law. Return flows from senior appropriators can be diverted by junior appropriators downstream. In this manner, a legal (adjudicated) water right can be established on upstream return flows for water that originates wtihin the basin. The rights of the junior appropriator to the return flow must be considered if upstream water rights are transferred.

In Colorado, foreign waters diverted into the South Platte River Basin from another basin are not subject to the same water rights on the return flows as native water. Return flows from foreign water can be reused by the foreign water importer. Downstream appropriators who have used the return flows in the past have no legal rights to the continuance of return flows from foreign waters.

2.4.4 Apex Water Resource Development and Evolving Water Reuse Forms

Water resources development in the West has proceeded to a very high level of complexity in many regions. Direct stream diversions, groundwater pumping, on-stream and off-stream reservoir storage, high mountain storage, transbasin diversion, foreign basin water storage, and weather modificiation have all been utilized in developing and supplementing the basin water resources. Continued demand for water must be met in one of six ways:

1. conservation through water primacy and more efficient use of existing water supplies;
2. transfer of water rights from lower to higher valued uses (agriculture to municipal and industrial uses);
3. importation of additional water from other river basins;
4. capture and use of any excess water flowing out of river basins;
5. intensive use of groundwater storage during dry years;
6. weather modification to increase snowpack.

Water reuse can play a part in each of the first five ways mentioned above for increasing water supply. Both sequential reuse and recycle reuse can take on different forms to fit the special needs of water-short areas.

2.5 Reuse Forms in the Los Angeles Area

The context for the evolution of reuse forms in coastal areas such as Los Angeles, California, and inland semi-arid regions such as the South Platte River Basin in Colorado are very different. Los Angeles is located on the Pacific Coast and area streams empty into the Pacific Ocean. The coastal area has become highly urbanized. Land and water formerly used for agriculture have been changed to urban uses. The agricultural land and water resources served as a reserve for urban needs. In this respect, the Los Angeles of 40 years ago resembles the Front Range of today.

Southern California's native water supply is less than 2% of the state's total. Because of this, foreign water is imported from the Owens River, the Colorado River, and the Feather River. The municipalities along the coast have historically been the last water users in the use chain. Water not consumptively used or reused by the coastal communities is discharged into the Pacific Ocean. The following quote the "Orange and Los Angeles Counties Water Reuse Study" (1978) summarizes the water situation.

> Each year the 8.5 million people and industry of metropolitan Orange and Los Angeles Counties use 1,950,000 acre-feet of water. Two-thirds of these water demands are met by imported waters delivered via three large aqueduct systems: the Los Angeles Aqueduct, owned and operated by the City of Los Angeles Department of Water and Power; the Colorado River Aqueduct, owned and operated by the Metropolitical Water District of Southern California; and the California Aqueduct, owned by the State of California and operated by the Department of Water Resources. Imported waters supply some 85% of the City of Los Angeles needs, 60% of Orange County's needs, and 50% of Los Angeles County's (exclusive of the City of LA) needs. The natural flows of the Los Angeles, San Gabriel, and Santa Ana Rivers supply about one-third of the total water usage, with planned water reuse accounting for about 3%.

A breakdown of water uses, as shown in Table 2-4, illustrates the predominantly urban uses of the water supply.

Of the 1.95 MAF used in the Los Angeles area, approximately 0.85 MAF is lost to evaporation, deep percolation, and runoff. Approximately 1.1 MAF enters the sanitary sewers. Of the 1.1 MAF, approximately 0.6

Table 2-4. Water Use in the Los Angeles Area

Use	Amount	%
Residential	900,000 AFY	46
Commercial/Industrial	580,000 AFY	30
Public	200,000 AFY	10
Agricultural	90,000 AFY	5
Other	180,000 AFY	9
TOTAL	1,950,000 AFY	100

MAF is lost to the ocean and not economically reclaimable. Another 0.50 MAF is available for reuse. Currently, 50,000 AF (0.05 MAF) is reused. This leaves 0.45 MAF potentially available for reuse (Metropolitan Water District of Southern California, 1978).

The schematic shown in Figure 2-4 depicts the Los Angeles reuse forms. The groundwater aquifer underlying the entire Los Angeles area is an essential component of the water reuse systems. The aquifer is used as a storage reservoir for water awaiting reuse. Groundwater recharge is currently accomplished using both injection wells and groundwater percolation basins.

The injection wells, located four miles inland, are used to pump water into the upper aquifers to prevent saline water from moving inland. Extractive wells are placed next to the sea to intercept salt water and return it to the sea. The system of injection and extraction wells acts as a hydraulic barrier to prevent saline water intrusion.

The groundwater recharge basins are located along the Santa Ana River. The basins are used to percolate water into the groundwater aquifer for subsequent municipal and industrial pumping and usage.

The Los Angeles reuse system is a combination of sequential reuse, recycle reuse, and potable reuse. Recycle reuse is the predominant type of reuse associated with groundwater recharge. The recycle reuse groundwater system incorporates a significant amount of potable reuse (70%) as the well water is treated and distributed through the municipal systems. Industrial cooling and process water will amount to 20% to 25%; landscape irrigation, 10%; agricultural irrigation, 3%; and other uses, 2% of the water reuse total. These reuses can be either sequential or

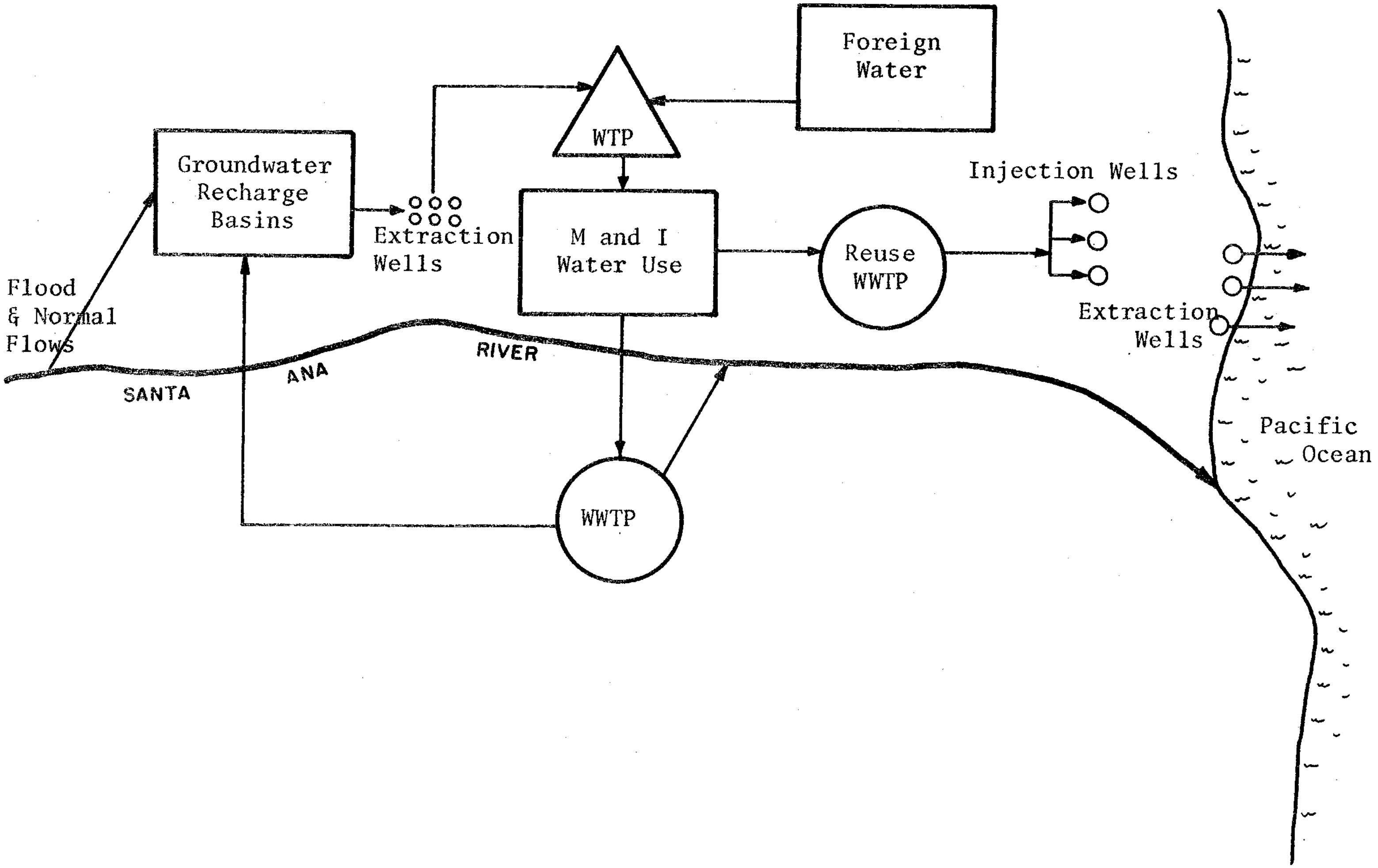


Figure 2-4⁄. Los Angeles water system schematic.

recycle reuse depending on whether the second user is the same as the first user.

The Los Angeles metropolitan area is developing a recycle reuse system that makes use of the groundwater aquifer for storage and filtering of treated wastewater prior to reuse. Direct potable reuse is not proposed as a method of reuse for the future. Use of the aquifer is a long-term integral part of the reuse systems. The type of reuse form evolving for Los Angeles might be termed recycle reuse via aquifer filtration.

2.6 Water Reuse Forms in the South Platte River Basin

The context of the SPRB is very different from that of the Los Angeles area. The urban areas are located at the foothills of the Rocky Mountains. Domestic and industrial water is returned to the streams for downstream agricultural uses. Agriculture is the main water user. Agricultural consumptive use amounts to 1.3 MAF or 87% of the total consumptive use, while urban consumptive use is 6.7% of the total. Of the 1.8 MAF of surface water available for use during an average year, only 17% or 0.3 MAF leaves the state. South Platte River runoff eventually empties into the Mississippi River and the Gulf of Mexico, thousands of miles downstream (U.S. Army Corps of Engineers, 1977).

In the South Platte River Basin, sequential reuse has been practiced in a defacto manner since the early years of irrigation development. A typical sequence is shown in Figure 2-5. Wastewater discharges from municipalities (return flows) are diverted downstream by irrigators who apply the water to their crops. Approximately 60% of the water diverted

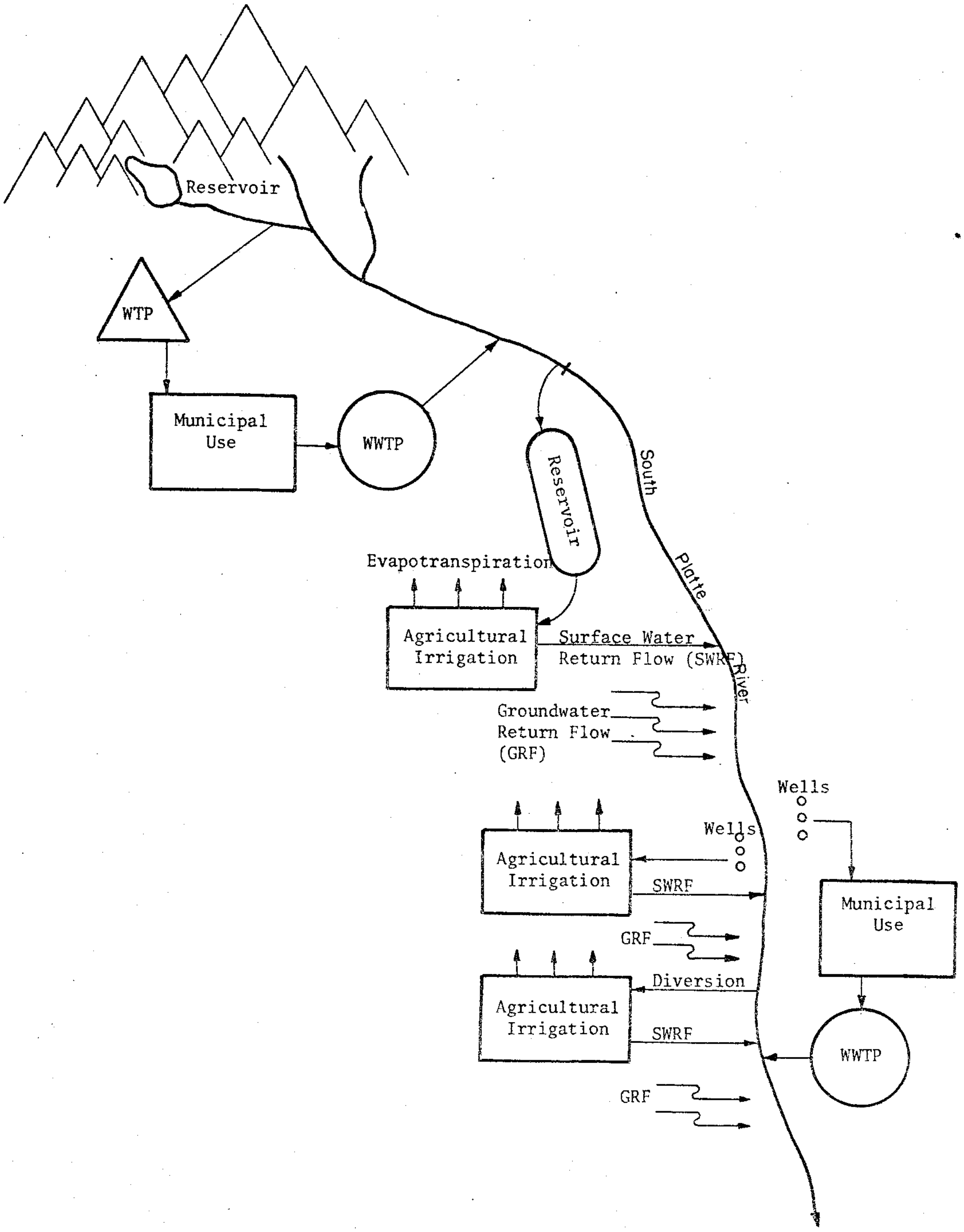


Figure 2-5. Sequential reuse in the South Platte River Basin.

for irrigation is returned to either the stream or the groundwater table. The return stream flows are diverted once again and the recharged groundwater aquifer is pumped for another sequential reuse cycle. In this manner, water is sequentially reused by stream and groundwater users in the conjunctive use system. In the South Platte River Basin, a volume of water 2.5 times the average annual available surface water supply of the basin is put to consumptive uses such as irrigation each year (U.S. Army Corps of Engineers, 1977).

Water reuse forms are evolving rapidly in the South Platte River Basin. Water law, water quality law, and the physical and hydrologic characteristics of the basin are shaping the reuse projects and proposals.

A summary of these reuse projects is presented in Table 2-5. Eighteen projects are listed. Of the eighteen, only six have actual reuse programs that are operational. Aurora and Fort Collins "current" reuse figures are based on estimates by those municipalities for reuse during 1980. Aurora has a 2.0 mgd Sand Creek wastewater treatment facility. The effluent from this WWTP is used for urban irrigation. Aurora's industrial usage figure of 5000 acre-feet/year is dependent on the lease of its MDSDD No. 1 Central Plant effluent to the Public Service Company of Colorado for the planned power plant at Brush. The 500 megawatt Brush power plant is scheduled for completion in December 1980.

The Fort Collins Water Reuse plan should be operational in 1981 upon completion of an eighteen-mile-long pipeline north to the Rawhide Power Plant site and a 16,000 acre-foot

Table 2-5. Water Reuse Projects in the South Platte River Basin

	Current Reuse (acre-feet/year)	Proposed Reuse (acre-feet/year)
Aurora	10,800 total 5,000 (industrial-successive) 300 (mun. irrig.-successive) 5,500 (ag. irrig.-sequential)	20,000 total 15,000 (industrial-successive) 1,000 (mun. irrig.-successive) 4,000 (potable)
Arvada	None	800 (park irrig.-successive)
Boulder	None	8,000 Windy Gap Water
Broomfield	None	Proposed but quantity of water unknown
Castle Rock Silver Heights Castle Pines	None	500 to 1,500 (mun. irrig.-successive)
Denver Water Department	12,000 (1977 ag. irrig. sequential)	1 MGD (1982 - potable) 100 MGD (2000 - potable) 15,000 to 40,000 (year 2000 - sequential) 132,000 (year 2000 - available for reuse)
Englewood	None	Denver Water Dept. retains rights to reuse foreign water exchanged with Englewood
Estes Park	None	276 for 150 day irrigation season (1980-2000 = mun. irrig.-sequential)
Fitzsimons Army Hospital	290 for 7 months (mun. irrig.-successive)	290 for 7 months (mun. irrig.-successive)

Table 2-5. Continued.

	Current Reuse (acre-feet/year)	Proposed Reuse (acre-feet/year)
Fort Collins - Rawhide	4,200 (ind.-sequential)	4,200 (ind.-sequential) Potential to go to 12,000 ac-ft/year by 2000
Golden	None	300 (plus?) (mun. irrig.-sequential)
Greeley	None	12,000 (ag.-sequential & successive)
Highland Ranch	None (development not yet built)	3,700 (ind. and mun. irrig.-successive) (5,000-7,000 year 2000)
MDSDD No. 1	7,200 (unplanned reuse to Burlington Ditch)	7,200 (limited by plans of municipalities to reuse foreign water)
Northglenn	None	5,000 to 6,000 (ag. irrig.-sequential with FRICO)
Sterling	None	1,000 (year 2000 - ag. irrig.-sequential)
Thornton	None	2,400 Northglenn's plan interferes (ag. irrig.-sequential)
Westminister	774 (2cfs for 200 days) (ag. irrig.-sequential)	2,980 (7.7 cfs for 200 days/year) (ag. irrig.-sequential)

reservoir at the site. Wastewater will be pumped from the Fort Collins wastewater treatment plant to the reservoir site.

Denver's annual exchange is dependent on flow in the South Platte River. The exchange is accomplished by diverting all water in excess of diversion and instream requirements between Kassler and MDSDD No. 1. The return flows from MDSDD No. 1 are used to meet water rights downstream of MDSDD No. 1.

The quantity of water proposed for future reuse schemes shown in Table 2-5 is in excess of 200,000 acre-feet/year. This figure assumes Denver reuses the 123,000 acre-feet/year available for reuse from municipal return flows of water that is foreign in origin. Denver's interpretation of the Blue River Decree may limit reuse to a quantity substantially lower than the 132,000 acre-feet/year figure. Denver has interpreted the Decree to mean that sequential reuse exchanges with agriculture that require written agreements are not permissible.

The following three subsections build on the proposed and existing water reuse schemes outlined in Table 2-5. Three reuse forms are identified that have evolved because of the context of the South Platte River Basin. While these forms may not be unique to this basin, the characteristics of the basin have and continue to shape them. All three forms are derivatives of sequential reuse.

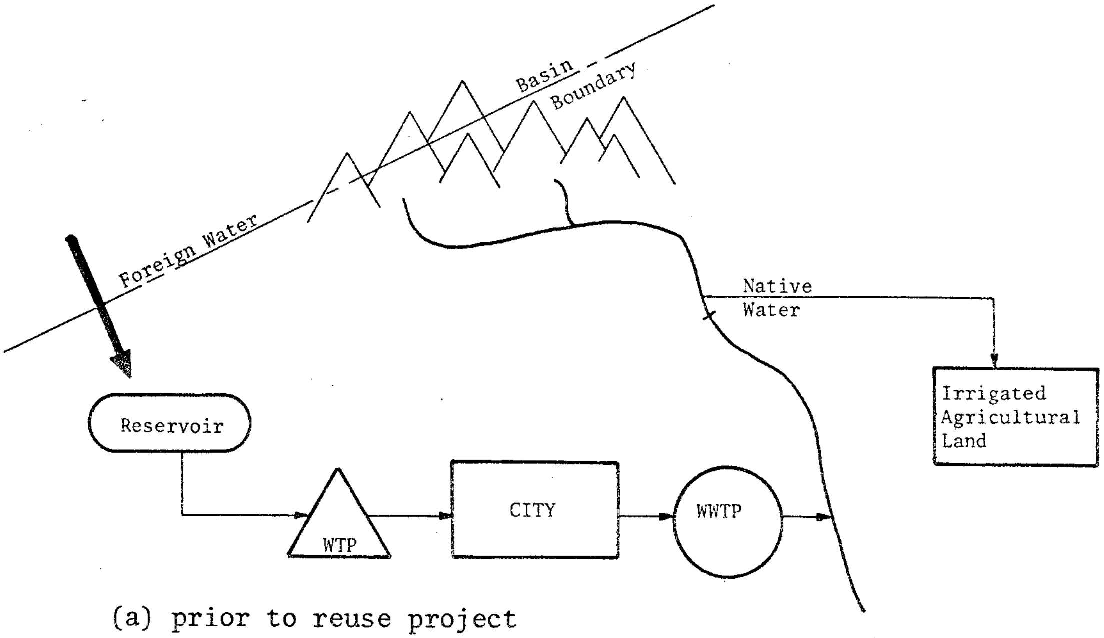
2.6.1 Sequential Reuse/Foreign Water Exchange

This reuse form involves the exchange of treated municipal wastewater effluent which was originally foreign in origin, for high quality primary water. High quality primary water is mountainous in origin, relatively clear with low total dissolved solids. The primary water used in the exchange is generally owned by agricultural or industrial interests. The exchange benefits the municipality because high cost alternatives involving the purchase of agricultural water rights or new imports are avoided. The primary water owners benefit because they receive an equal or larger quantity of treated wastewater in exchange for the primary water. Municipalities are not forced to purchase water rights from other users. Since return flows from foreign water can be reused, the municipality does not have to seek replacement water for consumptive losses within the system. Instead, the amount of water available for exchange from the municipality is equal to the total quantity of water imported minus the consumptive losses of foreign water within the system (lawn watering, human consumption, etc.). Figure 2-6 is a schematic of a sequential reuse/foreign water exchange system.

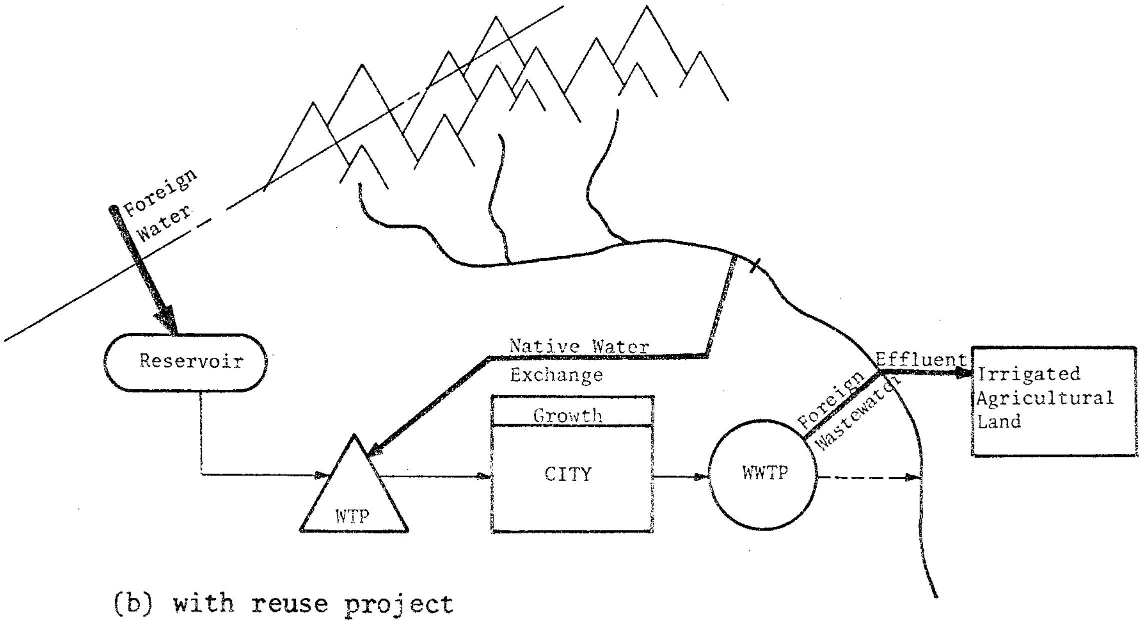
Aurora, Fort Collins, and Denver are all involved in proposals to reuse foreign water in this manner. Denver currently exchanges water with agricultural users. Aurora plans to exchange water with agricultural users in 1981, and Fort Collins with Platte River Power Authority for reuse at the proposed Rawhide Power Plant beginning in 1981.

2.6.2 Sequential Reuse/Native Water Exchange

Treated municipal effluent that is native in origin can be exchanged for high quality primary water from agricultural users or other users as long as downstream users of historically established return flows continue to receive those flows. The owner of the primary water used in the exchange receives a larger or equal quantity of treated municipal wastewater in exchange for a given quantity of primary water as shown



(a) prior to reuse project



(b) with reuse project

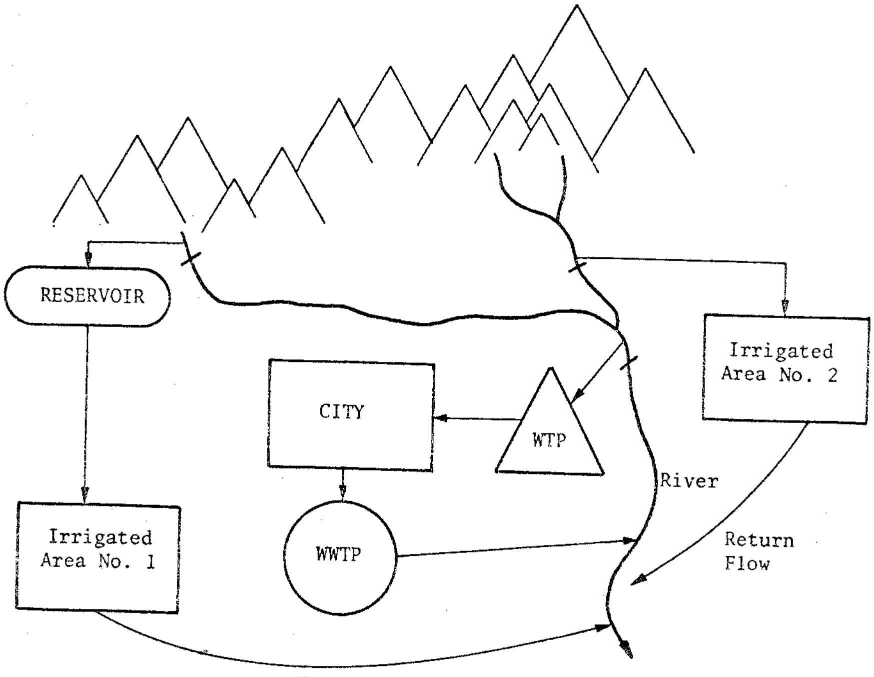
Figure 2-6. Schematic of sequential reuse/foreign water exchange.

in Figure 2-7. The municipality avoids the high cost of recycle reuse but must find replacement water for consumptive losses within the municipality. The consumptive losses cannot be made up at the expense of downstream users of return flows. In addition, bonus water must be found to entice agricultural water owners into the exchange. The additional water is generally obtained by purchasing agricultural water rights.

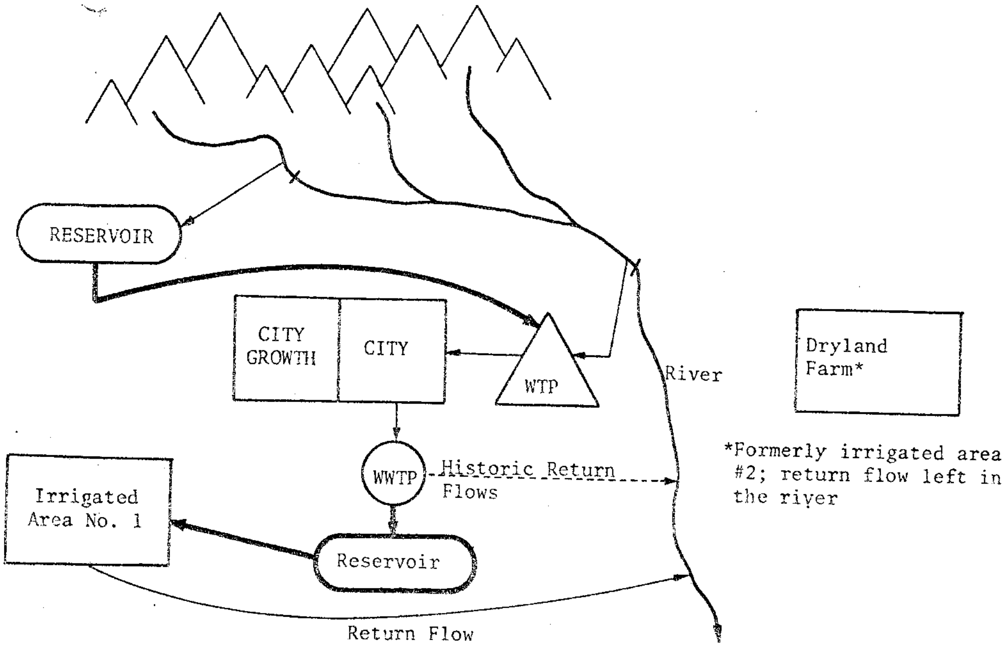
The communities of Northglenn and Westminster are involved in reuse projects that can best be described as sequential reuse/native water exchange. Westminster is actively engaged in an exchange program with Farmer's Reservoir and Irrigation Company at the present time. Greeley and Northglenn have both selected land treatment as the final stage of their wastewater treatment process.

2.6.3 Sequential Reuse/New Water

A use entity such as a municipality can utilize winter stream flows to create "new water" during the summer months as shown in the schematic in Figure 2-8. Treated municipal effluent can be stored during the winter in either the groundwater aquifer or in a surface storage reservoir. Currently, "excess" water flows out of Colorado into Nebraska. Flows in the lower portion of the South Platte River are in excess of compact requirements during the winter months thereby enabling a use entity to store the treated wastewater rather than return it to the stream. The stored water is later returned to the stream during the summer months for reuse. The hydrograph of the stream, shown in Figure 2-9, is changed by reducing unutilized winter flows and

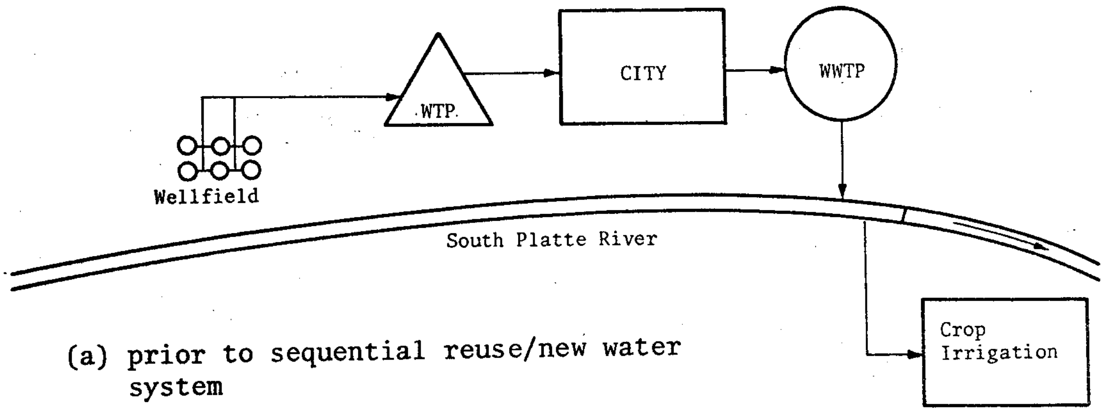


(a) prior to project

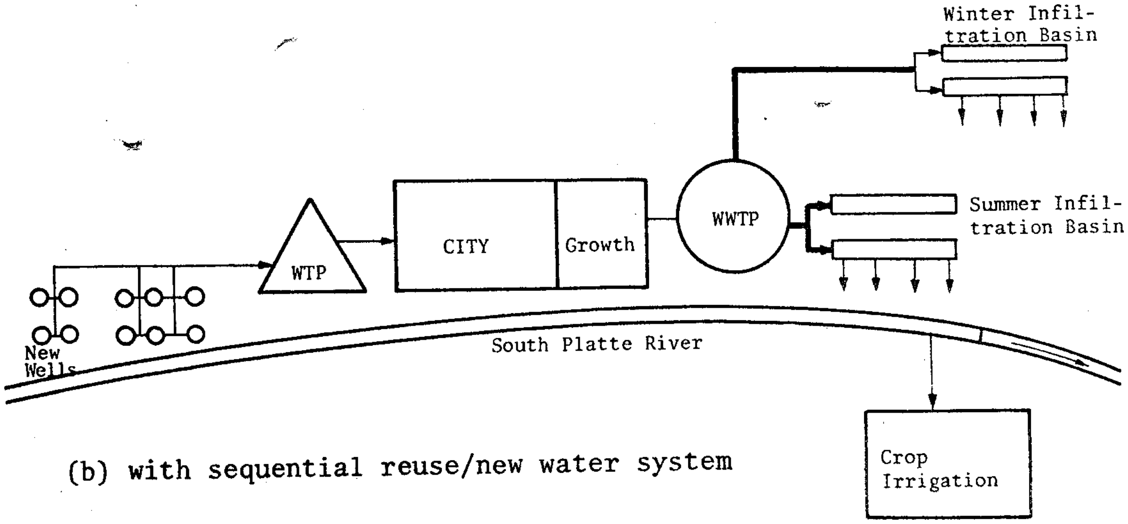


(b) with reuse project

Figure 2-7. Schematic of sequential reuse/native water exchange.



(a) prior to sequential reuse/new water system



(b) with sequential reuse/new water system

Figure 2-8. Schematic of sequential reuse/new water.

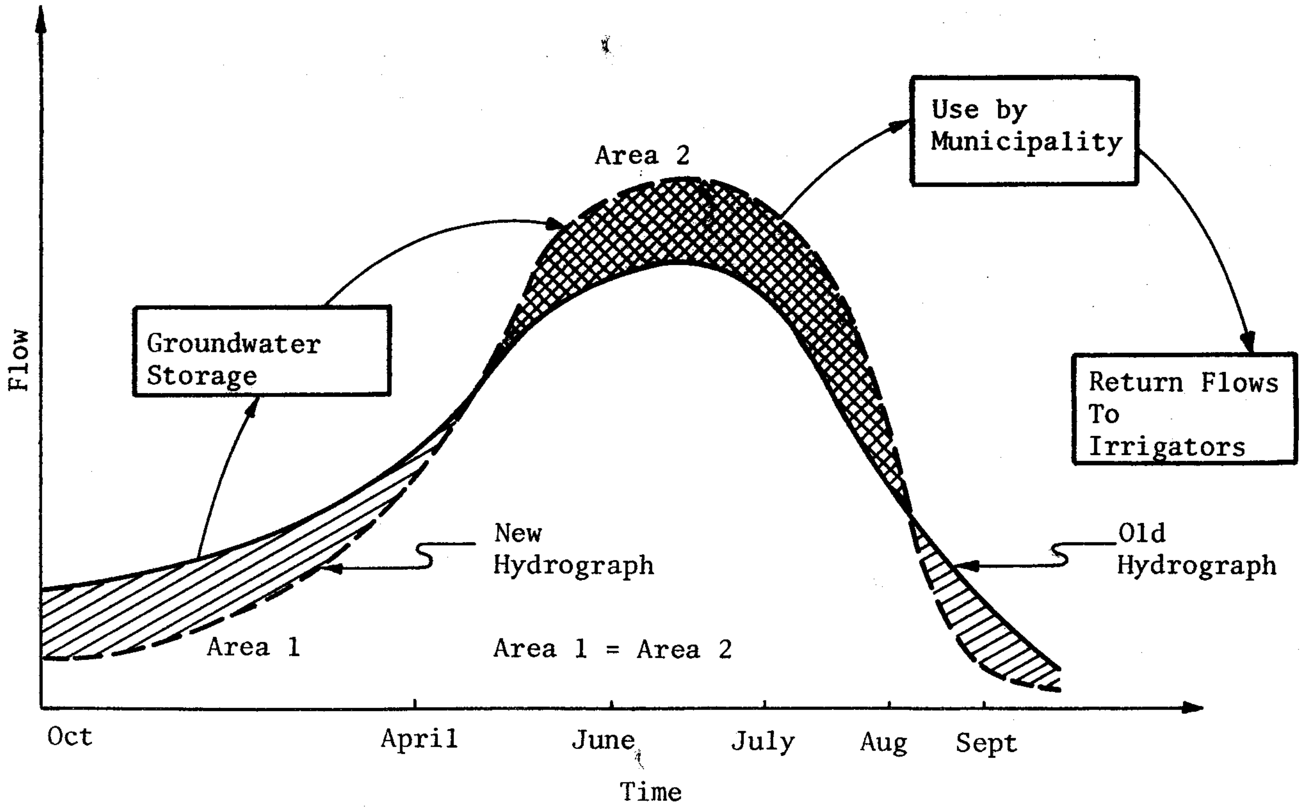


Figure 2-9. Stream hydrograph for creation of "new water".

transferring those flows to the summer months for reuse. In this manner "new water" is created.

The City of Sterling is presently involved in the final design stages of a sequential reuse/new water system. Sterling's wastewater treatment plant must be upgraded to produce a higher level of treatment to meet water quality standards. A new aerated lagoon system discharges to sand filters next to the South Platte River in the summer. During the winter, lagoon effluent will be discharged to an offstream natural groundwater recharge site. By the year 2000, Sterling will have modified the stream hydrograph enough to claim an additional 1,000 acre-feet of water during the high demand summer months.

2.7 Summary

A profusion of water reuse terms are appearing in the literature. These terms are not based on any comprehensive system for defining the water reuse universe. The definitions arrived at in this chapter and summarized in Table 2-6 are based on those found in the literature but are designed to be more comprehensive. A breakdown of these terms reveals that the water user, water use (purpose), and planning intent are at the heart of every reuse definition. The water reuse terms selected for definition are categorized using a tree-branch system and set theory to illustrate their coverage.

Water reuse is rapidly becoming a feasible alternative for meeting increasing municipal and industrial water demands. The reasons behind this are discussed and then illustrated using the Los Angeles area and the South Platte River Basin as examples. In the South Platte

Table 2-6. Water Reuse Definitions

Water Reuse:	*A series of two or more consumptive uses that occur due to the acts of man in which a portion or all of the water originating from the first use and then used a second time has not passed through an unconfined gaseous state between uses.*
Unplanned Reuse:	*Unplanned reuse occurs when water after a first use is discharged to either a surface or groundwater body and the water is subsequently captured and put to use by a second or subsequent user without coordination or planning between the first and second or subsequent users.*
Planned Reuse:	*Planned reuse is a deliberate second or repetitive use of water by the same or another user that involves planning to coordinate the transfer of water between the first and second or subsequent users.*
Sequential Reuse:	*Sequential reuse occurs when water is put to a second or subsequent use by another user or a different use by the first user.*
Successive Reuse:	*Successive use is a subsequent use (of foreign water) by the water importer for a different purpose.*
Recycle Reuse:	*Recycle reuse is the recirculation of water through a given use entity for the same purpose.*
Potable Reuse:	*Potable reuse is the reuse of wastewater effluent after special treatment for domestic purposes, including human consumption.*

River Basin, the evolution of various forms of water is described. Each of these reuse forms is specially adapted to the context of the basin. Evolution is a continuous process and additional adaptations of the basic water reuse types can be expected to take place.

CHAPTER 3

WATER QUALITY LAW REUSE INCENTIVES

During the 1950's and 1960's the western United States sustained rapid rates of urban growth. Many areas experienced difficulties meeting the increased demand for domestic water supplies. The easily developable raw water supplies were being exhausted and Federal water resource development programs were slowing down. Increased municipal wastewater loads were resulting from the rapid growth and the municipalities were not prepared to provide adequate treatment. This was the case despite the relatively moderate standards of performance for wastewater treatment plants.

When the environmental movement took hold in the late 1960's, the situation was ideal for the incorporation of water reuse incentives into the yet to be drafted Water Pollution Control Act. Urban water demand was high, the public was aware of serious water quality problems, recycling of resources was becoming an important issue, and treatment of wastewater through land application was being aggressively pursued by the Corps of Engineers.

All of these factors came together in the early 1970's and lead to the passage of the Water Pollution Control Act of 1972 (PL92-500). The states followed suit and many, including Colorado, provided additional reuse incentives beyond those contained in the Federal legislation. Both the Federal and state incentives are playing important roles in providing the impetus for water reuse projects. The sections of the laws relating to water reuse are quoted and discussed in order to discover the impact they are having on water reuse projects today.

3.1 Federal Incentives to Water Reuse

Federal water quality law is encouraging water reuse in the West. The shortage of additional raw water supply sources has, in combination with the state Federal water quality laws, created a sudden surge in reuse proposals. Federal water quality law has encouraged water reuse in three ways:

1. Minimum Levels of Wastewater Treatment (PL92-500, Section 301): The legally mandated effluent standards make the quality of treated wastewater adequate for immediate use for some purposes. The cost of rennovating treated wastewater for higher quality uses is now lower and is often cost competitive with new sources of water supply. If tertiary treatment is required, the economics of reusing wastewater is even more desirable.
2. Mandatory Evaluation of Reuse Alternatives (PL92-500, Section 201): Plans for wastewater treatment facilities must evaluate water reuse alternatives in order for the project to be eligible for Federal funding. In the South Platte River Basin, reuse proposals are being implemented by several municipalities.
3. Higher Rate of Funding [PL92-500, Sections 201(j) and 202(a)]: Wastewater treatment facilities incorporating water reuse are eligible for 85% Federal funding compared to the normal 75%. The cost of a wastewater reuse facility can exceed the most cost-effective alternative by 15%.

3.2 Water Pollution Control Act of 1972

In 1972 Congress enacted the Federal Water Pollution Control Act (PL92-500) (U.S. Congress, 1977). The objective and goals of this Act are:

> The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters...
> (1) it is the national goal that discharge of pollutants into the navigable waters be eliminated by 1985;
> (2) it is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propogation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983.

These broad goals were made specific by a number of measures contained in the Act. Water quality standards for streams and lakes were supplemented by effluent limitations for wastewater discharges. The wastewater dischargers were required to obtain a permit. Provisions in the permits required construction of wastewater treatment facilities where necessary. Federal grants for paying 75% of construction costs were made available. A system of facility (201), area-wide (208), state (203e), and basin (209) water quality planning was initiated to ensure adequate coordination between meeting water quality goals, wastewater treatment facility construction, and best management practices for nonpoint source runoff.

The 1972 Act did encourage water reuse. Section 201 of Title II, Grants for Construction of Treatment Works, encouraged the recycling of wastewater pollutants and reclamation of wastewater using agriculture, silviculture, and aquaculture (U.S. Congress, 1977):

> (d) The Administrator shall encourage waste treatment management which results in the construction of revenue producing facilities providing for--
>
> (1) the recycling of potential sewage pollutants through the production of agriculture, silviculture, or aquaculture products, or any combination thereof;
>
> (2) the confined and contained disposal of pollutants not recycled;
>
> (3) the reclamation of wastewater; and
>
> (4) the ultimate disposal of sludge in a manner that will not result in environment hazards.
>
> (e) The Administrator shall encourage waste treatment management which results in integrating facilities for sewage treatment and recycling with facilities to treat, dispose of, or utilize other industrial and municipal wastes, including but not limited to solid waste and waste heat and thermal discharges.
>
> (g) (2) The Administrator shall not make grants...unless the grant applicant has satisfactorily demonstrated to the Administrator that--
>
> (A) alternative waste management techniques have been studied and evaluated and the works proposed for grant assistance will provide for the application of the best practicable waste treatment technology over the life of the works consistent with the purposes of this title;
>
> (B) as appropriate, the works proposed for grant assistance will take into account and allow to the extent practicable the application of technology at a later date which will provide for the reclaiming or recycling of water or otherwise eliminate the discharge of pollutants.

3.3 Clean Water Act of 1977

Although wastewater reuse is encouraged by Section 201 of the Water Pollution Control Act of 1972, major activity in the municipal water reuse area did not occur until the law was amended by the Clean Water Act of 1977 (PL95-217) (U.S. Congress, 1977). The Clean Water Act provides the planning and financial incentives needed to encourage reuse implementation. Section 201(g)5 from the Federal Water Pollution Control Act as amended by the Clean Water Act encourages water reuse:

> (5) The Administrator shall not make grants from funds authorized for any fiscal year beginning after September 3, 1978, to any State, municipality, or intermunicipal or interstate agency for the erection, building, acquisition, alteration, remodeling, improvement, or extension of treatment works unless the grant application has satisfactorily demonstrated to the Administrator that innovative and alternative wastewater treatment processes and techniques which provide for the reclaiming and reuse of water, otherwise eliminate the discharge of pollutants and utilize recycling techniques, land treatment, new or improved methods of waste treatment management for municipal and industrial waste (discharged into municipal systems) and the confined disposal of pollutants so that pollutants will not migrate to cause water or other environmental pollution, have been fully studied and evaluated by the applicant taking into account section 201(d) of this Act and taking into account and allowing to the extent practicable the more efficient use of energy and resources.

Reuse projects generally cost more than standard wastewater treatment projects because both water quality and water supply purposes are included in the project. The benefits associated with the additional uses of the water are not taken into account. Cost effectiveness studies are made rather than cost-benefit analyses. Cost effectiveness compares the cost of one alternative with another based on meeting the effluent criteria necessary to maintain the designed water quality standard for the receiving body of water. Since reuse projects achieve additional benefits beyond the water quality goal, an additional 15% cost increase over the nonreuse alternative is allowed. Section 201(j) of the Act authorizes the additional expenditures (U.S. Congress, 1977):

> (j) The Administrator is authorized to make a grant for any treatment workds utilizing processes and techniques meeting the guidelines promulgated under Section 304(d)(3) of this Act, if the Administrator determines it is in the public interest and if in the cost effectiveness study made of the construction

> grant application for the purpose of evaluating alternative treatment works, the life cycle cost of the treatment works for which the grant is to be made does not exceed the life cycle cost of the most effective alternative by more than 15 percent.

In addition to the 15% increase allowed for water reuse projects, the Act provides for an additional 10% Federal funding. Section 202(a) (1-3) provides for the extra funding:

> Section 202.(a)(1) The amount of any grant for treatment works made under this Act from funds authorized for any fiscal year beginning after June 30, 1971, shall be 75 percent of the cost of construction thereof (as approved by the Administrator)...
>
> (2) The amount of any grant made after September 30, 1978, and before October 1, 1981, for any eligible treatment works or significant portion thereof utilizing innovative or alternative wastewater treatment processes and techniques referred to in Section 201(g)(5) shall be 85 percent of the cost of construction thereof...
>
> (3) In addition to any grant made pursuant to paragraph (2) of this subsection, the Administrator is authorized to make a grant to fund all of the costs of the modification or replacement of any facilities constructed with a grant made pursuant to paragraph (2) if the Administrator finds that such facilities have not met design performance specifications unless such failure is attributable to negligence on the part of any person and if such failure has significantly increased capital or operating and maintenance expenditures.

The additional 10% funding can make reuse projects less expensive to the municipality than conventional wastewater treatment projects. If the most cost effective conventional project costs $100 million, the reuse project can cost up to $115 million based on the 15% cost increase allowed for reuse projects. On the $100 million project, the Federal share is 75% or $75 million. This leaves $25 million for state and local funding. For the $115 million reuse project, federal funding is 85% or $97.75 million. This leaves $17.25 million for state and local funding or a net decrease of $7.75 million. The funding applies to construction costs only. Operational costs may be either higher or lower for reuse projects than for conventional wastewater treatment.

3.4 Relation of State Water Quality Laws to Federal Legislation

State water quality laws are based on requirements set forth in the 1972 Federal Water Pollution Control Act Amendments. State laws had to meet minimum Federal standards in order for a state to receive Federal construction grants for water pollution control facilities and to obtain control of the issuance of National Pollutant Discharge Elimination System (NPDES) permits. Current water quality law utilizes water quality standards for streams and effluent discharge limitations. This approach allows for the setting of stream classifications according to beneficial uses. Each classification has a set of water quality parameters and standards for those parameters. Once the standards are set, specific discharge requirements for point sources and best management practices for nonpoint sources can be set to meet the stream standards.

The State of Colorado is actively encouraging the utilization of land treatment processes for municipal wastewater treatment. Land treatment is being combined with water exchange agreements in order to increase municipal water supplies and take care of wastewater treatment responsibilities simultaneously.

3.5 Colorado Water Quality Control Act

The Colorado Legislature set water quality policy for the state in the Colorado Water Quality Control Act (State of Colorado, 1973). These policies are specifically stated in CRS (1973) 25-8-102 (20):

> It is further declared to be the public policy of this state to conserve state waters and to protect, maintain, and improve the quality thereof for public water supplies, for protection and propagation of wildlife and aquatic life, and for domestic, agricultural, industrial, recreational, and other beneficial uses; to provide that no pollutant be released into any state waters without first receiving the treatment or other corrective action necessary to protect the legitimate and beneficial uses of such waters; to provide for the prevention, abatement, and control of new or existing water pollution; and to cooperate with other states and the federal government in carrying out these objectives.

The Act also provides for establishing types of water classes based on present uses and uses that might become desirable in CRS (1973), 25-8-203 (2):

> (c) Present uses of the water, the uses for which the water is suitable in its present conditions, or the uses for which it is to become suitable as a goal, and
>
> (e) The need to protect the quality of the water for human purposes and also for the protection and propagation of wildlife and aquatic life.

3.6 Water Quality Control Commission

The Water Quality Control Commission is currently authorized by the Colorado Water Quality Act. The Commission has the responsibility of developing a program for preventing water pollution and enhancing water quality throughout the state. The Commission classifies the state waters, enacts water quality standards, and passes regulations to implement those standards. The Commission has not passed regulations that deal specifically with water reuse. Water reuse proposals are handled within the existing framework for maintaining water quality.

3.7 Stream Classifications

The Commission classifies streams according to their use. Streams are broken into segments based on their physical and use characteristics. These segments are then given use classifications. Section 3.1.6, Process for Assigning Classifications, of the Commission regulations provides the following guidance (Colorado Dept. of Health, 1979):

> Waters shall be classified for all uses for which they are suitable or are to become suitable. It should be noted that existing high quality waters may include beneficial uses. The assignment of one or more classifications to a portion of the waters of the State is based upon its current suitability for the designated uses or goals for future uses.

The following serve to guide the Commission in assigning classifications:

(a) Classifications should be directed towards the realization of the water quality goals as set forth in the Federal and State Acts.

(b) It is State law and policy to prevent any water quality degradation that can interfere with present uses.

(c) Upstream classifications must not jeopardize downstream classifications or actual uses.

(d) Classifications must protect all current classified and actual uses, unless it is determined after a public hearing that downgrading is justifiable.

(e) Classifications should be for the highest water quality attainable. Attainability is to be judged by whether or not the use classification can be attained in approximately twenty (20) years by any recognized control techniques that are environmentally, economically, and socially acceptable as determined by the Commission after public hearings.

(f) Nonchemical quality parameters such as flow and stream bed conditions are valid quality concerns.

Waters of the state are divided into five use classifications: (1) recreation, (2) agriculture, (3) aquatic life, (4) domestic water supply, and (5) existing high quality waters. Table 3-1 summarizes the characteristics of each of these classes.

3.8 Standards

Standards are by definition "a narrative and/or numeric restriction established by the Commission applied to waters of the State to protect one or more beneficial uses of such waters" (Colorado Dept. of Health, 1979). Standards are tied to the use concept. The standards are divided into three categories: (1) anti-degradation standard, (2) basic standards, and (3) numeric standards.

The antidegradation standard requires that the quality of water cannot be degraded to the point where the quality interferes with existing uses. In addition, high quality waters can be identified and, because of special values associated with those waters, no parameters may be degraded.

Basic standards apply to discharges into waters that are not covered by NPDES permits or best management practices for agricultural runoff. These standards are closer to effluent regulations than use standards.

Numeric standards are assigned by the Commission. The Commission reviews evidence that supports the adoption of a particular numeric value for the protection of a particular use classification. Numeric standards may be exceeded due to temporary natural conditions such as spring runoff or drought. Numeric standards are divided into physical, biological, inorganic, total metal, and organic parameters. Standards

Table 3-1. Summary of Colorado Water Quality Control Commission Adopted Classification System*

Water Use	Definition
RECREATION	
Class 1 - Primary Contact	These surface waters are suitable or intended to become suitable for prolonged and intimate contact with the body or for recreational activities when the ingestion of small quantities of water is likely to occur. Such waters include but are not limited to those used for swimming.
Class 2 - Secondary Contact	These surface waters are suitable or intended to become suitable for recreational uses on or about the water which are not included in the primary contact subcategory.
AGRICULTURE	These waters are suitable or intended to become suitable for irrigation of crops usually grown in Colorado and which are not hazardous as drinking water for livestock.
AQUATIC LIFE	These surface waters are suitable or intended to become suitable for the protection and maintenence of aquatic life forms as described below:
Class 1 - Cold Water Aquatic Life	These waters provide, or could provide, a habitat consisting of water quality levels and other considerations such as flow and stream bed characteristics which do or could protect and maintain a wide variety of cold water biota, including sensitive species. Cold water biota are considered to be life forms, including trout, in water where temperatures do not normally exceed 20°C. If there are limitations to the potential variety of life forms, they are due primarily to uncorrectable water quality conditions. This information will be considered in assigning specific standards.
Class 1 - Warm Water Aquatic Life	These waters provide, or could provide, a habitat consisting of water quality levels and other considerations such as flow and stream bed characteristics which do or could protect and maintain a wide variety of warm water biota, including sensitive species. Warm water biota are considered to be the life forms in waters with temperatures frequently exceeding 20°C. If there are limitations to the potential variety of life forms, they are due primarily to uncorrectable water quality conditions. This information will be considered in assigning specific standards.

Table 3-1. Continued.

Water Use	Definition
AQUATIC LIFE (cont.)	
Class 2 - Cold Water Aquatic Life	These are waters where the potential variety of life forms is presently limited primarily by flow and stream bed characteristics. Standards will be assigned to protect existing species and encourage the establishment of more sensitive species which are compatible with the flow and stream bed characteristics.
Class 2 - Warm Water Aquatic Life	These are waters where the potential variety of life forms is presently limited primarily by flow and stream bed characteristics. Standards will be assigned to protect existing species and encourage the establishment of more sensitive species which are compatable with the flow and stream bed characteristics.
DOMESTIC WATER SUPPLY	These waters are suitable or intended to become suitable for potable water supplies. There may be waters which do not fit into either the Class 1 or Class 2 classifications but which may be suitable for domestic water supplies after special treatment.
Class 1 - Uncontaminated Groundwaters	These are groundwaters which receive a high degree of natural protection and meet, without treatment, all Colorado drinking water regulations and any revision, amendments, or supplements thereto. Colorado drinking water regulations require disinfection of all domestic water supplies regardless of source unless a waiver has been obtained.
Class 2 - Waters Requiring Disinfection and/or Standard Treatment	These are waters which, after receiving approved disinfection, such as simple chlorination or its equivalent or which after receiving standard treatment (defined as coagulation, flocculation, sedimentation, filtration, and disinfection with chlorine or its equivalent) will meet Colorado drinking water regulations and any revisions, amendments, or supplements thereto. This class may include groundwaters which, due to natural or human causes, do not meet the requirement for Class 1 waters.

Table 3-1. Continued.

Water Use	Definition
EXISTING HIGH QUALITY WATERS	Waters currently of a quality higher than necessary to support primary contact recreation and propagation of fish, shellfish, and wildlife and are generally suitable for agriculture and domestic water supply may be classified as high quality waters. This classification precludes the necessity to classify for other beneficial uses.
Class 1	These are high quality waters which constitute an outstanding state or national resource such as waters in national and state parks and forests, wildlife refuges, and waters of exceptional recreational and ecological significance. For example, waters which provide a unique habitat for an endangered or threatened species or rivers designated under the Wild and Scenic Rivers Act may be designated as outstanding state or national resource waters. No degradation of these waters will be allowed; thus, these waters will be protected and maintained at their existing quality.
Class 2	These are other high quality waters which are not classified as outstanding state or national resources. These waters shall be maintained and protected at their existing quality unless the Commission chooses, after full intergovernmental coordination and public participation, to allow lower water quality as a result of necessary and justifiable economic or social development. In no event, however, may degradation of water quality interfere with or become injurious to existing instream water uses.

*Full text is contained on Colorado Department of Health, Water Quality Control Commission, Regulations Establishing Basic Standards and an Antidegradation Standard and Establishing a System for Classifying State Waters, for Assigning Standards, and for Granting Temporary Modifications. Adopted May 22, 1979; Effective July 10, 1979.

set for parameters such as ammonia, chlorine, nitrate, suspended solids, and fecal coliforms have important impacts on reuse proposals. Reuse exchange proposals where treated municipal wastewater is used for agricultural irrigation must often use waters of the state for transport to the irrigation site. Water quality that is acceptable for irrigation use may not be acceptable for the beneficial use classification set for the stream or canal used to transport the wastewater to the irrigation site.

3.8.1 Nitrate and Ammonia Standards

Waste products from humans and animals contain protein and urea that release significant quantities of ammonia into wastewater. Although ammonia is beneficial when contained in water applied to crops, it is highly toxic to aquatic life. Domestic wastewater typically contains 25 mg/ℓ of ammonita nitrogen as N. Total nitrogen is generally 40 mg/ℓ (Metcalf and Eddy, 1979). If the wastewater is discharged to a domestic water supply source, ammonia must be 0.5 mg/ℓ. If the water body is classified for aquatic life as a beneficial use, the ammonia level must be 0.02 mg/ℓ unionized for cold water and 0.06 mg/ℓ unionized for warm water. At a pH of 7 and a water temperature of 20°C, 0.02 mg/ℓ unionized ammonia converts to 10 mg/ℓ total ammonia. If the pH is raised to 7.5 at 20°C, 1.24% of the ammonia is unionized so that 0.02 mg/ℓ gives 1.6 mg/ℓ of total ammonia and 0.06 mg/ℓ gives 4.8 mg/ℓ. The pH of the receiving water is critical in meeting standards. This pH is not, however, generally controlable. Treatment facilities, therefore, must be designed to meet the maximum ammonia removal level necessary on historic pH variations in the receiving body of water.

Wastewater treatment facilities incur substantial costs when required to reduce ammonia levels below 20 mg/ℓ, the average value for ammonia in wastewater from a biological treatment process. Ammonia reduction can be accomplished through extended periods of aeration. As an example, Fort Collins' new wastewater treatment plant has a capacity of 12 mgd when operated as an extended aeration plant for purposes of nitrification and 18 mgd as a high rate activated sludge facility (no nitrification) (Blair, 1978).

If the wastewater is discharged to a domestic water supply source, prior to reuse, nitrate is also limited. Total nitrate levels cannot exceed 10 mg/ℓ as N and nitrite is limited to 1.0 mg/ℓ as N. Thus, another step must be added to the wastewater treatment process to remove nitrates.

Nitrogen, whether in ammonia or nitrate form, is valuable as a growth nutrient to agricultural crops. The classification of a receiving stream for its beneficial uses becomes very important to a municipality. The cost of reuse/exchange plans can vary widely depending on the classification of the stream or canal used for transportation of the treated wastewater.

Canals are considered waters of the state and cannot be used without considering use classifications that may be assigned by the Commission. Currently, no classifications have been assigned to canals. Aquatic life or domestic water use classifications would require extensive treatment processes not necessary for agricultural reuse. Treatment for protection of the transport waterway may require higher water quality standards than necessary for the reuse purpose itself.

2.3.2 Biological Standards

The biological parameter used is the number of fecal coliforms per 100 ml (using the geometric mean) (Environmental Protection Agency, 1979). Fecal coliforms are an indicator organism that inhabits the intestines of man and warm blooded animals and is not itself a pathogen. The presence of fecal coliforms indicates the potential for the presence of pathogenic organisms. Fecal coliform standards are 200/100 ml for recreational primary contact, 2,000/ml for recreational secondary contact, 0/100 ml for Class 1 domestic water supply and 2,000 for Class 2 domestic water supplies.

The Colorado Water Quality Control Division has applied a fecal coliform limit of 1,000/100 ml on instream fecal coliform densities for agricultural use. The Environmental Protection Agency (EPA) in the Northglenn reuse plan, is requiring a limit of 200/100 ml because public access to reuse wastewater is not restricted (EPA, 1980). In cases dealing with water reuse, the instream standards are often times the same as effluent standards because the entire flow of the stream or canal may be composed of treated wastewater.

The health risk associated with various fecal coliform counts has not been established in absolute terms, but it is a relative indicator of risk. Certainly, the level considered safe for full-body (primary) recreational contact (200/100 ml) should provide adequate protection. Full-body recreational use anticipates that ingestion of small quantities of water is likely to occur. The secondary contact recreation classification permits the water body to have a fecal coliform level of 2000/100 ml. Limited body contact is assumed for secondary recreation classification. Assuming that these figures are reasonable, a safe agricultural reuse fecal coliform level of 2000/100 ml would seem adequate under most circumstances. Northglenn's situation is special in that full-body contact is anticipated in the Bull Canal which is used as the transportation mechanism between the wastewater storage facility and the land application site.

Neither the EPA nor the State have developed standards that apply to the application of wastewater to raw edible food crops. California has set the level for fecal coliform organisms at a maximum of 2.2/100 ml for edible crops. This level is very restrictive. To achieve the 2.2/100 ml level, the standard states that the wastewater must be disinfected, oxidized, coagulated, chlorinated, and filtered. Exceptions can be made by the California State Department of Health when the wastewater is used to irrigate food crops that require extensive processing that would destroy pathogenic organisms prior to human consumption. When wastewater is to be used for irrigating fodder, fiber, and seed crops, no coliform standard is set. The wastewater must receive only primary treatment (California Department of Health, 1975). This standard is more liberal than Colorado's which requires secondary treatment of wastewater prior to application.

Biologically treated wastewater contains approximately 10^6/100 ml coliforms (Clark, Viessman and Hammer, 1977). Raw wastewater contains approximately 10^7/100 ml coliforms (McKinney, 1962). A reduction of coliforms from 10^7/100 ml to 200/100 ml represents a 1/50,000 ratio or 0.002% of the original number in the wastewater. Colorado's administrative fecal colfirm requirement of 1000/100 ml (0.01% of the original number) appears reasonable for wastewater applied to nonedible crops.

Viruses are the smallest plant cells known at the present time. They are intracellular parasites deriving their nutrients from host organisms. Viruses are almost pure chemical entities that reproduce only within a host. Enteroviruses are present in much smaller numbers (2-44/100 ml) and are more resistant to chlorination than coliforms. Removal mechanisms in wastewater treatment are not well understood although floc formation, aeration, and settling does reduce their number. Filtration using coagulants for floc formation is the main water treatment process known to remove high percentages (99%) of viruses (Clark et al., 1977). Tests for the detection of enteroviruses are lengthy and complex. At present, no satisfactory routine procedure for their detection exists. Therefore, no standard exists for enteroviruses.

3.8.3 Low Flows and Standards

Water quality standards do not apply when surface flows are less than the average annual seven-consecutive-day low flow expected to occur once in ten years. For ammonia standards, the seasonal seven-day, ten-year, low flood is used.

3.9 Regulation of Point and Nonpoint Discharges

Stream classifications are integrated with discharge permits under Section 3.1.14 of the "Regulations Establishing Basic Standards" (Colorado Department of Health, 1979):

> (1) A classification and/or standard assigned by the Commission to any segment of waters of the State may affect the degree of treatment required prior to discharge of effluent to such waters. Where effluent limitation regulations applicable to discharges into a segment of state waters or Best Management Practices

(BMP's) or other activities are adequate to maintain or attain the assigned classifications and standards, only the effluent limitation regulations will control the discharge. (See Regulation 10.1). Such segments are termed "effluent limited."

(2) Where the effluent limitation regulations applicable to the discharge or BMP's or other controls are inadequate to maintain or attain the assigned classifications and standards, a degree of treatment which will maintain or attain such classifications and standards will be required. Such segments are termed "water quality limited."

(3) For water quality limited segments, Total Maximum Daily Loads (TMDL's) and Waste Load Allocations will be developed and integrated into discharge permits. Flow modifications and other factors may also affect TMDL's and may have a corresponding effect on discharge permits. Permits will also be written in accordance with any temporary modification granted by the Commission to the underlying numeric standard assigned to those waters and a plan for eliminating the temporary modifications shall be included in the discharge permits.

NPDES permits are an important part of reuse plans because the permit establishes a minimum level of treatment for discharge. The treatment level can be used to estimate the cost of wastewater treatment alone. This cost can then be used in calculating the cost effectiveness of reuse plans.

Another important aspect is that the effluent limitations set minimum treatment levels for discharge to state waters. Many reuse/exchange proposals involve the use of irrigation canals to transport the treated wastewater in exchange for high quality raw water. Irrigation canals are considered part of the state waters so effluent limitations do apply to discharges into canals (Colorado Department of Health, 1979). No use classifications have been assigned to canals.

No water quality limitations can be defined without state use classifications. Therefore, the standard effluent limitations apply to all discharges into canals. Effluent limitations are given in Table 3-2.

Effluent limitations that differ from those in Table 3-2 can be issued for industries. Treatment applicable to industry requires that Best Practicable Control Technology be used by July, 1983.

On March 5, 1979, the Water Quality Control Commission (Colorado Department of Health, 1979) issued an amendment to the effluent regulations to encourage reuse/exchange agreements with irrigators. The policy statement is quoted below:

> It is also a policy of the Commission to encourage cooperation between urban and rural interests wherever possible. One such area is the potential recycling of treated sewage effluent by exchanges with irrigators which may be mutually beneficial to both the municipality and the irrigators. This kind of exchange is already possible under existing laws and standards and is already taking place in Colorado. Without the amendment to relax suspended solids for larger ponds, however, the lagoon treatment and exchange opportunities are limited to smaller communities, that is, to communities whose effluent can be handled in a pond no greater than 2 mgd. In order to make it possible for larger communities and for ditches capable of handling larger flows to take advantage of this method, the amendment relaxes the suspended solids standard for waste stabilization ponds which are larger than 2 mgd if such discharge is made to "irrigation canals". This relaxation of the suspended solids limitation does not change the secondary effluent limitations on any other parameters, nor does it affect any other existing laws, in particular, Colorado water law and ditch rights. In addition, the regulations states that the suspended solids limits may be adjusted, not that the suspended solids shall be adjusted.
>
> The Federal Clean Water Act does not permit states to establish effluent limitations which are less strict than federal standards. However, the federal act does not have jurisdiction over all of the

Table 3-2. Specific Limitations for the Discharge of Wastes

Parameter	Parameter Limitations	
	7 Day Average	30 Day Average
BOD_5	45 mg/ℓ	30 mg/ℓ
Suspended Solids	45 mg/ℓ	30 mg/ℓ
Fecal Coliform	As determined by the Division of Administration of the State Health Department to protect public health in the stream classification to which the discharge is made.	
Residual Chlorine	Less than 0.5 mg/ℓ	less than 0.5 mg/ℓ
pH	6.0 to 9.0	6.0-9.0
Oil and Grease	10 mg/ℓ and there shall be no visible sheen.	

Source: Colorado Department of Health, 1979a.

> waters of the state, only those waters which are "navigable waters". While the term "navigable waters" has been interpreted very broadly, the term "irrigation canals" as defined in the regulation is intended to include only those waters of the state which are not under the jurisdiction of the federal act.
>
> The basic purpose of the amendment is to reduce the cost of treatment for suspended solids removal.

3.10 Construction Grant Priority System and Reuse

The construction priority system allocates state and federal funds to municipalities for the construction of wastewater treatment facilities and interceptor sewers. The point system is a method for identifying municipalities that have the most severe wastewater treatment problems. Population, quality of receiving water body, project type, completion of 201 planning requirements, and water reuse are taken into consideration. Table 3-3 shows the priority point system. If a municipality's proposed project meets the reuse definition, an additional 45 points is added to the total. In fiscal year 1979, the number one priority project had a total of 168 priority points and the number 20 project had 119 points. An increase of 45 points would have moved the number 20 priority project up to number two. The inclusion of reuse in a project can make a difference between being funded and no funds.

The definition of water reuse in the priority system is given below (Colorado Department of Health, 1979).

> WATER REUSE - The recycling of a substantial portion of the effluent stream through the production of agricultural, silvicultural, or aquacultural products, through irrigation or public areas such as open space or recreation sites, or through industrial or domestic reuse, which results in substantial and

Table 3-3. Priority Point System

Item	Points
(1) Basin Point System for All Municipalities	
(A) Population: The population of the municipality or the municipalities served. See the population chart.	50 max.
(B) Discharge State Waters: Actual or potential discharge from a treatment to waters which presently are classified A1, A2, or B1	15
(2) Project Points: Only one category can be used for each project	
(A) Interceptor Sewers: which eliminate an existing plant or eliminate a designated health hazard. This will also include approved inflow/infiltration correction projects.	*
(B) All other interceptor sewers	5
(C) Expansion of Treatment Plant: where current loading exceeds 80% of the rated organic or hydraulic capacity	10
(D) Overloaded Secondary Treatment Plant: including sludge handling (actually exceeding rated capacity)	30
(E) Treatment Beyond Secondary: includes land treatment needed to meet water quality requirements	20
(F) Designated Health Hazards: malfunctioning of a majority of the septic tanks serving an area to be sewered, or pollution of state waters which causes a health hazard. These must have been officially designated a health hazard by a responsible health authority.	40
(3) Special Points: to be added only for Step II and Step III grants and only where there is a needed project shown by a completed 201 plan or equivalent.	
(A) Completed 201 Plan or Equivalent Justifying a Step II or III Project: This could include a 201 plan nearing completion or those needed projects which received 50 points on the previous year's priority list.	50
(B) Water Reuse: see definition of water reuse in Section 5.3.2 to determine whether or not the project qualifies for reuse projects	45

*Same points as receiving in treatment plant or 20 points, whichever is larger.

> effective upgrading of the effluent prior to discharge into a natural watercourse. Reuse can include discharge to an irrigation reservoir. Any dispute regarding whether or not a project qualifies as a water reuse will be resolved by the Commission.

This definition of reuse is very broad. Some communities are already practicing unplanned reuse according to this definition because their wastewater is discharged directly into irrigation ditches. One problem arising from this regulation, which amounts to a reuse incentive, is reduction of streamflow. Flow reduction in streams can result when canals are used to transport reusable water. In some instances, reuse schemes may have an overall negative environmental impact.

3.11 State Policy on Land Treatment of Municipal Wastewater

The State of Colorado, through the Water Quality Control Commission, has decided to actively encourage land treatment of municipal wastewater. The State policy is stated below (Colorado Department of Health, 1978):

> It is the policy of the Colorado Water Quality Control Commission to press vigorously for publicly owned treatment works to utilize land treatment processes to reclaim and recycle municipal wastewater in accordance with established water law and the appropriative doctrine of the State of Colorado.

The land application treatment process is being combined with municipal/agricultural water exchange agreements to solve both municipal water supply needs and wastewater treatment requirements. High quality mountain water owned by agricultural interests is exchanged for treated municipal wastewater containing plant nutrients. The treated wastewater is then applied to agricultural lands to complete the treatment process and the planned reuse cycle.

The Commission has stated that land treatment can be used for secondary or tertiary treatment. Land application when used for tertiary treatment may also reduce secondary treatment requirements. Land treatment is viewed as "a vehicle" for cooperation between municipalities and agriculture (Colorado Department of Health, 1978).

> Land treatment systems can provide the vehicle by which municipal and agricultural interests can cooperate with regard to water use by allowing cities to use agricultural water, then either treat and discharge it to ditches for irrigation and fertilization or apply it directly to agricultural land. In this way, a harmonious approach to water use, rather than a competitive one, may be encouraged and enjoyed.

The effect of the Commission's land treatment policy is evident in the many reuse/exchange proposals being made in the South Platte River Basin.

3.12 Summary

Strong incentives for implementing a water reuse program have been provided by the federal government and the State of Colorado. Federal reuse incentives include mandatory consideration of water reuse alternatives during early stages of WWTP 201 facility planning, a 15% increase in the cost of reuse facilities over standard WWTP designs and a 10% higher level of federal funding, 85% versus 75%. The State of Colorado provides additional reuse incentives by providing priority funding and reduced effluent standards for water reuse projects. Reduced effluent standards provisions are made for water reuse exchange projects by raising the suspended solids levels for large municipal lagoons that are holding wastewater for delivery via canal to farm fields.

Although several federal and state reuse incentives have been provided, at least two water reuse policy areas remain troublesome. First, a definitive policy statement on the health hazards associated with the reuse of domestic effluent is needed from both the EPA and the Colorado Department of Health. Second, as water reuse exchange becomes more popular, natural streams may be dried up due to reduced effluent standards for discharges into irrigation canals. Both of these problems have already been encountered in the South Platte River Basin. Other problem areas requring policy statements or regulation are going to surface as water reuse practice expands. The state and federal agencies will have to act propmptly to protect public health and other public interests.

CHAPTER 4

WATER LAW

Water law is the single most important factor shaping water reuse forms in the West. Water quality laws and regulations set the stage for reuse but water law determines the cast of characters. Every water reuse proposal must address significant water law issues that will involve many of the water users in the basin. The very nature of appropriative water law makes the water users interdependent. This interdependency means that relatively simple modifications of the physical system involve complex legal issues.

At present, legislative water law does not specifically address many of these issues. A comprehensive set of water reuse laws and regulations does not exist in Colorado. A single paragraph of legislative law deals with water reuse. The resolution of water reuse issues not specifically covered in this single paragraph must rely on case law and the judicial process. In this chapter the impact of appropriative water law on reuse, legislative and case law that affect water reuse, and specific reuse issues that depend on the water law system for resolution are brought together to illustrate the legal framework that controls the water law aspects of reuse.

4.1 Prior Appropriation Doctrine in Colorado

Water rights in Colorado were recognized by the Territorial Legislature in 1861 and 1864. The 1864 law set forth the basic elements of appropriation. In 1876 Colorado became a state and adopted the Colorado Constitution containing the basic tenets of appropriative doctrine (Radosevich et al., 1976). Sections 5 and 6 of Article XVI on mining and irrigation from the Colorado Constitution are quoted below (Radosevich, 1977):

> Section 5. Water of streams public property--The water of every natural stream, not heretofore appropriated, within the State of Colorado, is hereby declared to be the property of the public, and the same is dedicated to the use of the people of the State, subject to appropriation as hereinafter provided.
>
> Section 6. Diverting unappropriated water--priority preferred uses. The right to divert the unappropriated waters of any natural stream to beneficial uses shall never be denied. Priority of appropriation shall give the better rights as between those using the water for the same purpose; but when waters of any natural stream are not sufficient for the service of all those desiring the use of the same, those using the water for domestic purposes shall have the preference over those claiming for any other purpose, and those using the water for agricultural purposes shall have preference over those using the same water for manufacturing purposes.

In addition to Sections 5 and 6, Sections 7 and 8 provide the right-of-way for ditches and flumes and allow county commissioners to fix maximum rates for the use of water. Sections 5 through 8 provide the basis for water law in Colorado.

4.2 Principles of Prior Appropriation

Prior appropriation is characterized by three general principles: (1) the water must be diverted from the stream, (2) the water must be put to a beneficial use, and (3) in times of shortage, the diverter with the earliest priority date has preference over a later diverter, thus the phrase "first in time, first in right."

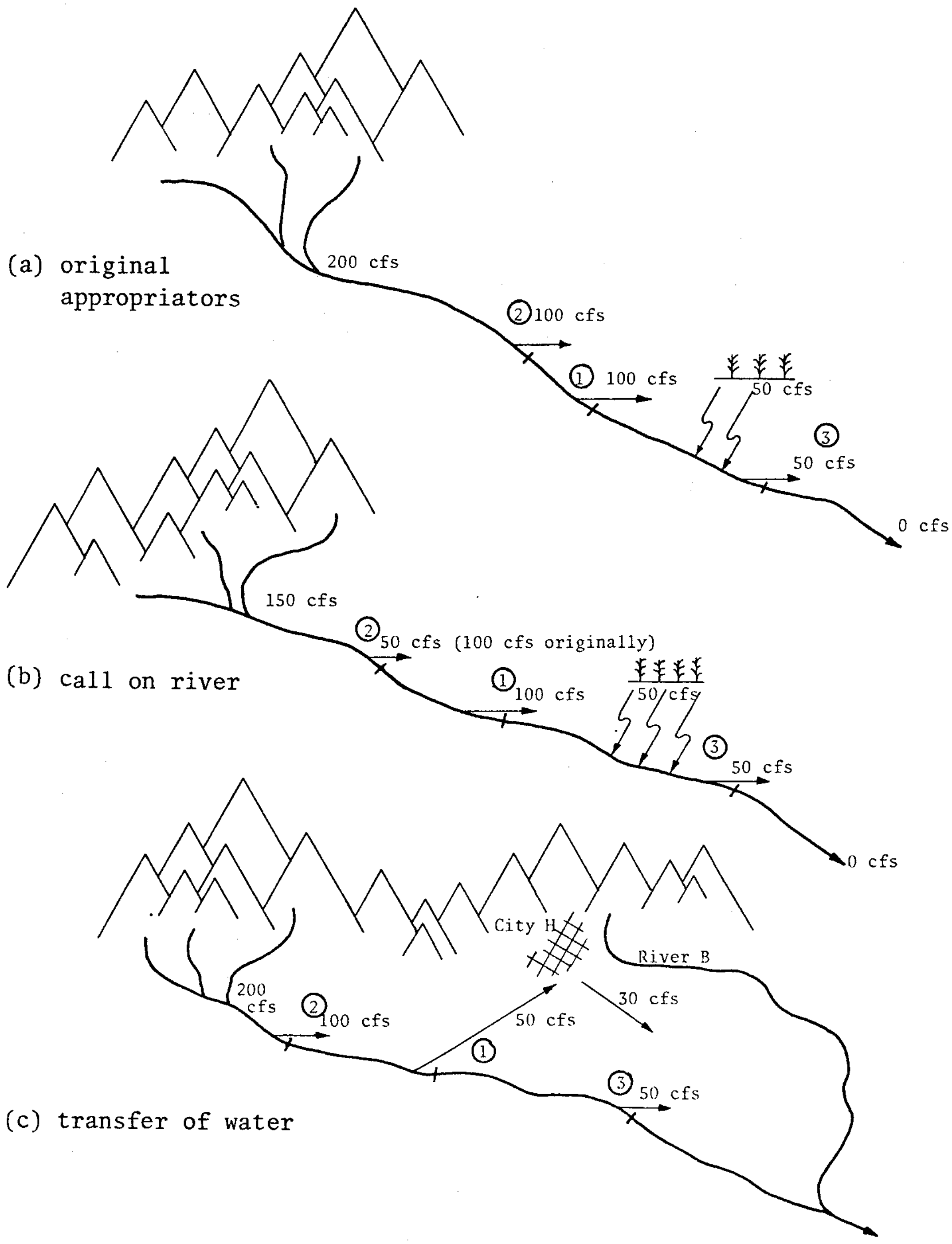
A water right is not attached to any parcel of land and the land to which the water is applied need not be adjacent to the stream. Water rights can be bought and sold like any other piece of property. The owner of a water right owns the right to use the water but does not own the water itself. The right of use but not ownership is called an unsufructuary right. Therefore, once water has been used by the appropriator, return flows to a water course once again become available for appropriation and use by downstream water users. The downstream appropriators can thereby obtain junior water rights that are dependent on return flows from a senior appropriator. Any sale of a water right or subsequent change in the point of diversion or use of the water must not harm downstream appropriators--even if they are junior (later priority date). Transfers or changes in use must leave the downstream system in the same condition as it was prior to the change. Therefore, the purchaser of a water right who wishes to transfer the right to another basin, a different location in the same basin, or put the water to a different use must meet an important restriction. The purchaser may only transfer or consumptively use water up to the level of consumptive use established in the past.

The appropriation doctrine imposes constraints on water reuse schemes. A municipality that has established a historical pattern of return flows cannot arbitrarily decide to reuse return flows. Reuse would increase consumptive use and reduce return flows thereby harming downstream appropriators. This general principle applies only to water originating within the basin and may be subject to modification on certain points. These points are examined in a later section.

The working of the prior appropriation doctrine is illustrated in Figure 4-1. In part (a) of Figure 4-1, a stream with three appropriators is shown. The first diversion, (1), from the stream is 100 cfs and is applied to crops. The return flow from the crop irrigation is 50 cfs. The second appropriator in time, (2), diverts 100 cfs and has no return flows. The third appropriator, (3), is downstream from the other two appropriators and diverts 50 cfs. With 200 cfs in the stream, appropriator (3) is dependent on return flows from appropriator (1). The stream is dry downstream from appropriator (3).

In sequence (b) of Figure 4-1, the flow in the river is 150 cfs; a flow of water insufficient to meet the diversion requirements of all three appropriators. If appropriator (2) diverts 100 cfs, only 50 cfs remain for appropriator (1). Number 1 being senior puts a "call" on the river. The call means that number (2) can divert only 50 cfs instead of 100 cfs. Appropriator (3), however, can continue to divert 50 cfs because his diversion requirements are dependent on return flows from appropriator (1). A call on appropriator (3) by (2) would be futile. If number (3) discontinues his diversion, no additional water is made available to number (2). Number (3)'s water right is dependent on number (1)'s return flows.

In part (c) of Figure 4-1, appropriator (1) decides to sell his water right to City H in an adjoining basin. City H is allowed to divert only 50 cfs because historically the long-term consumptive use of appropriator (1) was 50 cfs. Although 100 cfs was applied to number (1)'s field, 50 cfs returned to the river. If more than 50 cfs is diverted from the sub-basin, appropriator (3) will be harmed.



(a) original appropriators

(b) call on river

(c) transfer of water

Figure 4-1. Schematic of prior appropriation.

City H can now use the 50 cfs purchased water right in its municipal system. Only 20 cfs of the 50 cfs is consumptively used in the city. The remaining 30 cfs returns through the sewage collection system to River B for a number of years. If City H now decides to reuse the 30 cfs return flow, can it legally do so? Since the transfer of the water was for 50 cfs of total consumptive use, City H might argue that it has the right to consumptively use the full 50 cfs. Downstream appropriators on River B would argue against this reuse position. They have invested money in diversion works and irrigation systems that depend on the 30 cfs return flows. Who is right? Current water law does not provide a ready answer.

4.3 Legislative Water Law on Reuse and Exchange

Only one law has been enacted by the Colorado State Legislature that deals directly with water reuse. This law is part of the 1969 Water Rights Determination and Administration Act and is now incorporated in Article 82 on the "Appropriation and Use of Water."

> 37-82-105. Right to Reuse of Imported Water
> Whenever an appropriator has lawfully introduced foreign water into a stream system from an unconnected stream system, such appropriator may make a succession of uses of such water by exchange or otherwise to the extent that its volume can be distinguished from the volume of the streams into which it is introduced. Nothing in this section shall be construed to impair or diminish any water right which has become vested.

This section states the right of an appropriator who diverts water from an unconnected basin to reuse or exchange return flows from the foreign water. Water has been separated into two classes for reuse--native or inbasin water and foreign water. Nontributary groundwater is placed in the same classification as foreign water. The rights of reuse are very different for these two classes. The differences are examined in detail in the section on native and foreign waters.

Exchange of water has been practiced for many years and is an integral part of any appropriative system that maintains flexibility. Without the ability to exchange or transfer water, maximum utilization of the resource cannot be made. The reuse/exchange systems described in Chapter 2 would be difficult or impossible to carry out without the ability to transfer and exchange water. All of the following laws are from Article 83, "Exchange of Water". The first deals with transfers between streams.

> <u>37-83-101. Transfer from one stream to another--</u> Whenever any person or company diverts water from one public stream and turns it into another public stream, such person or company may take out the same amount of water again, less a reasonable deduction for seepage and evaporation, to be determined by the state engineer.

The next section is crucial to the full development of water resources. Early water rights were generally direct flow rights. Later irrigation companies irrigated land "higher up" but found inexpensive convenient reservoir sites at lower elevations. The reservoir-ditch exchange law allows waters stored in reservoirs in early spring to be exchanged for direct flow rights. The junior "higher up" irrigation company diverts based on the senior right while the senior irrigation company located further downstream in the basin takes reservoir water.

> <u>37-83-104. Reservoirs and ditches may exchange--</u> When the rights of others are not injured thereby, it is lawful for the owner of a reservoir to deliver stored water into a ditch entitled to water or into the public stream to supply appropriations from said stream, and take in exchange therefore from the public stream higher up an equal amount of water, less a reasonable deduction for loss, if any there be, to be

> determined by the state engineer. The person or company desiring such exchange shall be required to construct and maintain under the direction of the state engineer measuring flumes or weirs and self-registering devices at the point where water is turned into the stream or ditch taking the same or as near such point as is practicable so that the division engineer may readily determine and secure the just and equitable exchange of water.

Water rights may also be loaned on the same stream in order to save crops or maximize water use efficiency.

> 37-83-105. Owner may loan water right--It is lawful for the owners of ditches and water rights taking water from the same stream to exchange with, and loan to, each other, for a limited time, the water to which each may be entitled, for the purpose of saving crops or using the water in a more economical manner; except that the owners making such loan or exchange shall give notice in writing, signed by all the owners participating in said loan or exchange, stating that such loan or exchange has been made, and for what length of time the same shall continue, whereupon said division engineer shall recognize the same in his distribution of water.

4.4 Augmentation Plans

Another section of legislative law used frequently in water reuse proceedings deals with augmentation plans. The legislature has defined Plan for Augmentation as follows:

> 37-92-103. Definitions--"Plan for Augmentation" means 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 runoff but not adding to the existing supply of water.

Augmentation plans provide a mechanism for review of complex water projects and proposals by the State Engineer's Office and the courts. When used in conjunction with a reuse project, augmentation plans generally provide for alternate points of diversion in order to prevent injury to junior appropriators when water right uses or points of diversion are changed.

The City of Northglenn developed an augmentation plan for its reuse scheme. In the Northglenn case, water that was originally released to Dry Creek from Standley Reservoir for irrigation is now routed to the respective community for municipal uses. Any change in the hydraulic regime of a water system can harm downstream appropriators. An augmentation plan identifies the water rights directly involved in the plan, lists changes in the historic use pattern of those rights, and proposes remedial measures so that other appropriators will not be harmed. When native water is removed from one use and put to another use, such as agricultural water changed to domestic and industrial uses, the historic return flows from the agricultural use must be maintained to protect downstream junior appropriators dependent on those flows. This can be accomplished by returning wastewater at some lower point on the stream or purchasing additional water from another source to augment the system (Leonard Rice Consulting Water Engineers, Inc., 1978).

4.5 Condemnation of Water Rights

The Constitution of Colorado gives preference to domestic uses of water over agricultural use and agricultural use has preference over manufacturing uses. This statement of preferences has been interpreted to mean that municipalities can condemn agricultural and manufacturing water rights. As a result of a condemnation suit against Farmers Reservoir and Irrigation Company (FRICO) involving Westminister, Thornton and Northglenn, the State Legislature enacted laws (CRS38-6-201 to 216) regulating the condemnation process. The FRICO suit was settled out of court and resulted in the implementation of a sequential water reuse exchange plan.

The condemnation of water rights by a municipality involves three major steps. First, the municipality must prepare or update a community growth development plan and a detailed statement similar to an environmental impact statement listing alternatives and adverse impacts. Second, the water court must appoint a three person commission that prepares a report on the need for the condemnation. Third, a hearing is held on the report and if the solution proposed is not satisfactory a jury trial can be requested to resolve differences. The municipality may not condemn water more than fifteen years in advance of its needs.

4.6 The Adjudicative System of Water Rights

A water right is created by the diversion of unappropriated water and its application to a beneficial use. A judge then issues a decree that places the water right in the priority system. The system is one of water rights adjudication by judicial decree. Adjudication is a process of determining the facts and applying the appropriate rules to those facts.

The Water Rights Determination and Administrative Act of 1969 modified the judicial system by giving the State Engineer's Office more authority. Colorado now has six water divisions under the State Engineer's Office. Division Number One encompasses all of the South

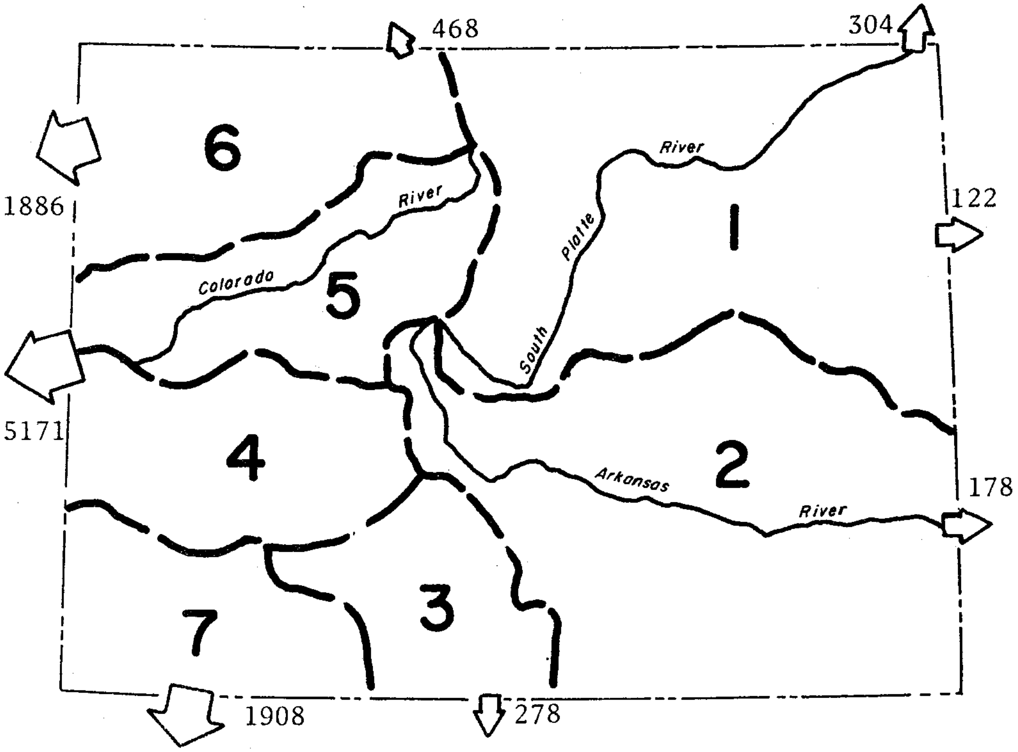
Platte River Basin and part of the Republican River Basin as shown in Figure 4-2. Each division has a water judge who can appoint referees as needed. In addition, each division office has a Water Clerk responsible for maintaining records. The Water Referee has the authority to rule upon water rights and is a member of the judicial system. Rulings by the referee can be appealed to the Water Judge. The ruling of the Water Judge can be appealed to the Colorado Supreme Court. The Water Referee or Water Judge rule upon all applications for water rights and water right changes involving surface water or tributary groundwater (Radosevich et al., 1976).

Colorado's water rights system is unlike other prior appropriation doctrine states in that neighboring states have an administrative adjudication process rather than judicial. The judicial adjudication system in Colorado has led to heavy emphasis on case law and a greater degree of uncertainty in the outcome of water rights filings.

4.7 Judicial Lawmaking

Every time a judge decides a case, he or she must interpret a statute or constitutional provision. When there is no law that directly applies, judges must base their ruling on the precedents established in a similar case. The tradition of judicial lawmaking comes from England where in early days most lawmaking was based on the judicial ruling on earlier precedents. The body of rules that evolved is known as common law.

Today, the State Legislature has enacted a large body of water law on which rulings are based. Legislative law dealing with water reuse is very limited. The only law directly affecting reuse was quoted earlier



COLORADO

STATE OUTFLOWS AND TRANS-MOUNTAIN DIVERSIONS AND WATER DIVISION BOUNDARIES

Figure 4-2. Colorado water division boundaries (League of Women Voters, 1975).

in this chapter. Unless additional laws are enacted, much of the law controlling water reuse will be made by the judicial system. Planned reuse is a new concept in Colorado. Many of the reuse proposals raise legal questions that are not covered by either legislative or judicial law. Referees and water judges are placed in the position of formulating water reuse law founded on limited legislative guidance and judicial precedent (Houghteling, 1968).

4.8 Water Reuse Case Law

A few legal cases are commonly referred to in papers concerning water reuse water law. These cases are identified and summarized here. The cases are later referred to in the text as needed. The summaries are extracted from the Pacific Reporter, except as noted.

4.8.1 City and County of Denver vs Fulton Irrigation Ditch Company (Pacific Reporter, 1973) - Reuse of Foreign Water

Denver, acting through its Board of Water Commissioners and the Adolph Coors Company, requested a judgement from the court to determine the validity of a water exchange agreement. The Supreme Court held that subject to contrary contractual obligations, Denver could reuse, successively reuse, or dispose of imported transmountain water as it pleased. The Court defined "reuse" as a subsequent use of imported water for the same purpose as the original use, "successive use" as a subsequent use for a different purpose; and "right of deposition" as the right to sell, lease, exchange, or otherwise dispose of effluent containing imported water after distribution through Denver's water system and collection in its sewer system.

The agreement between Denver and Coors proposed to replace water diverted by Coors on Clear Creek with Denver effluent from the Central Plant discharged to the South Platte River. The Denver-Coors agreement was declared invalid because of a preexisting 1940 agreement between Denver and ditch companies in the South Platte River Basin. In the 1940 agreement, Denver agreed it would not use or lease any water, irrespective of source, once used through its municipal water systems. The Court did not make a determination on whether the agreement applies to water that has been appropriated since the time the agreement was made.

The 1940 agreement is in conflict with the Blue River Decree. But since Denver did not request a declaratory judgement as to the validity of the 1940 agreement, in light of the Blue River Decree, none was made. The Court also found that Denver does not abandon or lose dominion over water distributed and subsequently collected and transported to its wastewater treatment plant.

4.8.2 Pulaski Irrigating Ditch Company vs City of Trinidad (Pacific Reporter, 1922) - Reuse of Native Municipal Effluent

The City of Trinidad wanted to sell its treated effluent to an irrigation company for application to cropland. The water used by the city was native in origin and had been discharged for many years to seepage pits beside the river. In 1917, the city started construction of two wastewater treatment plants and wanted to sell effluent from the plants. The plaintiffs contended that the wastewater returning to the river from the seepage pits was a return flow and that junior appropriators downstream had a right to the continuance of that return flow. The city claimed that by providing wastewater treatment, the water was salvaged or developed water and that other methods of treatment, such as evaporation, would have totally consumed the wastewater. Therefore, the wastewater effluent belonged to the city and the city could dispose of the water as the city saw fit.

The Court found that the city could not sell the treated effluent to the detriment of lower appropriators. Water taken from a stream by a city is not totally consumed by the municipal uses and the city is limited in its use to its actual needs.

4.8.3 Coryell vs Robinson (Pacific Reporter, 1948) - Independent Appropriation of Foreign Water

Coryell diverted seepage water from irrigation canals on the upper reaches of an adjoining watershed via three ditches constructed between 1910 and 1912. The diverted water was used for agricultural irrigation on Coryell's property. In 1930, a General Water Adjudication was conducted. Coryell's water rights were adjudicated junior to the defendents (Robinson). Coryell did not appeal the adjudication. In 1943 and 1945, the Water Commissioner released water from Coryell's ditches back into their native basin because Robinson's water rights were senior and were not being met. Coryell sought an injunction to prevent the Water Commissioner and/or Robinson from interfering with his water rights.

The Supreme Court denied Coryell's injunction request. The point pertinent to water reuse and the main point in the case was Coryell's contention that the water collected in Coryell's ditches was an independent appropriation of extraneous water from a foreign watershed. Therefore, Coryell's priorities are independent of Robinson. Also, additional waters due to seepage from irrigation with foreign water above Coryell's ditches were Coryell's to appropriate separately.

The Court found that Coryell had not, by his own labor or efforts, contributed extraneous water to the normal flow of the watershed. The water appropriated by Coryell belongs to the watershed and is subject to distribution according to the decreed priorities. Hickey (1965) in his article on reuse summed up the case as follows:

> ...Any prior and independent right to foreign water lay only in the person who had by his own labor and efforts contributed it to the normal flow of the watershed and hence, in absence of such effort on his part, Coryell the junior must defer to his seniors below under the regular order of appropriative right.

4.8.4 Brighton Ditch Company vs City of Englewood (Pacific Reporter, 1951) - Continuance of Foreign Water Importation

Englewood sought to change the point of diversion in a stream and to change the use of water from irrigation to domestic and municipal purposes. The lower court ruled in favor of Englewood. Brighton Ditch Company appealed to the Supreme Court. The Supreme Court held that the evidence sustained the finding that Brighton Ditch Company's vested rights would not be injured by the change of the point of diversion.

This case is cited in Denver vs Fulton as supporting the Court's inclination to favor extensive reuse of water. The Court held that appropriators on a stream have no vested right to the continuance of imported foreign water which someone else has brought into the watershed.

The Court also held that each of several water appropriators using a ditch in common may separately abandon his right to use the ditch and injury to one by virtue of the other's abandonment of all or part of the ditch by a change in the point of diversion or place of use is not an actionable injury. This point may be of importance in reuse cases where water rights for augmentation are purchased from a ditch company and water that formerly flowed in the ditch is subsequently discharged to a stream for augmentation.

4.8.5 Metropolitan Denver Sewage Disposal District No. 1 vs Farmers Reservoir and Irrigation Company (Pacific Reporter, 1972) - Maintenance of Points of Return Flow

MSDD No. 1 constructed a new facility for the treatment of wastewater collected in the Denver metropolitan area. The new facility and its outfall were moved several miles downstream of the old outfall. The Burlington Ditch headgates, owned by Farmers Reservoir and Irrigation Company (FRICO), were located below the old facility but new wastewater treatment plant outfall. Flow in the South Platte River is not sufficient to meet the water rights on the Burlington Ditch with MDSDD No. 1 effluent. Therefore, FRICO sought to have the effluent from the wastewater treatment facility placed on the river above its headgate. The lower court ruled in FRICO's favor and MDSDD No. 1 appealed the decision to the Supreme Court.

The Supreme Court held that there is no vested right in downstream appropriators to the maintenance of the same point of return of irrigation wastewater and that the same rule applies to sewage effluent from a municipality or sanitation district. The Court pointed out that changes in the points of return of wastewater are not governed by the same rules as changes in points of diversion. An appropriator can change the point of diversion only if injury is eliminated to other appropriators.

4.8.6 City of Boulder vs Boulder and Left Hand Ditch Company (Pacific Reporter, 1977) - Reuse of Native Effluent by Municipalities

Boulder filed a complaint against the ditch company seeking an injunction against the transportation of water for use in another watershed. The Supreme Court decided that relief could be granted on the theory that a change of the place of irrigation would eliminate return flows and cause harm to the City of Boulder.

The Court defined return flows and wastewater in a manner that separates the two. "Return flow" is not wastewater but is irrigation water seeping back to a stream by percolation after it has been used for irrigation. "Wastewater" is defined as waters which escape without actually being used to irrigate crops and "an appropriator of wastewater cannot obtain a right against water wasters to compel continuation of the wastewater discharge." Wastewater, according to Ward Fischer, includes sewage effluent by the court's definition. Since the discussion of wastewater and return flows was not directly related to issues in the case, the Court may have been providing a precedent for future cases involving the reuse of wastewaters (Fischer, 1973). Jankowski (1978) views muncipal effluents as return flows rather than wastewater because "Logically, only water which is not beneficially used is waste...Having been beneficially used, effluent water would seem most logically classed as return flows." These two views are comflicting. Fischer's is favorable to the reuse of municipal wastewater while Jankowski's is not.

4.8.7 Cache la Poudre Water Users Association vs Glacier View Meadows (Pacific Reporter, 1976a) - Augmentation Plans

Glacier View Meadows is a mountain subdivision development located in the Cache la Poudre River Basin. Glacier View planned to provide a water supply by using junior wells diverting out of priority. Consumptive use resulting from the use of the well-water was to be replaced by releases to the stream from senior reservoir rights purchased by Glacier View. The Water Users Association objected to the augmentation plan on a number of points. The central issue was the validity of applying the augmentation plan concept to a residential development. Key points in the Water Users Association arugment were that: (1) 100% of well-water should be replaced, (2) the historic return flow pattern of the augmentation water to the stream would be altered, (3) the hydrologic and geologic analysis for the augmentation plan was too uncertain, and (4) the river was already overappropriated.

The lower court had upheld the augmentation plan and the Supreme Court affirmed that decision with some modifications. Modifications were related to procedures concerning the well permits. The case showed that an augmentation plan could be used for residential development leading to a more intensive use of water as long as no injury could be shown to senior water users (Jankowski, 1978).

4.8.8 Kelly Ranch vs Southeastern Colorado Water Conservancy District (Pacific Reporter, 1976a) - Augmentation Plans

This case is similar to the Cache la Poudre Water Users Association vs Glacier View Meadows. Kelly Ranch was a residential developer proposing to furnish a water supply from out of priority well diversions.

An augmentation plan to replace the water consumptively used was proposed. Consumptive use from the well diversions would be replaced with water that had historically been used to irrigate 14 acres of native hay. The conservancy district objected on many of the same points as Glacier View.

The Supreme Court reversed the lower court decision and ruled in favor of Kelly Ranch. Key to the decision was: (1) an augmentation plan is not the same as a decree for a diverted right and that the amount diverted should not be placed in the sequence of priority behind senior rights, (2) the augmentation plan could make allowance for return flows from the residential development, and (3) the proponent of the augmentation plan must prove the amount of return flow from the in-house use of water withdrawn from the wells (Hutchins, 1976).

4.8.9 Farmers Highline Canal and Reservoir Company vs City of Golden (Pacific Reporter, 1954) - Transfer of Water Rights

The City of Golden purchased water rights adjudicated to Swadley Ditch out of Clear Creek. The Swadley Ditch headgate is five miles upstream from the reservoir company headgate on the Church Ditch. Golden proposed to change the point of diversion from Swadley Ditch to Golden's water treatment plant and the water use from agricultural to municipal. The reservoir company appealed the lower court decision approving the transfer on grounds that injury to downstream appropriators would result. The Colorado Supreme Court ruled in favor of the reservoir company.

The Supreme Court decision was based on the grounds that no injury must occur to downstream junior appropriators due to a change in the point of diversion and use. The Court made the following statement:

> Where it appears that the change sought to be made will result in depletion to the source of supply and result in injury to junior appropriators therefrom, the decree should contain such conditions as are proper to counteract the loss, and should be denied only in such instances as where it is impossible to impose reasonable conditions to effectuate this purpose...What conditions and limitations should be imposed depend upon the facts and surrounding circumstances in each particular instance...It is the purpose of the law, both statutory and by decision, to protect all appropriators and holders of water rights; to this end all elements of loss to the stream by virtue of the proposed change should be considered and accounted for; and thereupon such appropriate provisions of limitation inserted in the decree as the facts would seem to warrant.

4.8.10 Comstock vs Ramsey (Pacific Reporter, 1913) - Water Rights Dependent on Return Flows

The owner of a tract of land along the banks of the South Platte River east of LaSalle constructed a drainage ditch to capture and return seepage flows flooding the land back to the river. The seepage flows were caused by the construction of irrigation ditches and irrigation of land on a bench above the river land. The owner of the drainage ditch subsequently sold the rights to water collected in the drainage ditch to Ramsey. Ramsey used the South Platte River to transport the water to the headgates of another ditch further downstream and diverted the water for application to Ramsey's previously dry grazing land. Between the point where the drainage ditch emptied into the river and where Ramsey desired to divert the water there were a number of ditches with adjudicated appropriations. These ditches were supplied with water that seeped back to the river after the entire surface flow had been diverted into ditches further upstream. The drainage ditch intercepted a portion of these seepage flows returning to the river.

The lower court had ruled in favor of Ramsey but the Supreme Court reversed the lower court decision.

> There is no law anywhere to support the contention that if these waters are naturally tributary to the river, still they may be taken by a new claimant to the damage and injury of prior appropriators upon that stream, simply because he captures and diverts them before they actually get into the river channels...appropriators of water out of a natrual stream for irrigation purposes, with priorities decreed, are entitled to have the conditions substantially maintained upon the stream as they were when the appropriations were made...

Trelease (1974) sums up this case as follows:

> Comstock vs Ramsey...is the leading case holding that _return flow_ seeping from the lands of a prior appropriator cannot be intercepted and reused on _different lands_ when water is tributary to the stream and junior appropriators have relied on it to serve their ditches downstream from the point of reentry.

4.9 Foreign Water and Reuse

Foreign waters are defined as "those waters which are taken from one watershed for use in a different drainage basin and are not naturally a part of the water supply in the area in which they are used" (Trelease, 1974). The legislature, as discussed earlier, has enacted a specific law on the "right to reuse of imported water" authorizing the importer to make a succession of uses or reuse of foreign water. The application of this law was tested in Denver vs Fulton when the Court upheld Denver's right to make successive use, reuse, or exercise the right of disposition of its foreign waters.

Although Denver vs Fulton authoritatively states that foreign water can be reused, the case does not specifically answer the question of whether the right to reuse of foreign water can be abandoned. The reuse of foreign water can be divided into three categories:

1. The appropriator of foreign water imported into the basin for many years can claim at any time return flows being used by junior appropriators downstream. The concept of water reuse abandonment does not apply.
2. Return flows from foreign water imported into a basin for a long period of time can be claimed by the appropriator only if the appropriator intended to reuse or make successive use of the return flows at the time the foreign water was imported. Abandonment of the right to reuse can occur if the importer did not originally intend to reuse the water.
3. The right to reuse foreign water is abandoned if the reuse does not commence at the time the foreign water is first imported.

Number three can be discarded immediately. The court, in Denver vs Fulton, declared that Denver should reuse its foreign water in the future and that it had planned to do so, possibly from the first diversion of foreign waters. The Court did not, however, rule on the issue of abandonment of foreign waters as outlined in item two. The Court dodged the issue. This is clear from the Court's statement, cited below (Pacific Reporter, 1973):

> Denver made quite a good record to the effect that it has never intended to abandon any imported water and that, possibly since its first transmountain diversion, it has had in mind for the future the reuse, successive use and disposition after use of

> foreign water. Since the trial court did not pass upon the issue of abandonment except in the narrow area above indicated, we do not believe that the issue of abandonment should become res judicata with this opinion, except as to our ruling that the delivery of sewage and effluent to Metro does not constitute abandonment for reasons other than delivery to the Metro plant, it will have to be in another proceeding.

The Colorado Supreme Court did, however, choose to include in their ruling a quote from Stevens vs Oakdale Irrigation District (Pacific Reporter, 1939):

> Waters brought in from a different watershed and reduced to possession are private property during the period of possession. When possession of the actual water, or corpus, has been relinquished, or lost by discharge without intent to recapture, property in it ceases. This is not the abandonment of a water right but merely an abandonment of specific portions of water, i.e., the very particles which are discharged or have escaped from control.

The Court neither accepted nor rejected this California ruling but the inclusion of it may indicate their future direction.

The Court also made the following statement regarding more efficient and intensive use of foreign water (Pacific Reporter, 1973):

> In order to minimize the amount of water removed from Western Colorado, Eastern Slope importers should, to the maximum extent feasible, reuse and make successive use of the foreign water. This goal was recognized in the decree of the District of Colorado which fixed the priorities of Blue River water imported by Denver and the City of Colorado Springs.

The Court would appear to be leaning in the direction of the number one classification cited above. It appears that appropriators of foreign water can reuse return flows regardless of their initial intent concerning reuse when importation first began.

4.10 Legislative Constraint on Reuse

The last sentence of Section 37-82-106 on the Right to Reuse of Imported Water reads: "Nothing in this section shall be construed to impair or diminish any water right which has become vested." Does this quote mean that the concept of reuse abandonment should be recognized? Ward Fischer (1973) has this to say about the quote:

> There is no unanimity of view among the Colorado water bar as to the meaning and intent of this sentence. The importer will argue that the downstream appropriator who has been using the water has no legal "rights" which can be impaired if the importer, even after a long delay, sells the water to others or uses it himself. The downstream appropriator will, of course, argue to the contrary.

4.11 Old and New Foreign Water

The leaning of the Court in the direction of not recognizing the abandonment of the right to reuse has been confused by the adoption of terms "old" and "new" foreign water. These terms have been used to decide which water will be available for reuse in the proposed Rawhide Power Generation Plant to be built north of Fort Collins. In an agreement between the City of Fort Collins, Platte River Power Authority, and the Water Supply and Storage Company, return flows from new foreign waters are to be piped to the Rawhide Plant for use as cooling water. The foreign water will first be used in the Fort Collins municipal water systems and then be collected and treated at the wastewater treatment plant. Old foreign water is to be discharged to the Cache la Poudre River, as has been done in the past.

The agreement describes this artifical separation in Section 7, as quoted below (City of Fort Collins, 1978):

> Water Company and Fort Collins recognize that each of them could, under the law, make claim to all of the benefits provided by the above statute in relation to all of said waters (Section 37-82-106, Right to Reuse of Imported Water). However, both Water Company and Fort Collins also recognize that certain volumes of foreign water have been imported into the Poudre Basin for a great many years, and that there has been historic reliance upon the return flows from those waters so historically imported. In recognition of this historic reliance, and in order to insure that no other water user suffers any injury whatsoever, the parties have agreed that the foreign waters should, for purposes of this Agreement, be further defined as "old" foreign and "new" foreign waters.
>
> a. "Old" foreign water is that volume of foreign water which has, for a great many years, been imported into the Cache la Poudre River Basin, has been used for irrigation within the Cache la Poudre Basin, and the return flow of which has been available to other water users of the Cache la Poudre Basin.
>
> b. "New" foreign water is that volume of foreign water which has only recently, or will in the future, be imported into the Cache la Poudre in excess of the waters which constitute the "old" foreign waters.
>
> Fort Collins and Water Company concur that if the plan for reuse of foreign water is confined to the "new" foreign waters, other water users of the Cache la Poudre Basin will necessarily conclude that they will in no way be injured by implementation of the plan as expressed in this contract. It is therefore their intent to limit the plan contemplated by this Agreement to the reuse of new foreign waters, without affecting their rights, if any, to make a succession of uses of all foreign waters.

Ward Fischer, acting as attorney for both the City of Fort Collins and the Water Supply and Storage Company, was responsible to a large degree for the authorship of the agreement. In a supporting document on water reuse, Mr. Fischer concluded that "the concept of reuse abandonment will be rejected in spite of some rather compelling arguments that can be advanced on its behalf" (Fischer, 1973).

4.12 Native Water and Reuse

Native water is water that occurs naturally within the drainage basin in which the appropriation is being made. In Colorado, native water includes both surface water and groundwater tributary (hydraulically connected) to the surface water system.

Under the appropriation doctrine, water is appropriated for a certain use. Once that use has been served, the remaining water must be allowed to return to the stream for use by appropriators downstream. In this manner downstream appropriators can establish junior water rights that are dependent on return flows from senior upstream appropriators. A municipality cannot suddenly decide to reuse its return flows from native water use. The reuse would deprive downstream appropriators of their legally adjudicated water rights.

In Pulaski Irrigating Company vs City of Trinidad, the city wanted to sell wastewater treatment plant effluent to a local irrigation company. The downstream appropriators (Pulaski) would have been deprived of historically established return flows. The Court ruled that purified wastewater is not developed water and that when a use has been completed the user's right terminates.

Judicial law prohibiting the reuse of return flows from native waters by municipalities is not completely clear. The sale of treated wastewater to a downstream irrigation company, as in the Pulaski case, would certainly be ruled against by the Court. A situation where a municipality would retain possession of its wastewater by not discharging to a stream, but recycling the wastewater within the system is not clear. Irrigators are allowed to capture runoff from their fields and reapply the water on their land as the runoff is captured before entering the lands of others (Radosevich et al., 1976). Applying the same logic to a municipality would enable the municipality to reuse native water as long as it did not relinquish possession of the water. This line of logic has been strengthened in Boulder vs Boulder and Left Hand Ditch Company. If municipal wastewater was classified as "wastewater" according to the court decision, appropriators of the "wastewater" could not obtain a right against "water wasters" to compel continuation of the discharge. Municipalities could, under this interpretation, reuse wastewater within the same municipal system.

4.13 Transfer of Water Rights and Consumptive Use

Plans for reuse often involve the sale and transfer of water rights. The principle behind transfer of water rights is that appropriators on the stream from which the transfer is being made must not be injured by the transfer. In practice, only the portion of the water rights that is consumptively used is available for transfer. Losses in transport of the water to its location for use must also be taken into account. Water lost in transit is not available for transfer. Changes in the use of water, even if in the same physical location, must not consumptively use more water than in the prior use. Farmers Highline Canal and Reservoir Company vs. City of Golden outlines these principles.

Transfer of water usually involves changes in use from agricultural use to municipal or industrial use. Since only the consumptive use portion of the water right can be transferred, the new user should be able to totally consume the transferred water. In many cases, municipalities have purchased and transferred a water right and put it to municipal use.

Since municipal use only consumes 40% to 50% of the water, can a municipality later decide to reuse that portion of the water that it has been returning to the stream? Logically, since the municipality was allowed to transfer only the consumptive use portion of the water right, the municipality should be allowed to reuse the return flows. The downstream appropriator has done nothing to augment his water supply and any return flows he receives are due to the efforts of the municipality. The courts have not yet heard a case involving this issue.

4.14 Changes in the Location of a Municipal Discharge

Construction of new wastewater treatment facilities often involves the relocation of the plant. The relocations are necessary because regionalization of wastewater treatment, growth downstream from the existing facility, or physical expansion of the treatment facility require more room than is available at the existing site. Changes in the location of wastewater treatment facilities generally involve the movement of the facility downstream. Appropriators on the stream who relied on the municipal effluent for water may not be above the new effluent discharge location. In Metropolitan Denver Sewage District No. 1 vs. Farmers Reservoir and Irrigating Company, the court ruled that as long as the change in point of return flow discharge is done without malice, the change in location is permissible. Downstream appropriators have no vested right to the continuance of the same point of return flow.

4.15 Storage Rights vs. Direct Flow Rights and Reuse

Storage rights are treated very differently than direct flow rights under Colorado water law. Direct flow rights are for water diverted from a stream and put to use in a short time period. Water diverted for a storage right can be placed in a reservoir and held for release at some later point in time.

The right to store water is limited by state statute. Storage rights, by law, are junior to all direct flow rights with dates prior to April 18, 1935. Water cannot be diverted to storage if all direct flow rights dated prior to April 18, 1935, are not being met with the streamflow. Only flows above the needs of the direct use diverters may be placed in storage.

> 37-87-101. Right to store waters. Persons desirous to construct and maintain reservoirs for the purpose of storing water have the right to store therein any of the unappropriated waters of the state not thereafter needed for immediate use for domestic or irrigating purposes, and to construct and maintain ditches for carrying such water to and from such reservoirs, and to condemn lands required for the construction and maintainence of such reservoirs and ditches in the same manner as now provided by law; except that after April 18, 1935, the appropriation of water for any reservoirs hereafter constructed, when decreed, shall be superior to an appropriation of water for direct application claiming a date of priority subsequent in time to that of such reservoirs.

Since no specific time table for application to beneficial use is applied to storage rights, water diverted under a storage right may be held over from one year to the next (Leonard Rice Consulting Water Engineers, Inc., 1978). The owner of the storage right, therefore, has complete control over the stored water and can release water in a manner to effect 100% consumption. In addition, because no set pattern of release is required, downstream appropriators cannot claim a legal right to return flows. If these assumptions are correct, water derived from storage rights, even though native in origin, could be reused without downstream appropriators having a valid objection to their reuse (Simpson, 1979).

Another viewpoint that could restrict the reuse of stored water exists. If a change in use or place of use were proposed, the historic consumptive use of that water cannot be changed. Storage water is often used to supplement water supplies in years of lower than average precipitation. Use of stored water for municipal purposes entailing reuse would remove return flows and deny downstream appropriators of a water source historically available during dry years. The Supreme Court has not ruled on this issue so no judicial precedent is available (ARIX, 1979).

4.16 Colorado Big Thompson Project and Reuse

The Colorado Big Thompson Project (CBT) imports an average of 230,000 acre-feet annually into the South Platte River Basin through the Adams Tunnel under Rocky Mountain National Park. Since CBT water is foreign in origin, it would normally be available for reuse by the importers. This is especially important since several Front Range municipalities own substantial quantities of CBT shares, as shown in Table 4-1.

CBT water is not, however, available for reuse because of provisions in an agreement between the U.S. Bureau of Reclamation and the Northern Colorado Water Conservancy District, dated July 5, 1938. The following sections from the contract state the restriction (Northern Colorado Water Conservancy District, 1938):

Table 4-1. Colorado Big Thompson Shares Owned by Front Range Municipalities*

City	Shares Owned**	Acre-Feet (Dry Year)	
		@ 0.75/share	@ 1.0/share
Boulder	20,636	15,477	20,636
Fort Collins	10,530	7,898	10,530
Greeley	15,160	11,370	15,170
Longmont	9,700	7,275	9,700
Loveland	8,900	6,675	8,900
TOTAL	64,926	48,695	64,926

* Source: Northern Colorado Water Conservancy District, 1980.
**Each share is worth 0.75 to 1.0 acre-feet in a dry year and 0.60 to 0.80 acre-feet in an average year.

> 16...(T)he District shall have the perpetual right to use all water...that becomes available through the construction and operation of this project, for irrigation, domestic, municipal, and industrial purposes... [with certain exceptions not here relevant]
>
> 19. The District will cause all water filing for the project made in its name or in its behalf to be assigned to the United States...There is also claimed and reserved by the United States for the use of the District for domestic, irrigation and industrial uses, all of the increment, seepage, and return flow water which may result from the construction of the project and the importation thereby, from an extraneous source, to-wit from the Colorado River watershed, of a new and added supply of water to average 320,000 acre-feet or more annually, into the stream of the South Platte watershed from which the irrigable lands within the District derive their water supply; and the right is reserved on behalf of the District to capture, recapture, use, and reuse the said added supply so often and as it may appear at the stream intake headgates of ditches and reservoirs serving lands within the District. Said captured, recapture, and return flow water shall be, by the Board of Directors of the District, allocated only to the irrigable lands within the District already being partially supplied with water for irrigation, using as a basis for such allocation the decreed priorities existing at the date of this contract, and without other or additional consideration of payments by the owners of such lands therefore; provided no such captured, recaptured, or return flow water shall be taken and held as supplying any appropriation or decreed priority of any such ditch or reservoir.

Reasons for the restriction are given in a history of the Northern Colorado Water Conservancy District (Dille, 1958).

> This disposition of the expected return flows from the project supplies was one of the difficult problems. Some of the Bureau officials believed that the District should collect revenue from the beneficiaries of these flows, if only to strengthen its repayment ability. The District negotiators felt that such a plan would conflict with recognized state laws and also be impracticable of administration and enforcement.
>
> The state courts have repeatedly ruled the return flows belong to and are a part of the stream and cannot be recovered by the original appropriator. Briefly, therefore, Article 19 of the contract provides that any

> rights claimed by the United States, as a legal appropriator of the Colorado River water, to the seepage and return flows from the project supplies are reserved to the District for recapture and use.
>
> The Article further provides that the Board of Directors of the District shall allocate the return flows to the irrigable lands already being partly supplied, using as a basis the existing decreed priorities and without additional payments by the owners of the lands.
>
> In effect, this important provision determines that the return flows shall become part of the streams, subject to state administration, and also forestalls any possible future interference by federal agencies in state control of the water supplies.
>
> Therefore, the direct allottees pay the only water assessment and the secondary users obtain the benefits of the return flows with no costs except, of course, the payment of the mill tax on the assessed value of their property.

Mr. Dille's interpretation of state law in the second paragraph is not entirely correct. Return flows belong to the stream only if they originate from waters native to the basin. CBT water is imported from the Colorado River Basin. Return flows from foreign water can be recaptured and reused. The District has reserved the right to "capture, recapture, use and reuse" the return flows. Based on this, then, it appears that the District could choose to make reuse of return flows. Reduction of return flows would have negative effects in the lower part of the District where irrigators make use of the return flow. These secondary irrigators do not pay a direct water assessment but do pay a mill tax on their property.

4.17 Blue River Decree

In 1955, the United States District Court of Colorado issued a consent decree requiring Denver to make use of return flows from foreign water obtained from the Blue River. The decree is commonly called the Blue River Decree. The decree fixed priorities of Blue River water imported by Denver and the City of Colorado Springs. An additional purpose of the decree was to assure that no more water than absolutely necessary was diverted from the Colorado River Basin to the Eastern Slope.

The Blue River Decree was referred to in the Denver vs. Fulton case reviewed earlier. Importation of foreign water is to be minimized through the reuse and successive use of foreign water. The Colorado Supreme Court has reaffirmed this purpose and the State Legislature has put it into law. Questions do arise, however, concerning whether Colorado River water imported by Denver can be exchanged after municipal use for agricultural water. In order to understand the Blue River Decree the historical perspective must first be established (U.S. District Court, 1958).

> <u>Findings of Fact and Conclusions of Law--History of Litigation:</u>
>
> (1) The case of the United States of America vs Northern Colorado Water Conservancy District, et al., was initiated in this court on June 10, 1949. Involved in this action are the respective rights to the use of water in the Colorado River and its tributaries and the Blue River and its tributaries of the United States of America, Northern Colorado Water Conservancy District, the Colorado River Water Conservation District, the Palisade Irrigation District, the City and County of Denver, the City of Englewood, the City of Colorado Springs. Originally named in the cause were the Public Service Company of Colorado and the South Platte Water Users Association. The Public Service Company of Colorado has been dismissed without prejudice. Also involved are the rights to the use of water of the City and County of Denver from and in the South Platte, Fraser and Williams Fork Rivers, and their respective tributaries.
>
> (2) The United States of America in initiating Civil Action No. 2782 sought to have its rights to the use

of water in the Colorado River and its tributaries quited against the adverse claims of the City and County of Denver, the City of Colorado Springs, the South Platte Water Users Association and the Moffat Tunnel Water and Development Company, predecessor in interest of the City of Englewood. It is likewise sought to have declared in regard to the other parties defendent the validity of Senate Document No. 80, 75th Congress (authorization of Colorado Big Thompson Project), First Session, and to have construed certain features of that document."

Stipulation of October 5, 1955, Filed with This Court on That Date and the Amendment to That Stipulation, Dated October 10, 1955: In an effort to resolve the conflict among the parties to these consolidated cases extensive conferences have been held. The result of those conferences has been an agreement among the parties pursuant to which the respective rights have been set forth and the basis of an amicable settlement declared. There follows a verbatim copy of the Stipulation, together with a copy of the Amendment to it:

Stipulation: The parties through their respective counsel, hereby stipulate and agree as follows:

3. ...It is further stipulated and agreed by and between the parties to this case that the City and County of Denver and the City of Colorado Springs are in need of adequate supplies of water for municipal purposes both present and future. Likewise recognized by the parties is that the Blue River constitutes a source of supply to which each must look in the future if the respective municipalities are to reach their greatest potential.

4. Notwithstanding their priority dates, the parties hereto further stipulate and agree that the parties to this cause will recognize the right to divert Blue River water by the City and County of Denver and the City of Colorado Springs for municipal purposes only, including domestic, industrial, yard, ground, and park care, storage, fire, sewage, military and governmental excluding, however, water for purposes of irrigation for agriculture, their rights as set forth in the decrees entered by the District Court of Summit County, Colorado, Water District No. 36, Civil Actions Nos. 1805 and 1806, which are part of the record in consolidated Cases Nos. 5016 and 5017; subject nevertheless to the following limitations:

> (a) The rights of the City and County of Denver and the City of Colorado Springs <u>are limited solely to municipal purposes</u> herein described and subject to the rights of the United States of America to fill each year the Green Mountain Reservoir to capacity of 154,645 acre-feet for utilization by the United States of America in accordance with the "Manner and Operation of Project Facilities and Auxiliary Features," contained in Senate Document No. 80, 75th Congress, First Session.
>
> (e) To the extent that the importation and the use of water from the Colorado River System, over and above the quantity of water diverted from that source during the last year being October 1st, 1954 to September 30th, 1955, <u>by reason of the return flow from the municipal systems</u> of said cities increase the amount of water said cities may lawfully utilize from all sources in order to supply their municipal needs, <u>through exchange or otherwise</u>, to that same extent the right to divert water from the Blue River shall be correspondingly decreased, if such exchange is not exercised; provided, however, that the obligation to utilize water from the Colorado River System by exchange or otherwise shall be subject to the conditions, limitations, and safeguards, as set forth in the following subdivision, the same being subdivision (f) of this paragraph.

Denver is required to prepare an annual report to the Secretary of the Interior showing its efforts to make use of return flows. The intent is to minimize the importation of Colorado River Basin water and this intent is reiterated throughout the agreement.

> (f) In order to accomplish the objectives set forth in the immediately preceding subdivision hereof, the same being lettered (e), each city undertakes and exercise due to diligence within legal limitations and subject to economic feasibility. To that end, the City and County of Denver and the City of Colorado Springs shall, respectively, submit to the Secretary of the Interior on or before December 31st of each calendar year, beginning with the year 1957, a report showing by months for the water year ended September 30th last past, the quantities of water diverted by the reporting city from the Colorado River System, and whether and to what extent such water was used directly or placed in storage. After

each city commences use of Blue River water said report shall also show by months for the same period the quantities of return flow from their municipal uses of such Colorado River water accruing to the South Platte River and to Fountain Creek, respectively, as measured at the gauging stations provided for herein. Each such report shall also show what steps, by legal action or otherwise, the reporting city has taken during the period covered by the report to utilize such return flow by exchange or otherwise to the extent water of the Colorado River System is included therein, so as to reduce or minimize the demands of such city upon Blue River water. The United States of America reserves the right, at any time after use of Blue River water commences hereunder, to apply to this. . .Court for injunctive or other remedial orders, suspending or proportionately reducing diversions or imposing conditions upon the taking of Blue River Water by the particular city, if the United States shall establish as a fact that the particular city has failed to exercise due diligence in taking, with respect to return flow of water of the Colorado River System, all steps which, in view of legal limitations and economic feasablity, might reasonably be required of such city in establishing, enforcing, utilizing, or operating a plan designed to accomplish said reduction by such city of its Blue River water use.

(g) The City and County of Denver and the City of Colorado Springs will utilize Blue River water for municipal purposes and no other within their metropolitan areas. Such metropolitan areas shall be limited to such an area as is reasonably integrated with the development of Denver or Colorado Springs, as the case may be. To the extent that those municipalities utilize water beyond their respective metropolitan areas from sources other than the Blue River, or lease or permit others to utilize waters from other sources for purposes other than municipal in character, the Blue River water diversions will be reduced pro tanto. Provided that the limitations in the subparagraph shall not apply in the case where electrical energy is produced by such water as an incident to its use for municipal purposes."

The Denver Water Board has intepreted the decree as prohibiting the exchange of return flows for agricultural purposes. In several places, (where emphasis is added) the decree states that Blue River water is to be used solely for municipal purposes and not for agricultural irrigation. Paragraph (g) states that Denver "will utilize Blue River water for municipal purposes and no other within their metropolitan areas." The question of interpretation that arises is whether these use restrictions apply to use of the return flows from Blue River water as well as the first municipal use. The intent of the decree regarding the first use of Blue River water is explicit--municipal use only. The use of return flows is not nearly so clear. Steve Work of the Denver Water Board has written "use of water derived from the Colorado River or its tributaries for agricultural purposes within the areas served by Denver is prohibited by the Blue River Decree" (Work and Hobbs, 1976). Others might interpret the decree differently.

4.18 Water Quality and Prior Appropriation Doctrine

A separate body of law relating to water quality exists at the state and federal levels. These laws are not, however, integrated into the water rights system. State water quality legislation and appropriative water law are two separate bodies of legislation administered by separate agencies. Water reuse proposals, by their very nature, involve complex water law and water quality problems. Current practice is to handle water quality and water law problems separately.

The appropriative doctrine does, however, address water quality to a limited extent. Problems of water quality are restricted to cases involving appropriators and their uses of the water. No general law applying to instream quality exists in the prior appropriation doctrine. Water quality is a consideration only as it applies to appropriators and not the aquatic system.

The appropriation doctrine affords limited protection to both junior and senior appropriators. An upstream appropriator whose use of the water subsequently harms or restricts the beneficial use of a downstream appropriator can be required to cease his polluting activities. The appropriator harmed by the pollution can institute a civil adversary action for the taking of his property right (Radosevich et al., 1976). The State Engineer does not become involved in these actions. Although the appropriation doctrine establishes water quality as part of the water right, the remedy is separate civil actions--hardly an efficient or effective means of controlling water pollution.

4.19 Interstate Compacts and Interstate Litigation Affecting Water Allocation in the South Platte River Basin

All compacts and litigations have significant quantitative effects on reuse potential in the South Platte River Basin. These documents place upper limits on the amount of water that can be imported or lower limits on the flow leaving the basin. Unlike native waters, imported or foreign waters can be reused until totally consumed. Upper limits placed on the importation of foreign water limit future imports and water reuse.

The legal documents are listed in Table 4-2. All of these documents are assembled in Radosevich (1975).

The most important of these documents are those controlling the allocation of water on the Colorado River and the South Platte River

Table 4-2. Interstate Compacts and Litigations

Colorado River Compact

The Upper Colorado River Compact

The Mexican Treaty of Rio Grande, Tijuana, and Colorado Rivers

North Platte River Decree (325 US 589, 1945)

Laramie River Decree (353 US 953, 1957)

Arkansas River Compact

South Platte River Compact

Compact. The upper limits on imports into the South Platte River Basin from the North Platte, Laramie, and Arkansas river basins have been nearly reached. The import of additional quantities of water from these basins is likely to be relatively small in volume.

Imports from the Colorado River Basin average approximately 350,000 acre-feet annually. This amount could increase to 700,000 acre-feet by the year 2020 (Hendricks, 1977). The import of additional water from the Colorado River Basin is becoming more difficult. Absolute upper limits in Colorado's use of Colorado River water cannot be predicted due to legal battles over the interpretation of the Colorado River compacts and the treaty with Mexico. Energy development in western Colorado is projected to use large quantities of water. Because of uncertainty related to these treaties and compacts, energy development, recreational development, and environmental concerns, western Colorado interests strongly oppose the export of additional Colorado River water.

The potential limit for the development of additional South Platte River water does exist under terms of the 1923 South Platte River Compact. Between April 1 and October 15 of each year, Colorado cannot permit diversions on the South Platte between Balzac and the Nebraska-Colorado state line with priorities subsequent to June 14, 1897, to diminish mean flow at the state line to less than 120 cfs. This amounts to approximately 47,000 acre-feet during an average year. The average annual runoff to Nebraska between 1947 and 1974 was 370,200 acre-feet. In 1973, a wet year, 1,249,000 acre-feet, and in 1954, a dry year, 75,550 acre-feet flowed into Nebraska (Hendricks, 1977). The compact allows for the development of all flows above the 47,000 acre-foot annual figure. This amounts to 323,000 acre-feet during an average year. Because of the difficulty associated with capturing peak flood flows, Colorado could probably economically develop considerably less than the 323,000 acre-feet annually. The Bureau of Reclamation's proposed Narrows Dam and groundwater storage proposals have been advanced to make use of this "excess" water that flows into Nebraska.

4.20 Summary

Water law plays an extremely strong role in shaping water reuse forms. Interpretation of the law is not clear, however, when applied to the many different situations that arise in specific water reuse projects. Based on existing water reuse law, only a few general statements can be made concerning the reuse of return flows: (1) foreign water return flows are reusable, (2) return flows from the use of native direct flow water rights are not generally thought to be reusable, (3) reuse of return flows from native storage water rights is in a gray area of uncertainty, and (4) CBT water return flows, although foreign in origin, are not reusable.

Perhaps more important than these general conclusions is the course of action or non-action taken by the State of Colorado. A single paragraph of legislative law addresses water reuse. Many legal issues not addressed by this law are being raised by the proponents of future reuse projects. The State Legislature can direct the course of water reuse through the enactment of legislation on reuse or the water courts will determine reuse policy on the basis of precedent and case law.

CHAPTER 5

WATER REUSE ECONOMICS

The selection of a project alternative for implementation is often a controversial process. Through the years several methods of economic analysis have been devised to provide the decision maker with evaluative criteria on which to base decisions. These criteria, called objectives, are in the categories of economic, environmental, and social well being. This chapter focuses on the economic methods of developing evaluative information on municipal water reuse projects.

Water reuse projects for municipalities combine both water supply and wastewater treatment purposes. Both multiple purpose and single purpose projects can be analyzed using cost-effectiveness, benefit-cost, and marginal analysis methods. The cost-effectiveness method has been used almost universally by municipalities to select the best single or multiple purpose alternative (Duckstein and Kisiel, 1977). This type of analysis provides the decision maker with information on the monetary costs of designing, constructing, and operating each of the alternatives. It provides no information on the monetary benefits associated with the project purposes.

In this chapter, the benefit-cost method of analysis is proposed for use in evaluating: (1) the water supply purpose of water reuse projects, and (2) single purpose water supply alternatives. The cost-effectiveness method is used to evaluate the wastewater treatment purpose of both water reuse alternatives and single purpose wastewater treatment alternatives.

Prior to making the above analysis, each of the economic methods of analysis is reviewed and compared. EPA's municipal grant cost-effectiveness procedures are then reviewed as they apply to water reuse projects. The cost-effectiveness method used by municipalities for evaluating water supply alternatives is shown to lead to oversizing of the project. Benefit-cost analysis is proposed for use in place of cost-effectiveness procedures. In the last section of this chapter, a methodology is proposed for the economic evaluation of water reuse projects.

5.1 Methods of Economic Analysis

Three methods of economic analysis are reviewed in this section: (1) cost-effectiveness, (2) marginal analysis, and (2) benefit-cost analysis. Each of the methods is depicted graphically in Figure 5-1. The graphs in Figure 5-1 depict the relationship between an output such as water supply or improving water quality and the costs of those outputs.

5.1.1 Cost-Effectiveness Analysis

The cost-effectiveness method of analysis is shown in Figure 5-1(a). The total cost of any particular alternative is shown on the y-axis. The alternative used in Figure 5-1(a) could be three different wastewater treatment schemes. For example, let alternative one be a land application system; alternative two, an activitate sludge system; and alternative three a trickling filter system. Increasing levels of effluent quality requires more expensive solutions.

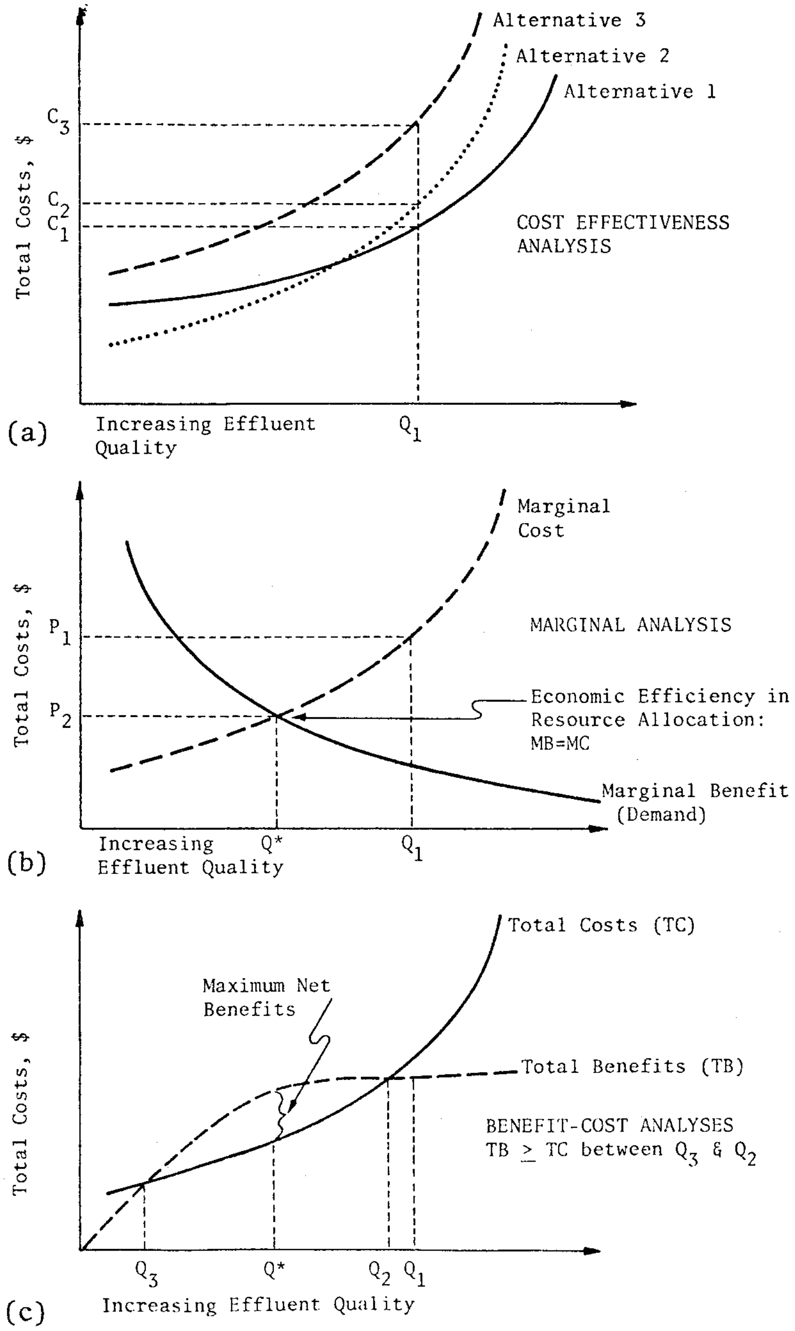


Figure 5-1. Methods of economic analysis.

Cost-effective analysis requires that the alternatives be compared by costs. In Figure 5-1(a) alternative three is the most expensive for all levels of effluent quality. Alternative one, the land application system, is less expensive than alternative two, activitaed sludge, at the mandated effluent quality, Q_1. Activated sludge is less expensive for lower levels of effluent quality. At effluent quality level Q_1, alternative one is selected because its total cost, C_1, is less than those of alternatives two and three. The most cost-effective alternative is number one. If the effluent quality requirements had been lower, alternative two would have been more cost-effective. The alternative that is selected is dependent on the level of effluent quality set by the regulatory agency.

5.1.2 Marginal Analysis

When economic efficiency in allocating resources is used as the decision criteria, the objective is no longer a set level of effluent quality. In Figure 5-1(b), the total cost curve has been replaced by the marginal cost and marginal benefit curves. Using marginal analysis, effluent quality can be increased to the point, Q_*, where additional incremental increases in quality are more costly than incremental benefits associated with those increases. Figure 5-1(b) shows Q_* as being significantly less than Q_1. The efficient allocation of resources dictates that marginal cost must equal marginal benefit. The regulatory setting of Q_1 higher than Q_* has resulted in a net economic loss for society.

The net loss to society is shown in Figure 5-2. When effluent quality is set higher than Q_*, the marginal cost of providing that

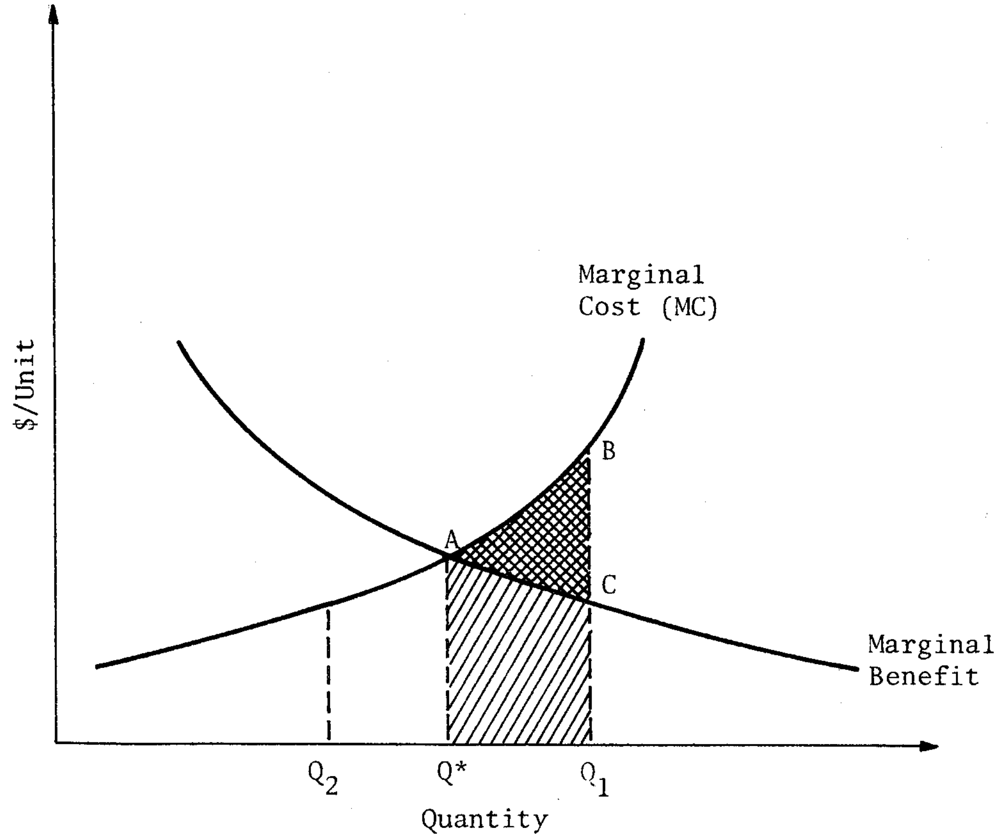


Figure 5-2. Marginal analysis.

quality of effluent exceeds benefits. If the regulatory agency sets the effluent quality at Q_1, the total increase in cost is area Q_*ABQ_1. The increase in benefits is area Q_*ACQ_1. The net loss to society is the area ABC shown as the double cross-hatched area. A similar analysis could be used to show that setting of the effluent quality at level Q_2 would result in an under-investment of resources. Each increment of additional effluent quality provides benefits in excess of costs to Q_*.

5.1.3 Benefit-Cost Analysis

Benefit-cost analysis can result in the economically efficient or optimal allocation of resources. It does not, however, necessarily mean that the solution with the highest benefit to cost ratio is selected. Benefit-cost numbers are shown as the ratio of benefits to costs for each alternative for a project. Any project with benefit-cost (B/C) ratio greater than one is considered economically feasible. Benefits and costs are compared with and without the project rather than before and after. Many benefits can occur without the construction of a project. If a before and after analysis were used, many benefits that would occur without the project could be included as benefits due to the project (Peskin and Seskin, 1975).

Benefits can exceed costs over a wide range of project outputs as shown in Figure 5-1(c). The output in this case is increasing effluent quality. The benfits exceed the costs between Q_3 and Q_2 because the benefit curve lies above the cost curve. All projects falling in this section of the curve are feasible because benefits exceed costs. Only one quality of effluent is optimal, however. This occurs at Q^* where net benefits are highest.

The points, Q^*, may not, however, be the numerically highest benefit to cost ratio. The ratio of benefits to costs could be higher at some lower level of effluent quality. The net benefits at this lower level would be less than the net benefit at Q_*. The numerical benefit to cost ratio cannot be relied upon as an indicator of the highest net benefits. Marginal value curves can be calculated from the total value curves and the optimum effluent quality selected (James and Lee, 1971).

The total cost curve shown in Figure 5-1(c) is a composite of the total cost curves in Figure 5-1(a) for alternatives two and one. Any point on the total cost curve is a least cost alternative for meeting that particular level of effluent quality. The lower portion of the total cost curve in Figure 5-1(c) is the lower part of the alternative two curve from Figure 5-1(a) and the upper portion is the upper part of the alternative one curve.

The point Q_1 represents the effluent level set by a regulatory agency based on water body use classifications. Q_1 is shown in the cost-effectiveness Figure 4-1(a). When the point, Q_1, is plotted in the cost-benefit analysis graph, Figure 5-1(c), it was outside the area where the benefit cost ratio is greater than one. Q_1 is even further from the optimal marginal analysis point, Q^* (Barkley and Sckler, 1972). Use of cost-effectiveness analysis without considering benefit levels can lead to a significant misallocation of resources. Municipal water supply and wastewater management utilities typically use cost-effectiveness analysis.

5.1.4 Comparison of Methods

Benefit-cost analysis goes one step beyond cost-effectiveness analysis by supplying information on benefits as well as costs. Project output levels of goods and services can be adjusted to obtain the largest net benefits possible. Cost-effectiveness analysis uses preset levels of output based on historical levels of consumption. Benefit-cost analysis allows for the adjustment of historical levels of output according to changes in cost of production and the willingness to pay of consumers. When used properly, benefit-cost analysis and marginal analysis produce the same outcome.

One serious problem arises with the use of the benefit-cost method of analysis. The calculation of the benefits is often times difficult. This is particularly true for water quality projects where methods of evaluating willingness to pay are still in the development stage. There are many aesthetic or non-pecuniary values that are difficult to place dollar values on.

5.2 Economic Evaluation of Water Quality Projects

5.2.1 Municipal Grant Cost-Effectiveness Procedures Used by the EPA

Municipal projects designed to meet water quality goals currently are not evaluated in accordance with the cost-benefit analysis concept. The Federal Water Pollution Control Act has an interim goal of "water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved by July 1, 1983" (U.S. Congress, 1977). This goal has often been pursued while considering only water quality factors. Other factors such as streamflow, habitat, and existing uses have not been taken into consideration. The current standard by which water quality projects are evaluated is the ability of the project alternatives to meet either minimum discharge criteria, or, in the case of water quality limited segments, a wasteload allocation based on stream standards.

The cost-effectiveness approach is used by the EPA to select the "best" alternative. EPA rules and regulations for 201 facility plans state that (Federal Register, 1978a):

> Through a systematic evaluation of feasible alternatives it (the facility plan) will also demonstrate that the selected alternative is cost-effective, i.e., is the most economical means of meeting established effluent and water quality goals while recognizing environmental and social considerations.
>
> A cost-effectiveness analysis of alternatives (will be made) for the treatment works and for the complete waste treatment system(s) of which the treatment works is a part. The selection of the system(s) and the choice of treatment works for which construction drawings and specifications are to be prepared shall be based on the results of the cost-effectiveness analysis.

The cost-effectiveness analysis guidelines provide policies and procedures for determining the most cost-effective alternative. The objective is to determine which waste treatment management system will result in the minimum total resources cost over time while meeting governmental requirements. The analysis procedure is quoted below (Federal Register, 1978b):

> Cost effectiveness analysis procedures:
> (a) Method of analysis. The resources costs shall be determined by evaluating opportunity costs. For resources that can be expressed in monetary terms, the analysis will use the interest (discount) rate established in paragraph 6e. Monetary costs shall be calculated in terms of present worth values or equivalent annual values over the planning period defined in section 6b. The analysis shall descriptively present nonmonetary factors (e.g., social and environmental) in order to determine their significance and

> impact. Nonmonetary factors include primary and secondary environmental effects, implementation capability, operability, performance reliability and flexibility. Although such factors as use and recovery of energy and scarce resources and recycling of nutrients are to be included in the monetary cost analysis, the nonmonetary evaluation shall also include them. The most cost-effective alternative shall be the waste treatment management system which the analysis determines to have the lowest present worth or equivalent annual value unless nonmonetary costs are overriding. The most cost-effective alternative must also meet the minimum requirements of applicable effluent limitations, groundwater protection, or other applicable standards established under the Act.

Innovative and alternative wastewater treatment processes and techniques (water reuse) are subject to the same cost-effectiveness procedures as ordinary projects. The present worth cost of the reuse treatment works, however, can be 15% more than the most cost-effective pollution control system. In addition, reuse facilities are eligible for an 85% federal grant as opposed to a 75% grant for standard wastewater treatment facilities. The cost-effectiveness guidelines for projects with more than one purpose are set forth in a March, 1980, EPA document on procedures for funding multipurpose projects (Longest, 1980).

For EPA to participate in the funding of a multipurpose project, the following criteria should apply (Longest, 1980):

1. The cost of the multiple-purpose project must not exceed the sum of the costs of the most cost-effective single-purpose options which accomplish the same purposes.
2. The primary and secondary environmental effects must be assessed in accordance with the NEPA review procedures, and the project must not have any significant net adverse environmental effects.

3. At least one of the purposes must be necessary to meet an enforceable requirement of the Act.

4. There is no purchase of existing facilities with EPA funds.

5. The project meets the definition of treatment works, and the works are publicly owned.

6. The project is consistent with the adopted and approved water quality management plan.

7. For agricultural reuse projects a commitment to this use for design life of the project is necessary.

5.2.2 Cost Effectiveness Analysis for Water Reuse Projects

The cost-effectiveness methodology used for evaluating wastewater treatment projects has drawbacks. It assumes that the water quality objective is worth obtaining regardless of cost. Cost-effectiveness analysis does not account for the benefits returned on the investment. The process is one of selecting the least cost alternative for achieving a given effluent quality.

The effluent quality to be achieved by a point source is based on the legal mandates in the Federal Water Pollution Control Act as amended (PL92-500 and PL95-217). The current effluent limitations are designed to produce fishable and swimmable waters by July of 1983. The benefit associated with attaining this goal was not quantified in dollars. The advisability of trying to place dolar values on "nonquantifiable" benefits has been questioned by some environmentalists and others.

Regardless of the pros and cons of benefit-cost analysis and cost-effectiveness analysis, the United States Congress has set the national goals and mandated the use of cost-effectiveness analysis. Therefore, the methodology set forth in this research also uses cost-effectiveness in the analysis for: (1) comparing the single purpose water quality alternatives, and (2) comparing the water reuse alternative with the least cost single purpose alternatives that accomplish the same objective.

5.3 Economic Evaluation of Municipal Water Supply Projects

5.3.1 Cost-Effectiveness Analysis--the Traditional Method

Municipal water supply economic analysis has been based on cost-effectiveness studies of water supply alternatives. The first step in the traditional analysis is the determination of an output level.

Water supply needs are projected using the average per capita daily water use rate coupled with a current population projection for the service population as shown in Figure 5-3. Per capita water use rates are often increased based on a trend line projection of historical per capita use rates. In Figure 5-3(c) the projected per capita use rates are multiplied by the projected population to determine water supply needs for various times in the future. The projected needs are the water supply output that each alternative must achieve.

The projected needs shown in Figure 5-3 are simplified. Projected needs are analyzed for variations due to wet and dry years, seasonal variations in demand, and storage capacities. These considerations add sophistication to the analysis but do not change the basic assumption that price and water demand are unrelated.

The American Water Works Association discussed the projection of future water demands in a similar fashion (American Water Works Assoc., 1969):

> Future water demands are predicted as a basis for establishing treatment plant capacity. Studies to forecast water demand must consider population,

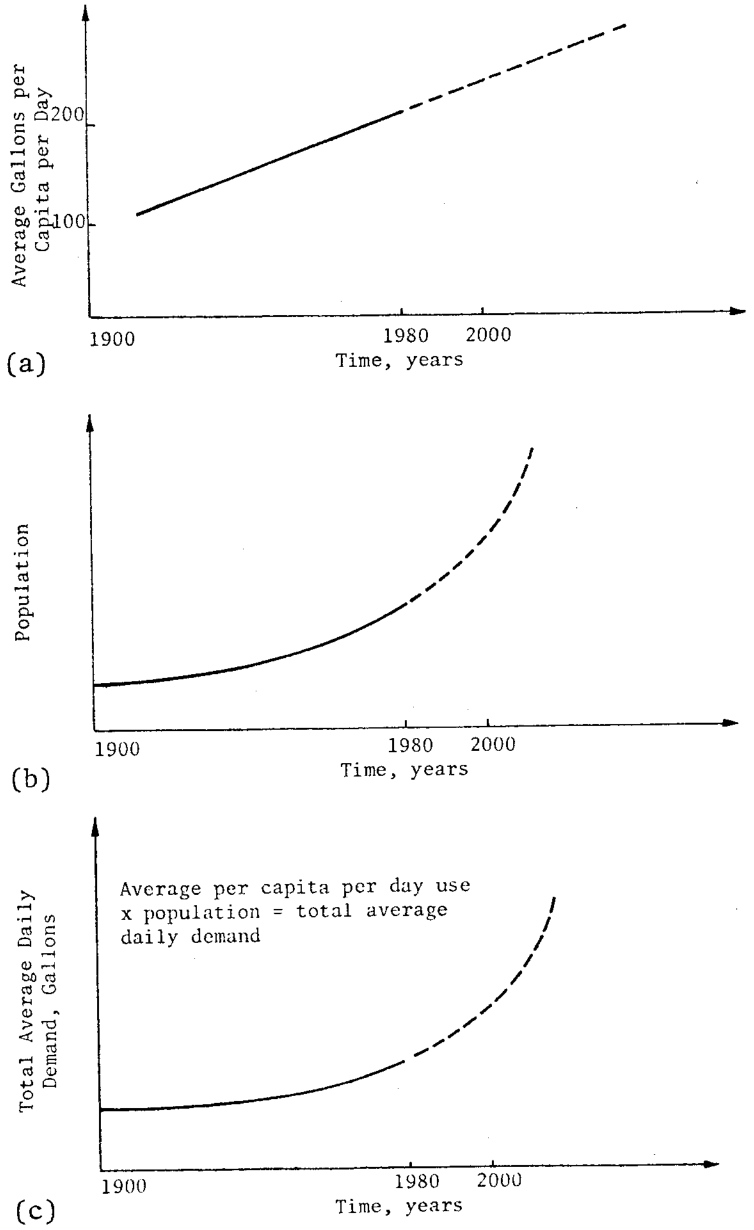


Figure 5-3. Traditional water needs projection.

> commercial and industrial growth, water use trends, metering and extension policies, and service area boundary changes (as might occur through annexation). System water demands are commonly projected for 25 years or more. Accurate records of past growth and water demands are especially valuable in forecasting studies. Many techniques or procedures are available for these studies and often more than one will be employed. In the final analysis, sound judgement is essential in the development and application of forecasts.

The primary considerations according to this quote are population, growth in per capita consumption (industrial included with residential), and growth of service area. Pricing is indirectly referred to through the mention of metering. The effects of water prices on water demand is not given a significant role in forecasting future demands. A more recent compendium of articles on "Managing Water Rates and Finances" assembled by the AWWA considers the economics of water supply, but no official policy is adopted (American Water Works Assoc., 1979) Use of marginal pricing policy by municipal water utilities is widely discussed in the literature but seldom applied.

Once the water demand has been projected, alternative plans are developed for meeting the projected water supply needs. If economic efficiency is the only evaluation criteria, the least cost alternative is selected for implementation. Other objectives, such as environmental quality or social considerations, may also be used as evaluation criteria. Consideration of these criteria may lead to the selection of an alternative other than the least cost solution. Cost, however, remains the primary criterion for evaluation. The AWWA has the following comments on cost-effectiveness analysis (American Water Works Assoc., 1979):

> Often various types and combinations of treatment units may be used to achieve the performance desired. Determination of the most suitable plan may be a comparative cost study which includes an evaluation of the merits and liabilities of each proposal.

A graphical analysis of the cost-effective approach to municipal water supply is shown in Figure 5-4. The determination of a given water supply level for a future year is shown as the vertical (perfectly inelastic) demand curve for the year 2000. The fixed water supply output is the same as a demand that does not change, regardless of price. The fixed water requirement is the weak point of cost-effectiveness analysis. Demand is not perfectly inelastic. One study by Howe and Linaweaver (1967) shows price elasticity for residential water to vary bewteen -0.23 for in-home domestic water and -0.7 for sprinkling demand in arid areas. Other studies have found higher negative elasticities for both in-home and sprinkling demand for residential users.

The alternatives, S_1 and S_2, can supply the incremental unit needed to meet year 2000 projected demand for different marginal costs. In this case, S_I would be selected because it is the least cost alternative.

5.3.2 Benefit-Cost Analysis for Municipal Water Supplies

At the beginning of this chapter, Figure 5-1 depicted the cost-effectiveness and benefit-cost methods of analysis. Figure 5-5 depicts the difference between cost-effectiveness and cost-benefit analysis. The price P_B is the price of water at the time of analysis. The water quantity Q_o is sold at the price P_B to meet current demand, D_o. The year 2000 population and per capita use projections are used to determine point B on the demand curve, D_1. The projected demand for Q_{2000}

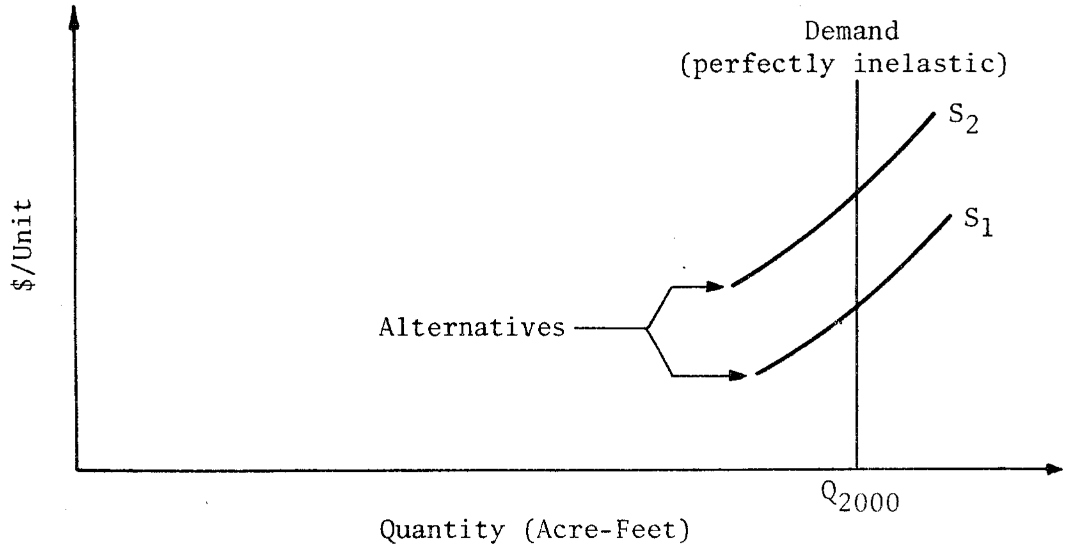


Figure 5-4. Cost-effectiveness and demand.

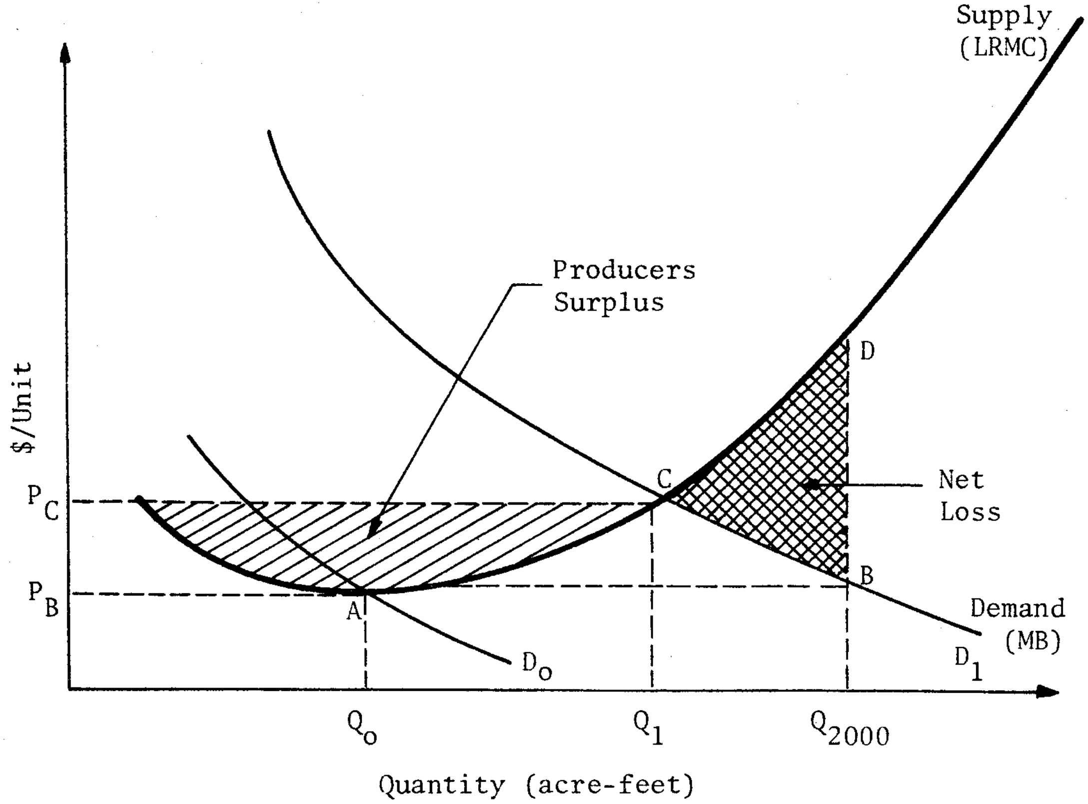


Figure 5-5. Marginal analysis for finding quantity demanded.

assumes that the current price, P_B, will be the same in the year 2000. Future prices, however, must increase because each additional increment to the water supply is more costly than the last.

The increasing incremental cost of water is shown by the rising long-run marginal cost (LRMC) curve. The intersections of the LRMC curve (supply curve) with the projected demand curve determines the optimal water supply quantity Q_1 and the marginal price, P_C. Supplying water beyond the quantity Q_1 leads to a net loss. For example, if Q_{2000} is supplied, the net loss is the difference between the area Q_1CDQ_{2000}, and Q_1CBQ_{2000} as shown by the cross-hatched area. Marginal cost equals the marginal benefit at the intersection of the demand and supply curves, point C. Suppling more water than this leads to an efficiency loss because the resources could be more profitably used elsewhere. The increment of output beyond Q_1 is worth less to water consumers (Q_1CBQ_{2000}) than it costs to produce (Q_1CDBQ_{2000}). Too many resources have been allocated to water supply and these "excess resources" can be transferred to some other purpose where values of the products or services produced are greater than or equal to the cost of these resources (Hanke and Davis, 1971; Goolsby, 1975).

Problems exist with this method. Water demands for any one year are dependent to a certain extent on the weather. Landscape irrigation demands are higher in dry years. In a dry year, the demand curve will be moved to the right. More water will be demanded at any given price than during an average year. These same problems, however, also exist for the cost-effectiveness approach.

5.4 Methodology for the Analysis of Multiple Purpose Reuse Projects

In the following section water supply and wastewater treatment methodologies are developed for making a decision on the choice between a dual purpose water reuse project and two single purpose projects that accomplish the same objective. The basic premise is that the dual purpose project has a lower total cost than the two single purpose projects accomplishing the same objectives. The difference between the methodology set forth here and others is that the water supply demand is not considered perfectly elastic and that water supply must undergo the benefit-cost type of analysis rather than the usual cost-effectiveness analysis. In effect, the benefit-cost analysis is used to determine the output level of the water supply purpose of the project.

5.4.1 Water Supply Methodology

1. Long-Term Plan. The objective of a typical water supply project is to meet water supply needs for some given time period. An individual project should be part of a larger overall plan designed to meet water needs for twenty to fifty years. The plan generally consists of a series of projects or alternative projects.

2. Long-Run Total Cost Curve. Based on the projects outlined in the community water plan, the project cost can be estimated. The planned projects and existing projects can be used to develop the long-run total cost (LRTC) curve. The LRTC curve depicts the change in total cash outlays for each level of production. An LRTC curve for a municipal water supply is shown in Figure 5-6(a). The LRTC curve forms an envelope that runs tangent to a series of short-run total cost (SRTC) curves. The

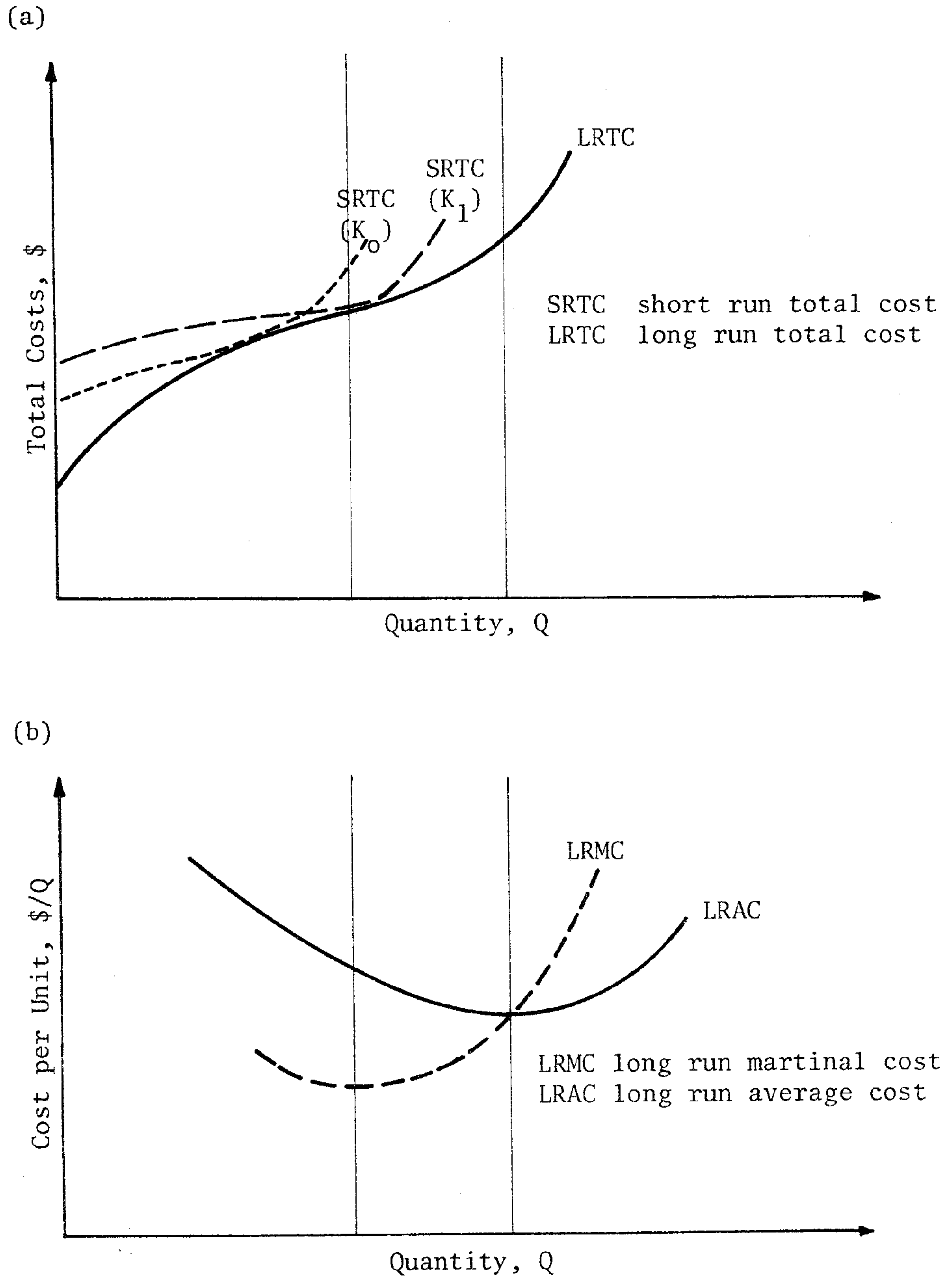


Figure 5-6. Long run total cost and marginal cost curves.

capital stock (k_o, k_1) is held fixed for each SRTC curve and allowed to increase for the LRTC curve. The LRTC curve can be viewed as the composite of least cost alternatives needed to produce any given level of water supply.

3. Average Cost Curve. Once the total cost curve is calculated, the average cost can be found for any given output level (X). The long-run average total cost (LRAC) is found by dividing the LRTC by the output level (X). The long-run average cost is the cost associated with the minimum total cost plant or project from all those available. Figure 5-6(b) shows an average cost curve based on the total cost curve in Figure 5-6(a).

$$\text{LRAC} = \frac{\text{LRTC}}{\text{X}}$$

4. Long-Run Marginal Cost Curve. Once the equation for the LRTC curve is calculated, the LRMC curve can be found by taking the first derivative of the LRTC equation with respect to output. Figure 4-6(b) depicts the LRMC curve derived from the LRTC curve in Figure 5-6(a).

As discussed previously, the most efficient use of resources occurs at the point where marginal revenue (MR) equals marginal cost (MC). At MR=MC the benefit of resource use relative to cost is maximized. The next step involves finding the marginal cost or demand curve in order to find the optimal output level.

5. Derive Demand Curve. The current demand curve can be obtained from an analysis of water consumption and price data by consumer class for the municipality. If price and consumption data are not available for a certain municipality, data for a similar city can be used to derive

the demand curve. Cross-sectional data is preferred to time series data because of potential changes in consumer preferences and tastes over time.

6. Future Demand Curves. The demand curve can then be shifted for each future year based on changes in population and tastes. In Figure 5-7, D_o represents the current demand curve and D_1 and D_2 future demands.

7. Determining Benefits. Benefits for each year can be determined by summing the area under the demand curve and subtracting benefits already attributed to the existing facilities at demand curve D_o as shown in Figure 5-7. Existing benefits are shown as the cross-hatched area under D_o. As the demand curve moves outward, benefits will increase for each new demand curve.

The "with" and "without" conditions must be evaluated in order to determine net benefits rather than benefits that would occur without the project. The short-run marginal cost curve (SRMC) in Figure 5-7 provides the left side boundary for determining additional benefits with the project. The SRMC curve is derived from the short-run total cost curve and it indicates the cost of each additional unit of water production without investing any more capital in facility expansion. The current water output, X_o, can be increased very little with existing facilities. The net benefits that would be foregone when the demand curve moves outwaterd to D_1 without constructing the project would be the area GBC. When the demand has expanded to D_2, the foregone net benefits would be the area FED. As demand grows, supply can be expanded very little with the existing facilities. At demand level D_2, output

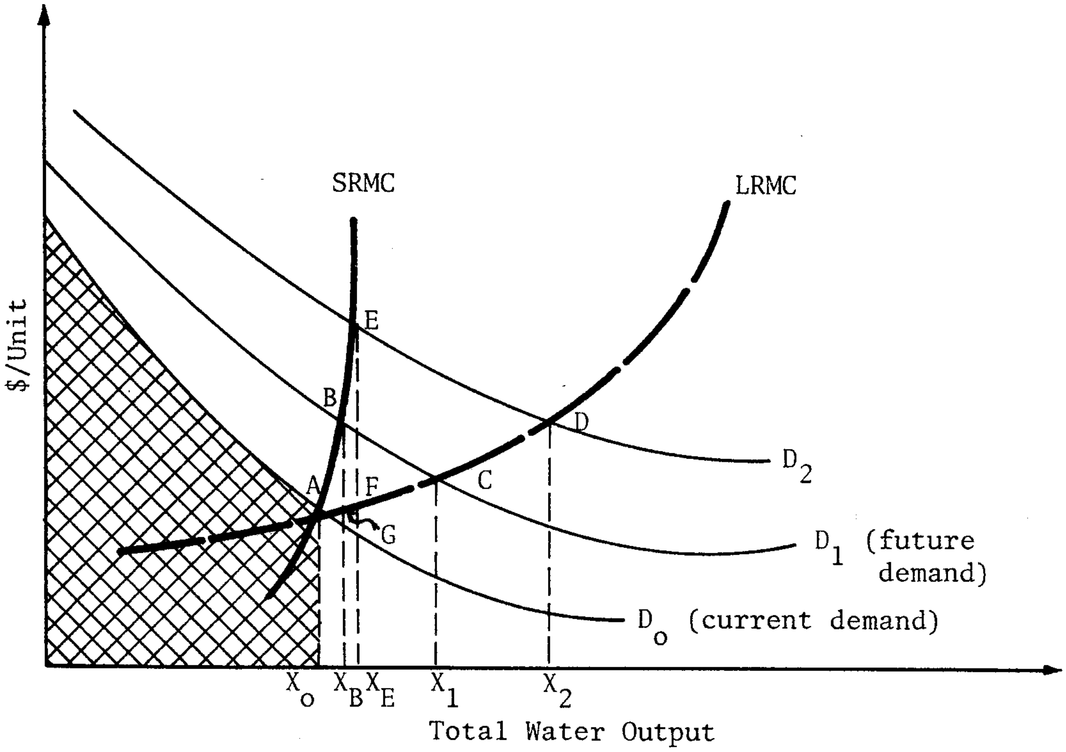


Figure 5-7. Demand shifts over time.

increases only to the level X_E. When the SRMC rises above the LRMC, expansion of the facilities should be undertaken.

In order to conduct the benefit-cost analysis, the gross benefits with the project should be determined for each period. For the first period, the gross benefits with the project would be the area X_oABCX_1 and for the second period, the area X_1CBEDX_2. The total benefits for the project can be obtained by discounting the benefits for each period and summing in order to yield the present worth of the gross benefits. The total benefits of the project without discounting is the area X_oABEDX_2. The total benefits without the project would be X_oABEX_E. The net benefits with the project is the difference between the two.

8. Determine Costs. The next step is to determine the costs associated with the development of the new increment of water supply. These costs consist of capital costs for facilities, operation and maintenance costs, and management costs.

Theoretically, the sum of the toal additional area under the LRMC for each new demand level can be found and then discounted to determine the present worth. For example, in Figure 5-7 the additional costs obtained by supplying the X_2 level of water as the demand moves from D_1 to D_2 is the area under the LRMC curve, X_1CDX_2. In a two-period analysis, this cost would have to be discounted back to the rpesent time.

For practical purposes, it is best to take each of the costs associated with the proposed project and bring them back to present worth. Generally, this involves an initial large capital expenditure followed by a continuous string of annual operation and maintenance costs. Some projects may involve additional capital expenditures at certain points in the future. Each cost must be dischounted back to present worth capital cost.

The derivation of the LRMC curve, as discussed earlier, is based on the total cost curve. The least cost alternatives are used for providing the additional water supply increments. Prices of project components, such as cement and energy products, change over time relative to other prices. Technology can also change the costs associated with producing the product. In addition, changes in the quality of the finished product, such as more stringent drinking water standards, can alter costs of future projects. The end result is that the costs used in determining the LRMC may not be exactly the same as those for the project being evaluated.

9. Evaluation of Analysis. In comparing costs and benefits, the output of the methodology should be considered. First, the quantity of water output is going to be less than for traditional analysis as long as the marginal costs are increasing. The marginal costs of water production are increasing in most areas. Each additional unit of water output is costing more than the last unit. Second, the construction of the LRMC curve is subject to uncertainty. The projections of future costs must be made for each of the SRMC curves. The LRMC curve should be regarded as an approximation, subject to change. The curve is, however, a conservative approximation. Costs are likely to increase and standards become more stringent resulting in a steeper LRMC. The steeper the LRMC is, the smaller the increase in water output that is justified. Third, changes in income and tastes can shift the demand curves. These shifts, both in outward movement and in elasticity, are difficult to

predict accurately. These projections are, however, a closer approximation of what happens in the real world than the traditional method of analysis.

Use of cost-benefit analysis can be combined with sensitivity analysis to establish confidence intervals of values or probability of values for key parameters. Results can be compared with the traditional methods of projecting the needed water supply to provide a sense of acceptability. Radical departures from values obtained using traditional methods are generally not acceptable to decision makers, regardless of technical accuracy.

At this point, the single purpose water supply project has been assigned a benefit-cost ratio and a water supply output level determined. The output level arrived at using the benefit-cost analysis method will be lower than the level that would have been arrived at using population and per capita projections.

This information serves two purposes. First, the single purpose water supply alternative can be combined with the least cost single purpose wastewater treatment alternative for comparison with the dual purpose water reuse alternative. Second, the water output level has been established for the water reuse alternative. If the water supply purpose of the water reuse alternative turns out to be substantially less expensive than the single purpose water supply alternative, the marginal cost curve will have to be adjusted and a new higher output level set.

5.4.2 Wastewater Treatment Methodology

The cost-effectiveness procedures required by the Environmental Protection Agency are descirbed in Section 5.2.1. Benefits related to water quality improvement are difficult to quantify. The "willingness-to-pay" method has been used by the Metropolitan Denver Sewage Disposal District Number 1 to evaluate benefits associated with different levels of treatment and the resultant water quality (Denver Post, 1979). This type of analysis is a surrogate for transactions in a real market place. It is difficult to determine values for flora, fauna, aesthetics, health, and social benefits. Even willingness-to-pay surveys may produce questionable results due to a lack of full information on the part of those being surveyed. An analysis of benefits associated with the mandatory effluent standards could serve, however, as a gauge of the public's willingness to pay for improved water quality. The benefit evaluation technique could be improved through use and modification and could eventually become a legislative barometer for future water quality legislation.

For this study, the pragmatic approach of utilizing EPA's cost-effectiveness analysis is recommended. Any municipality applying for an EPA grant must utilize the EPA process in order to obtain funding. EPA by law must meet certain water quality goals without regard to benefit-cost analysis. Since these goals, reflected in an effluent discharge limitation, must be met, the cost-effectiveness method assures that the goals will be met at the least cost.

As a methodology, then, the following steps should be followed in order to evaluate the water quality-wastewater treatment aspects of the dual purpose project:

1. Develop traditional (nonwater reuse) alternatives for meeting the designated effluent quality objectives.

2. Develop water reuse-exchange alternatives that meet the same or equivalent water quality objectives and also furnish water supply as a project purpose.
3. Identify any nonquantifiable costs or benefits associated with each alternative and their significance in the decision process. Opportunities foregone by the selection of any one alternative should be identified. For example, contractual commitment of wastewater resources to an irrigation reuse scheme could effectively eliminate internal reuse of the wastewater within a municipality at some future date.
4. Determine the costs of alternatives in items 1 and 2 above and bring back to a present worth cost.
5. Municipalities do not, as a municipality, incur the total costs of a federally funded wastewater treatment project. Costs to the municipality associated with each alternative should be calculated. Form an economic efficiency standpoint, only the total costs are relevant. From a practical standpoint, a municipality is interested in selecting the least cost project based on costs incurred by the municipality.

5.4.3 Comparison of Combined and Single Purpose Alternatives

The incremental principle is used to evaluate the combined versus the single purpose alternatives. The incremental cost is the difference in cost between the dual purpose reuse project and the most cost-effective (least cost) single purpose wastewater treatment alternative. If the incremental cost of the reuse project is less than the most cost-effective single purpose water supply project, the water reuse project is the most economically efficient. The reuse project would accomplish both the wastewater treatment and water supply purposes at a lower cost than the two most cost-effective single purpose projects.

5.4.4 Allocation of Costs Between Purposes

The allocation of project cost is necessary for three reasons: (1) project users should pay in proportion to the cost incurred in providing a particular purpose, (2) the financing of the project is often separated by purposes, and (3) if the water supply portion of the dual purpose project is substantially lower in cost than the single purpose water supply project, the water supply output should be adjusted upward. The output should be adjusted because the marginal cost curve (supply curve) will be lowered and consumers will demand more water at the lower price.

The Alternative Justifiable Expenditure (AJE) method and the separable costs remaining benefits method are the two most commonly used methods to allocate costs. The AJE method is used by EPA to allocate costs between purposes so that the federal grant level can be established for the wastewater treatment purpose. The AJE method allocates costs in proportion to those incurred for the single purpose projects. The assumption for the AJE method is that achieving multiple purposes simultaneously should be less costly than separate single purpose projects, and that all projects should share in the cost savings.

The separable costs remaining benefits (SCRB) method is recommended in the Water Resources Council "Principles and Standards" for use with federal multiple purpose water resource projects (Federal Register, 1973).

The SCRB method divides costs between beneficiaries commensurate with the beneficial effects received. Costs identifiable with a particular purpose, separable costs, are allocated to each purpose and the remaining joint costs are divided according to the lesser of beneficial effects or single purpose alternative costs.

Either the AJE or SCRB method can be used for water reuse projects. The AJE method is very simple and easy to apply. The SCRB method is more complex but allocates costs based on project expenditures and benefits.

5.5 Northglenn Water Reuse Economics

The Northglenn reuse project consists of an exchange of high quality agricultural water stored in Standley Reservoir for treated municipal wastewater. EPA has described the project purposes as drinking water supply, wastewater collection and treatment, and agricultural reuse. Northglenn borrows the high quality raw water for municipal use, collects and treats the sewage effluent, makes up consumptive use losses and adds 10% to the total borrowed and then delivers the treated wastewater back to the Farmers Reservoir and Irrigation Company (FRICO).

The economic analysis was published in the Northglenn Draft and Final Environmental Impact Statements (Environmental Protection Agency, 1980a; Environmental Protection Agency, 1980b). The Northglenn Draft Environmental Impact Statement (EIS) eliminated the municipal water supply purpose for the cost-effectiveness analysis. The economic analysis was made using only the wastewater treatment and agricultural reuse purposes. The two reuse purpose costs were compared with two single purpose project costs. The results were necessarily inconclusive because the third purpose, municipal water supply, was left out of the analyses. This problem was resolved in the final EIS in which all three purposes were included in the cost-effectiveness analysis. The multiple-purpose water reuse project was found to be more cost effective than any combination of single purpose projects evaluated.

EPA also conducted an "agricultural productivity analysis" to determine whether water bought by Northglenn from Platte River ditches for make-up water for FRICO was more productive being used on FRICO land or on land along the South Platte River. Agricultural productivity is determined by EPA by dividing the gross value of the crops by the total quantity of water applied to the fields.

The assignment of gross productivity of agricultural production to a single factor of production, i.e., consumptive use of water, is theoretically and practically incorrect. The theoretically correct method of analysis involves a comparison of the rate of return for each agricultural alternative. The quantity of water used as a factor of production is merely one of many inputs. One alternative may use more water than another system, but if the rate of return on the investment is higher for the larger water user, it should be selected over the low water use system (Turner, 1980).

5.6 Summary

Both benefit-cost analysis and cost-effectiveness analysis have their place in evaluating water reuse projects. The cost-effectiveness method is used for comparing multiple-purpose water reuse alternatives with the least cost combination of single purpose alternatives as summarized in Table 5-1. Cost-effectiveness analysis is appropriate for use

Table 5-1. Economic Methodology for Water Reuse

Water Supply Purpose

1. Develop long-term water supply plan.
2. Find the long-run total cost (LRTC) curve.
3. Find the long-run average cost (LRAC) curve based on LRTC curve.
4. Find the long-run marginal cost (LRMC) curve using the LRTC curve.
5. Using price and consumption data, develop the existing demand curve (same as marginal benefit curve).
6. Develop demand curves for future years using changes in population
   Identify future water demands at points where MC=MB.
7. Determine benefits with the proposed projects as compared to without the project. Bring benefits back to a present worth.
8. Determine costs for the proposed project and bring them back to a present worth.
9. Evaluate sensitivity of critical parameters to change and rationality of conclusions. Use the water output levels found in the marginal analysis for sizing the water supply purpose of the reuse alternative.

Wastewater Treatment Purpose

1. Develop traditional (nonwater reuse) alternatives to meet water quality goals.
2. Develop water reuse exchange alternatives to meet water quality and water supply purposes.
3. Identify noneconomic variables for each alternative.
4. Determine present worth costs for the various alternatives.
5. Display allocation of costs between local, state, and federal entities.

Alternative Selection

1. If the least cost dual purpose water reuse project is less costly than the total cost of the two least cost non-exclusive single purpose projects, the water reuse project is the best choice in terms of economic efficiency.
2. Final selection is based on the consideration of all project objectives. Other objectives such as social well-being and environmental quality may lead to the selection of an alternative other than the most economically efficient.

where project outputs are preset such as for the wastewater treatment purpose. The output level of wastewater treatment projects is determined through the use of effluent standards. Therefore, cost-effectiveness analysis is also used in the selection of the least cost single purpose wastewater treatment alternative.

Benefit-cost analysis is recommended for use in the water supply analysis. This method of analysis can be used to determine water supply output for both the single purpose and multiple purpose alternatives. The incremental costs of supplying additional units of water has been rising rapidly and by using benefit-cost analysis, the water supply output is likely to be lower. The use of benefit-cost analysis coordinates project output with consumer demand and the cost of water.

The methodology recommended for water reuse project evaluation in Table 5-1 is a departure from the normal cost-effectiveness procedures used by most municipalities. The methodology relates consumer demand for water to the price of that water for both water reuse and single purpose water supply alternatives. The use of the procedure should prevent over-investment in water supply facilities whether the water is supplied by a reuse project or more traditional sources.

CHAPTER 6

METHODOLOGY FOR THE DEVELOPMENT OF WATER REUSE ALTERNATIVES

The planning process remains the same regardless of the type of study. Typically, the planner defines the problem, developes alternatives, selects the most feasible alternatives for additional study, and presents the results to the decision maker. Alternative development is a critical stage in the planning process because it determines the choices that will be available to the decision maker. The formulation of water reuse alternatives requires an approach that differs from the normal water supply and wastewater treatment alternative development methodology. The water resource informational base must include the water resources and use systems of others in the basin if all feasible alternatives are to be included in the planning process.

The reuse exchange market has as products both the water supply and wastewater resources controlled by the planning entity and the water resources and use systems of others. A number of water systems that may not meet the needs of users within one or more of the systems can be combined through water reuse exchange alternatives to satisfy the needs of all.

The reuse methodology proposed herein is designed so that reuse alternatives which might otherwise be overlooked are included in the planning process. It is built on a series of steps that systematically describe and quantify the water resources system. All water users and resources in the basin are treated as part of the potential market for exchange. The methodology is designed to foster the development of the widest possible range of reuse alternatives.

6.1 Steps in the Development of Water Reuse Alternatives

The preparation of a water resources inventory for the basin is the first step in the development of reuse alternatives. The water resources include the native surface water supplies, foreign water imports, and groundwater. The hydrologic characteristics and water quality of each water source should be identified so that the quantity, quality and time relationships between water supply and water demand can be established.

Next, the legal reuse status must be established for the water resources of the basin. The ownsership, distribution, and storage of water in the basin must be documented to enable the planning entity to see the "fit" between itself and the rest of the water suppliers and users. Water quality, water law, the physical arrangement of the basin and its water users, environmental quality, economics, timing of uses, aesthetics, and social acceptance are among the factors that can reduce both the quantity and the quality of water available for reuse. Each water user places limits upon the use of the water by some other user in the basin. Each user has different opportunities for water reuse based on the specific needs and resources available to that user.

The use entity then evaluates its own water resources, both raw water and wastewater. Only after these steps have been taken are the water reuse markets analyzed and developed into alternatives. The final step involves fitting the water reuse evaluation into the overall water resources planning process.

A summary of these steps is outlined below:

1. Quantify the water resources of the river basin, including foreign water imports, and identify the hydrologic and water quality characteristics of these resources.
2. Classify the basin water resources according to their reuse potential in accordance with the water laws of the state.
3. Determine the ownership, distribution, and storage of the basin's water resources.
4. Identify the water resources under control of the planning entity and the reuse potential of these resources. The identification of reuse potential should include an analysis of the various classes of reusable return flows, their quantity, quality, and flow variations.
5. Evaluate the reuse exchange market and develop water reuse alternatives that maximize reuse exchange potential and fit the water use context of the basin.
6. Integrate the water reuse alternatives into a comprehensive water resources planning process.

6.2 Basin Water Resources

The development of a methodology for evaluating water reuse potential starts with quantification of the water resources potentially available to the water user. The comprehensive approach makes it less likely that the water resource planner will overlook reuse opportunities. The extent of the water resources evaluation is partially dependent on the size of the project. The river basin is an accepted starting point. It has the advantages of being a physically self-contained water-producing unit for which information is readily available. In addition, political boundaries often correspond to the hydrologic boundaries because counties, states, and water management organizations often use the hydrologic boundaries as political boundaries.

The first step, then, is the quantification of the water supplies of the river basin or basins from which the planning entity draws its water supplies. The average, maximum and drought supplies should be determined for both the native and foreign water supplies. Drought supplies are central to the evaluation in order to determine the dependability of the various sources. The analysis should include a series of drought years because carry-over storage is often insufficient to relieve water supply shortages for more than a single year.

Foregin water supplies may not be subject to drought effects because of the location and priority of the diversion facilities. Also, drought periods in one basin may not coincide with those in another basin. If little fluctuation in water yields is found during drought years, the water source may be independent of the drought cycle. This situation often occurs when transbasin diversions are located at high altitudes and collect primarily spring runoff based on an early priority water right.

The water quality of the various sources should be determined in order to evaluate its suitability for various uses. Since water quality varies due to both natural and man-related reasons, the quality of the water should be evaluated as it moves downstream through the basin. In general, the quality of the water deteriorates as it moves downstream. This deterioration decreases the usefulness of the water and reduces reuse exchange potential between users downstream in a basin.

The storage facilities, their location and capacity should also be determined at this time. Storage water provides flexibility by making water exchanges possible when demand is high and reduces the effect of seasonal fluctuations.

6.3 Classification of Water Resources According to Their Legal Reusability

The water laws of Colorado were discussed in Chapter 4. Fortunately Colorado's laws are very similar to those of other western states so that similar opportunities or difficulties can be expected.

Table 6-1 lists the legal reuse potential of the various water classifications. The table ranks the resources in accordance with the ease of using the return flows. Both "new" and "old" foreign water return flows can be reused without legally damaging downstream junior appropriators. Reuse of storage water return flows is probably permissible but has not been tested in court. Reuse of return flows from native water is highly restricted because of valid legal claims to those flows. Ranking return flows by water source enables the planner to clearly see their reuse potential.

6.4 Ownership, Distribution and Storage of Basin Water Resources

The reuse exchange potential of any water use entity is in part dependent on the ownership, distribution, and use of water in the basin. If large quantities of water are owned by lower quality users such as agriculture, the exchange potential will be high for municipalities and industries. If other high quality users, such as municipalities, predominate, exchange of water between users will be more difficult. When

Table 6-1. Classification of Water by Reuse Potential in Colorado

	Water Classification	Legal Status for Reuse of Return Flows*
Decreasing Reuse Potential	FOREIGN**	
	New	Return flows belong to importer and may be recycled, exchanged or sold as best suits importer. Affirmed in water court.
	Old	Same as above except downstream junior appropriators may depend on historic return flows and file suit in water court. Current arguments favor the importer. Untested in water court.
	NATIVE	
	Storage	Storage waters are taken during periods when all direct use rights are being filled. Use of water once stored is unregulated. Therefore, return flows may be subject to recycling or exchange. Untested in water court.
	Direct Flow	Historic return flows from direct flow rights are subject to appropriation by downstream junior appropriators. Legal rights to these return flows do exist. These return flows cannot be sold or exchanged. They may be subject to recycle reuse within the use system if not returned to the receiving stream. Untested in water court.

---

* This table deals only with reuse of return flows. Water can be exchanged between users with make-up water for consumptive use being obtained from a separate source without altering return flow characteristics. Example: Northglenn Reuse/Exchange Systems.

**The law makes no distinction between old and new foreign water. The terms originate in the Fort Collins, Platte River Power Authority, Water Supply and Storage Co. Reuse Exchange Agreement.

most water uses are urban in nature, the sequential reuse exchange of water between municipalities and industry holds the greatest potential.

The most assured method of determining ownership and distribution of water in the western United States is to review water rights records. Priorities for water rights diversions are listed for each stream in the basin along with the owner of the water right. The water yield of any of these rights can be found by consulting the historic diversion records kept by the State Engineer's Office. Each water right is valid only for diversion at a specific site. Listing the water rights and matching the rights with the points of diversion and their historic yields provides valuable information for use in the reuse exchange analysis.

Information on storage reservoirs should also be collected. The ownership, capacity, location, and historical record of storage can also be found in state records. Reservoirs are useful in facilitating exchanges and storage of reusable return flows.

6.5 Water Resources of the Planning Entity

The water resources of the planning entity include not only the raw water supplies but also the return flows collected after use of the water. These resources form the base on which the planning entity formulates its water alternatives and future requirements. They should be classified according to the legal reuse potential given in Table 6-1. An accounting of the available water resources will aid the planner in determining the various reuse opportunities. The ownership of foreign water supplies places the planning entity in the most flexible position while native direct flow rights are the most restrictive.

In addition to the water resource supplies, the planning entity must take into consideration the location of its water supply and wastewater treatment facilities. The location of these facilities relative to sources of high quality exchange water and delivery points for treated wastewater can be critical. Also important is the location of storage sites such as reservoirs and groundwater aquifers relative to raw water supplies and treated wastewater that must be stored prior to reuse.

Each use entity has different water consumption and water quality characteristics. Water consumption for municipalities varies on a seasonal cycle. Consumptive use and the total water use are both high in summer. During the winter, return flows are high (low consumptive use) but total water use is low. In addition, different water sources may be used for different seasons which can directly affect the quantity of reusable water available for exchange.

The change in the water quality varies with the type of use. Municipal wastewater, for example, has TDS levels that are typically increased by 300 to 400 mg/ℓ for each pass through the system. The wastewater also includes additional nutrients such as nitrogen and phosphorous that are beneficial to agricultural crops. In a reuse exchange system with agriculture, the nutrients would be beneficial but the increased TDS levels could be harmful. Acceptable TDS levels and concentrations of elements harmful to agricultural crops, such as sodium and boron, must be closely monitored to ensure an acceptable quality.

In Colorado, unplanned sequential use has taken place for many decades between municipalities and agricultural irrigation canals diverting below municipal outfalls. Historical acceptance of these facts does not, however, lessen the need for matching the quality of the water to the use and then monitoring to ensure that the quality of reuse water is adequate for the intended purpose.

Another aspect of reusing municipal wastewater is public health. Pathogenic microorganisms, organic chemicals, inorganic chemicals, and radiological substances all pose hazards to humans. Although domestic wastewater is indriectly recycled for human consumption, direct reuse of domestic wastewater is contrary to current EPA policy. Still, wastewater is applied to raw edible vegetables such as those irrigated by the Burlington Canal below Denver and municipal wastewater return flows are used for domestic water supplies such as Boulder's wastewater being diverted at the Lower Boulder Dtich which serves as the municipal water supply for Firestone, Colorado. The hazards associated with various levels of contaminants, particularly bacteriological, are not fully understood and considerable variation exists in state regulations. As mentioned earlier, this paper does not address the public health hazards of reuse and these hazards are mentioned here only as a step in the planning process.

6.6 Evaluation of the Reuse Market and Alternatives

The informational base outlined above can be used to develop reuse alternatives. A screening process is needed to compare and weigh both objective and subjective factors of the reuse alternatives developed. Preliminary analysis should include the following elements (Environmental Protection Agency, 1980b):

1. How much flexibility would each system offer for future expansion or change?
2. Can reusable water resources be acquired that would enhance the reuse/exchange potential?
3. How much high quality water can be made available by each system?
4. How complicated would program implementation be given the number of agencies that would be involved in each proposed system?
5. How would each system affect land use in the area?
6. What is the economic, social, and environmental costs and benefits of each system?

Once these preliminary questions are answered and a number of reuse markets identified, the most promising can be further developed into alternatives that can be compared with the traditional water supply alternatives. The questions listed below include the most frequent and typical aspects encountered (Environmental Protection Agency, 1980b):

1. What are the specific water quality requirements of each user? What are the fluctuations in the quality of the reuse water and what effect would these fluctuations have on the user?
2. What is the daily and seasonal water use demand pattern for each potential user? How do these patterns match up with the supply pattern of water available for reuse?
3. Can fluctuations in demand be met by pumping capacity, direct release into ditches, exchange of water or by storage? What type of storage would be needed and what are the best locations? Can existing storage facilities be used or enlarged?

4. If additional treatment of effluent is required, who should own and operate the additional treatment facilities. If less treatment is required for the reuse water, how is WWTP capacity affected and what are the implications for seasonal variations in flows and effluent quality requirements?
5. What costs will the users in each system incur in tying into the reclaimed water deliery system? What are the advantages and disadvantages for all parties involved?
6. Will industrial users face increased treatment costs in using the water or treating their waste streams?
7. What interest do potential funding agencies have in supporting the type of reuse program being considered? What requirements would be imposed on a project eligible for funding?
8. Will the use of reclaimed water force agricultural users to alter irrigation patterns? If so, what would be the impact on other users dependent on the return flows? Would water rights be affected in any way?
9. How stable are the potential users in each potential reuse system? Will use of the reusable waters create stability and enhance the existing use systems?
10. What are the social and environmental impacts of the proposed reuse system? What will the public reaction be to the proposed reuse systems?

6.7 Meshing Water Reuse with the Planning Process

Water reuse alternatives should be part of the overall planning process. Although water reuse has been given special emphasis by state and federal water pollution control agencies, there is no guarantee that water reuse exchange will be considered when the water supply planning is carried on independent of water pollution control facility planning. Water reuse exchange is being accepted as a legitimate water supply alternative and should be systematically developed and evaluated along with the more traditional alternatives.

The methodology developed in this chapter should enable the water resources planner to evaluate the full spectrum of water reuse alternatives. The six steps outlined in Section 6.1 are the heart of the methodology. The first three steps are aimed at developing a comprehensive informational base on the water resources of the basin. In the fourth step the water resources of the planning entity are organized in a manner that enables the planner to see the fit of planning entity into the context of the basin. Only in the fifth step does the formulation of water reuse alternatives begin. With the broad informational background, the planner will be able to generate innovative alternatives that might have gone unnoticed. In the final step, the water reuse alternatives are integrated into the comprehensive planning process for comparison with other alternatives.

CHAPTER 7

REUSE POTENTIAL IN THE SOUTH PLATTE RIVER BASIN

The South Platte River Basin is at an ideal period in its history for the development of water reuse exchange as a water supply alternative. Four conditions set the stage for this development: (1) urban water demand is increasing as evidenced by the projected doubling of population over the next twenty years, (2) the construction of additional in-basin reservoirs would produce low water yields considering the expenditures involved, (3) the importation of foreign water from the Colorado River Basin is also costly and controversial, and (4) the random purchase of agricultural water erodes the agricultural base and produces conflict between agricultural and urban water users. This setting provides the ideal basis for an evaluation of the water reuse potential of the basin.

The water reuse potential of the basin is established in five steps. First, the current level of agricultural water reuse in the basin is determined as a background for evaluating future urban water reuse potential. Second, the raw water supplies of the Front Range are inventoried and classified according to their reuse potential. Third, the water supplies and return flows of the major Front Range municipalities are summarized in order to determine their future needs and the "reusability" of their existing supplies. Fourth, the existing and future raw water supplies of the Front Range, both native and foreign, are compared with projected Front Range municipal needs. Finally, the overall potential of the various water reuse forms is established for meeting future municipal water supply needs.

Each of these steps draws on the informational base established in the previous chapters. The water reuse forms, water quality laws, appropriative water laws, and water reuse methodology are all used in evaluating the future of water reuse in the South Platte River Basin.

7.1 Current Level of Water Reuse

Water reuse currently is practiced via an ad hoc agricultural water reuse system. Return flows are diverted at more than 80 agricultural diversion points on the South Platte River between Denver and the Colorado-Nebraska state line. Since water reuse is already extensively practiced, why is this research concerned with the water reuse potential of the basin? The answer involves changes in the type of water reuse. This research explores municipal water reuse potential and its interactions with agricultural uses in the basin. The existing reuse system should be understood before advocating a change in that system.

The number of use cycles and the total quantity of water applied in the South Platte River Basin (SPRB) in Colorado is shown in Table 7-1. These figures are calculated using the average annual surface water runoff and imports, the average consumptive use factor for each water application, and the basin outflow to Nebraska at the state line.

The average annual surface water runoff in the basin is 1,355,919 acre-feet. The average annual imports into the basin are 323,122 acre-feet. The total surface water supply is approximately 1,729,000 acre-feet. The average annual surface water outflow into Nebraska is

Table 7-1. Water Reuse in the South Platte River Basin

Available Water a (acre-feet)	Return Flow Ratio (%)	Number of Cycles n	Reuse Factor Q/a	Basin Outflow O (acre-feet)	Total Water Applied or Used Q (acre-feet)
1,729,000	50	2.3	1.6	352,000	2,756,000
1,729,000	60	3.1	2.0	352,000	3,435,000
1,729,000	50	2.2	1.6	372,000	2,705,000
1,729,000	60	3.0	2.0	372,000	3,389,000
1,729,000	50	5.2	1.9	48,000	3,364,000
1,729,000	60	7.0	2.4	48,000	4,201,000

Calculated using: $O = ar^n$

$$n = \frac{\log \frac{O}{a}}{\log r}$$

$$Q = \frac{a(1-r^n)}{1-r}$$

where: O = basin outflow

a = initial water supply

r = return flow fraction

n = number of uses

Q = total water applied in "n" uses

351,752 acre-feet (U.S. Army Corps of Engineers, 1977). The return flow fraction can be assumed to be in the area of 40% to 50%. Irrigation system efficiency has been calculated to be approximately 43%. Since irrigation system efficiency measures the percentage of irrigation water that is stored in the soil and available for consumptive use by the crops, the remaining 60% to 50% of the water is available for another use cycle.

Given a consumptive use rate of 50% to 40%, the number of use cycles for each unit of water is between 2.3 and 3.1, as shown in Table 7-1. This range is based on the average surface runoff and average outflows to Nebraska. Groundwater flow into Nebraska is not taken into account. Groundwater recharge due to precipitation can be assumed to be negligible. Groundwater flows into Nebraska have been estimated to be approximately 20,000 acre-feet annually. Adding this flow to the surface water outflows, the total basin outflow is 372,000 acre-feet annually. When the groundwater outflow is accounted for, the number of use cycles drops to between 2.2 and 3.0.

The highest number of water applications for the South Platte River Basin is limited by the Nebraska-Colorado South Platte River Compact. According to this agreement, Nebraska is entitled to 48,000 acre-feet annually of surface water flow in the South Platte River. Given the 50% to 40% consumptive use range as before, the ultimate number of applications for each unit of water is between 5.2 and 7.0 times.

The total quantity of water applied in the basin is 2,756,000 acre-feet per year for 2.3 application cycles. If the number of application cycles is raised to 5.2 in order to reduce outflows to Nebraska to the

48,000 acre-foot quantity, the total quantity of water applied is 3,364,000 acre-feet or an increase of 608,000 acre-feet for approximately three more applications of the return flow. The increased consumptive use is 304,000 acre-feet.

A reuse factor can also be calculated by dividing the total quantity of water applied (Q) by the initial supply (a). The reuse factor indicates total quantity of water applied in the basin in relation to quantity of water initially available. The reuse factor should be used in conjunction with the number of use cycles n as an indicator of the increase in water yield for additional applications of return flows. Beyond three use cycles the gain in total water yield drops sharply as shown in Table 7-1.

Each use cycle increases TDS levels through salt pick-up and concentration from evapotranspiration. The current number of use cycles, 2.3 to 3.1, has raised TDS levels from less than 50 mg/ℓ to between 1,100 and 1,600 mg/ℓ. The water in Denver has a TDS level of approximately 140 mg/ℓ (U.S. Army Corps of Engineers, 1977). The increase in TDS is very marked as return flows enter the South Platte River and are diverted and reapplied. These increased TDS levels create problems for both domestic supplies drawn from alluvial aquifers along the Platte and agricultural irrigation waters.

7.2 Water Supplies and Characteristics of the South Platte River Basin

The native water supplies of the South Platte River Basin originate in the mountains along the western side of the basin. The majority of the runoff occurs during snowmelt in the months of May and June. The urban centers shown in Figure 7-1 are located along the foothills of

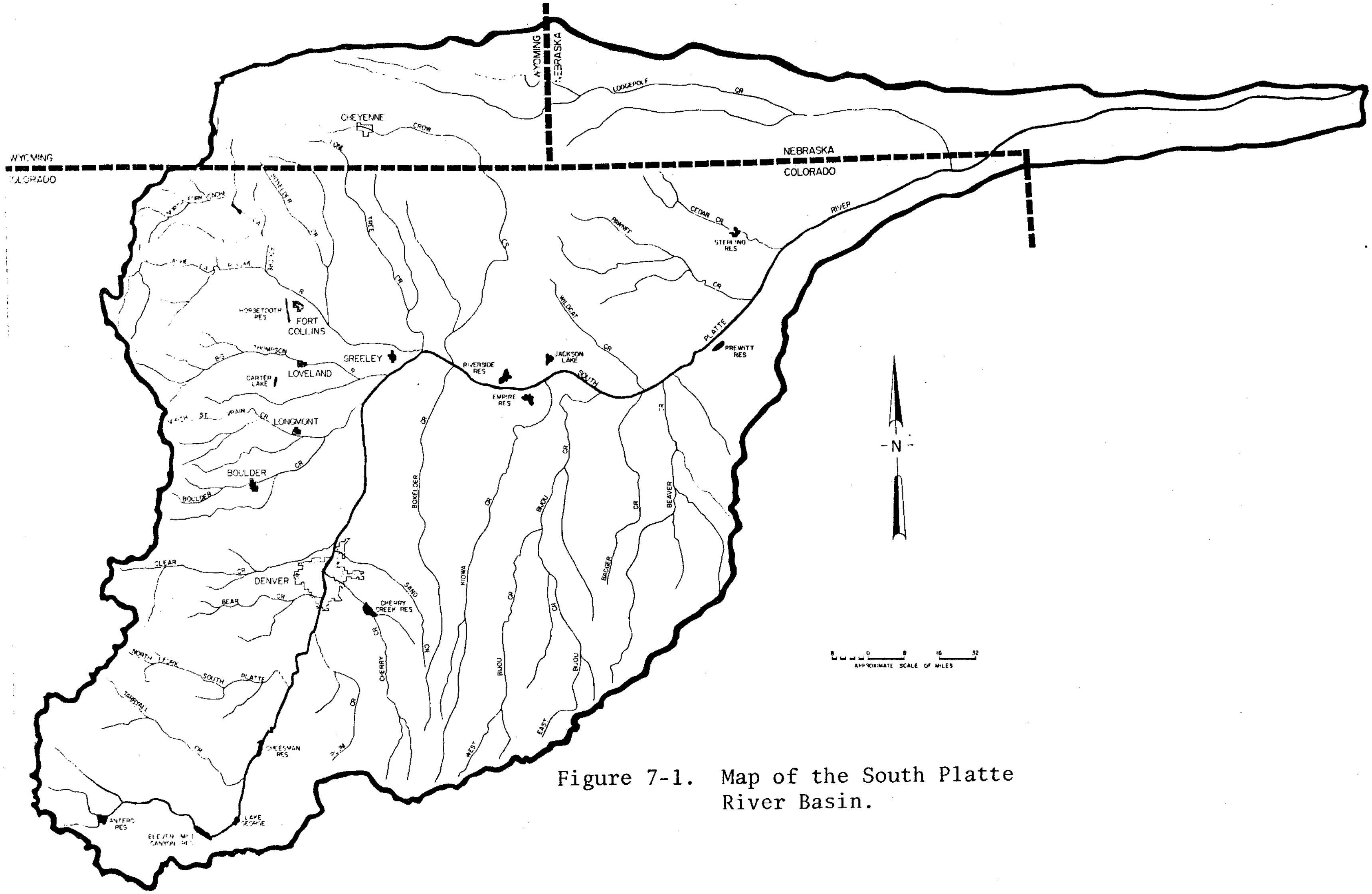


Figure 7-1. Map of the South Platte River Basin.

the mountains. These Front Range communities draw their water supplies from the mountain runoff and foreign water imports.

The irrigated lands are located in the plains region just to the east of the foothills and along the South Platte River.

Over 80% of the consumptive water use in the basin is the result of agricultural irrigation. Agricultural water rights account for the earliest and largest water rights in the basin. Sequential reuse exchange works best if the agricultural lands are located downstream of the municipalities as is the case in the SPRB. The location of irrigated agricultural lands is important to the success of exchange plans. Flow by gravity using existing canal and stream systems can greatly reduce costs of exchange projects.

7.2.1 Basin Structure and Suitability for Reuse

The physical arrangement of the SPRB is ideal for sequential reuse exchange. Water flows from the high mountainous country in the west past the urban centers for use on irrigated agricultural lands. Rapid expansion of the urban centers has made it desirable to purchase agricultural water and apply it to urban uses. Water reuse exchange avoids the high cost of outright purchase and preserves the existing agricultural infrastructure.

7.2.2 South Platte River Sub-Basins and Counties

The South Platte River Basin was divided into 16 sub-basins for work on the input-output model for the U.S. Army Corps of Engineers (1977). The irrigated acreage for each of the sub-basins is shown in Table 7-2.

Table 7-2. 1970 Total Diverted Irrigation Water for the Sub-Basins of the South Platte River Basin in Colorado and Wyoming (U.S. Army Corps of Engineers, 1977)

Sub-Basin	Irrigated Acreage	Total Diverted Irrigation Water
Cache la Poudre	227,660	633,295
Big Thompson	109,560	321,465
Saint Vrain	88,340	255,772
Boulder	44,800	146,015
Clear Creek	0	0
Bear Creek	380	1,484
Plum Creek	1,700	6,970
Cherry Creek	3,040	12,388
North Fork South Platte	0	0
South Platte - Mountains[1/]	72,520	165,137
South Platte - Transition[2/]	205,762	648,858
South Platte - Plains[3/]	295,200	1,025,120
Crow Creek	89,818	255,957
Lodge Pole Creek	33,924	90,493
North Plains Tributaries[4/]	560	1,535
South Plains Tributaries[5/]	147,852	433,342
South Platte Basin Study Area Total	1,307,878	3,997,831

1/ South Park to mouth of canyon at Kassler.
2/ Mouth of canyon to Greeley.
3/ Greeley to Colorado-Nebraska border.
4/ Includes Wildat, Pawnee and Cedar Creek drainages.
5/ Includes Boxelder, Kiowa, Bijou, Badger and Beaver Creek drainages.

The counties of the basin are shown in Figure 7-2. The irrigated acreage for each county is shown in Table 7-3. The counties along the western edge of the basin are mountainous in character and contain very little irrigated agriculture. Boulder and Larimer counties extend into the eastern plains and contain significant amounts of irrigated land on these plains. The irrigated land lies to the east and downstream of the major municipalities. The City of Greeley is the only exception. Greeley lies 30 miles to the east close to the junction of the Cache la Poudre and South Platte Rivers. The water sources of Greeley are located, however, in the mountains with water treatment facilities close to the foothills and pipelines to the city. Greeley's wastewater discharge is located on the east side of the city and flows into the lower end of the Cache la Poudre River just prior to its junction with the South Platte River.

7.2.3 Basin Water Supplies

The next task in evaluating reuse potential is to inventory the water supplies of the basin. The native surface water supplies for each of the sub-basins are shown in Table 7-4. The table is divided into mountains, transition, and plains sub-basins. The mountain sub-basins produce an average annual surface water runoff yield of 1,155,601 acre-feet or 85% of the basin total. The transition and plains sub-basins yield only 11% of the total. Water originating in the mountainous regions of the basin is advantageously located for sequential reuse exchange transfers between municipaliites and agricultural interests.

Foreign water is imported into the South Platte River Basin from the Colorado River Basin, the North Platte River Basin, and a small quantity

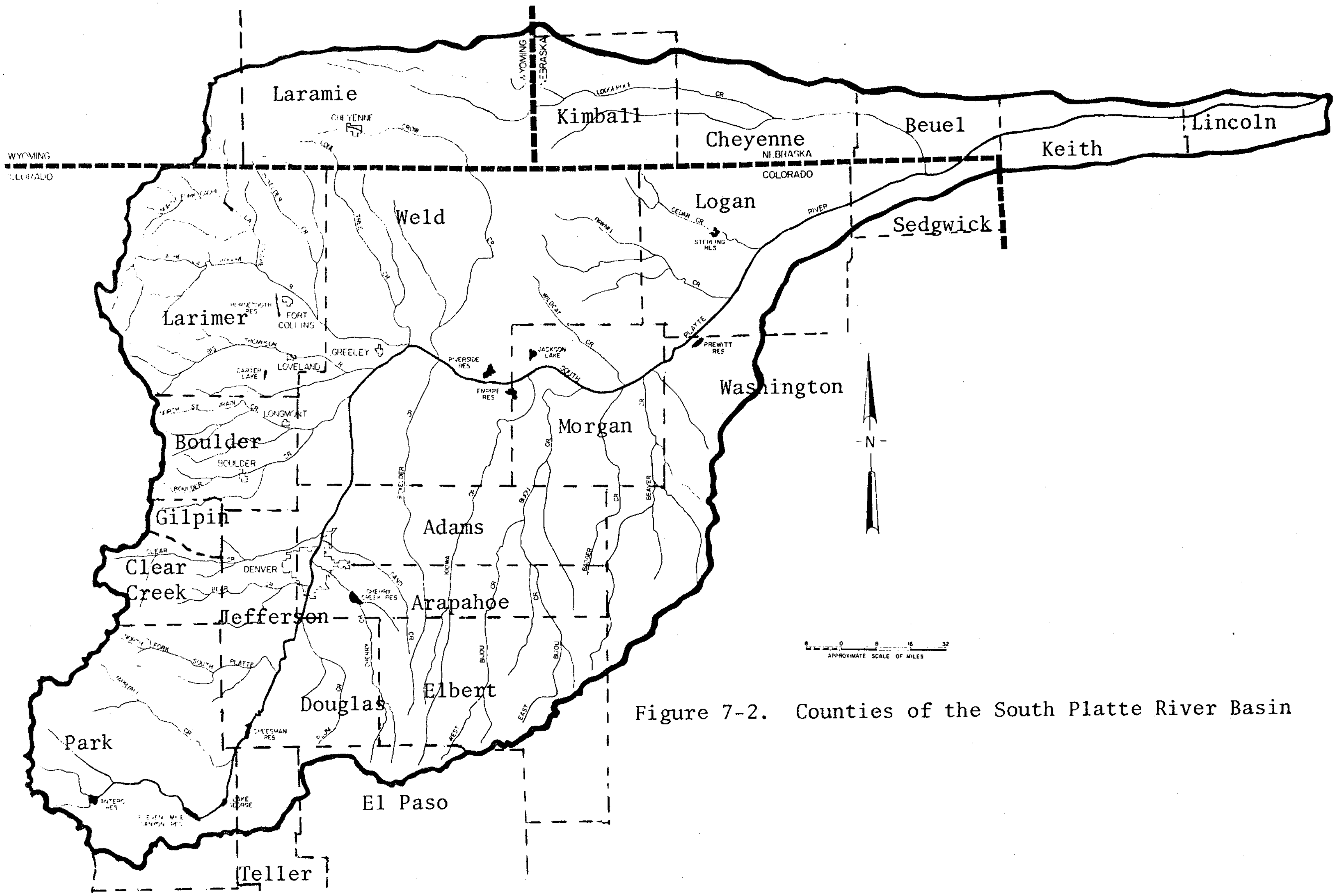


Figure 7-2. Counties of the South Platte River Basin

Table 7-3. Land Use in the South Platte River Basin by County by Square Miles (U.S. Army Corps of Engineers, 1977)

Zone	County	Irrigated Cropland	Urban Areas	Subdivision Under Development	Total Area
Mountain	Boulder	152.22*			758.
	Clear Creek	0*	4.50	10.00	394.70
	Gilpin	0*	1.76	10.52	148.00
	Larimer	231.00	23.90	23.70	2320.00
	Park	32.30	1.60	25.10	1900.20
	Teller	0*	6.20	0.70	444.
Front Range	Adams	107.01*			1251.
	Arapahoe	7.22*			820.
	Denver	0 *	67.00		67.
	Douglas	6.90	8.05	118.35	843.00
	El Paso	0*		5.00	130.72
	Jefferson	17.27*			791.
	Weld	640.00	29.20	14.80	4002.00
Plains	Elbert	4.05	0.45	16.55	1156.95
	Logan	191.50	17.20		1473.00
	Morgan	243.80	8.80		1278.00
	Perkins				
	Sedgwich	45.40	2.00		248.00
	Washington	20.60	0.20		959.80
Nebraska	Cheyenne				1186.
	Beuel				435.
	Kieth				1072.
	Kimball				953.
	Lincoln				
Wyoming	Laramie				2703.
	Albany				44.00
TOTAL		1,087,500			24030**

*Measured from SCS maps.
**South Platte Basin land area.

Table 7-4. Native Surface Water Runoff of the South Platte River Basin in Wyoming and Colorado (U.S. Army Corps of Engineers, 1977)

Sub-Basin	Drainage Area (square miles)	Surface Water Runoff (acre-feet/year) Long Term Average	1953-1956 Drought Period	1970 Water Year
MOUNTAINS				
South Platte River - Mountains	2,142	201,211	105,354	402,235
North Fork South Platte River	479	112,604	64,286	198,680
Bear Creek	214	44,927	4,411	76,244
Clear Creek	448	173,994	114,784	225,362
Boulder Creek	439	122,832	83,824	162,914
Saint Vrain Creek	547	117,600	74,820	131,549
Big Thompson River	828	147,600	93,903	177,006
Cache La Poudre River	1,877	234,823	158,066	321,220
Total	6,964	1,155,601	699,448	1,695,210
TRANSITION				
Plum Creek	302	22,789	7,142	31,440
Cherry Creek	385	11,075	4,606	6,119
South Platte River Transition	1,447	12,341	5,133	9,074
Total	2,134	46,205	16,881	46,633
PLAINS				
Crow Creek	1,824	60,000	36,540	60,000
North Plains Tributaries	2,400	1,090	664	1,090
Lodge Pole Creek	1,946	43,023	26,201	43,023
South Plains Tributaries	4,276	50,000	30,450	50,000
South Platte River - Plains	1,956	0	0	0
Total	12,402	154,113	93,855	154,113
GRAND TOTAL	21,500	1,355,919	810,184	1,895,956

from the Arkansas River Basin. Table 7-5 lists the diversion structures, sources, destinations, and quantities for all foreign water imported into the South Platte River Basin. The destination of the foreign water imports is listed by sub-basin. The total quantity of water imported during an average year is 373,122 acre-feet.

Foreign water can be reused by an import entity without consideration of downstream appropriators dependent on return flows from foreign water. The one exception is Colorado Big Thompson (CBT) project water. Reuse of CBT project return flow is forbidden in a 1938 agreement between the U.S. Bureau of Reclamation and the Northern Colorado Water Conservancy District (see Section 4.16). Because of this agreement, 227,626 acre-feet per year must be deducted from the total import figure to determine the foreign water available for reuse. On subtracting the CBT imported water figure from the total, 145,496 acre-feet of foreign water remains.

The Denver Water Department maintains that foreign water imported by them from the Blue River Basin cannot be exchanged with agricultural interests because of the Blue River Decree (see section 4.17). Each year Denver diverts an average of 28,654 acre-feet of water from the Blue River Basin through the Harold D. Roberts Tunnel. Loss of this quantity of water from the sequential reuse exchange for Denver seriously reduces the flexibility of Denver's future reuse options.

A summary of present and future foreign water supplies is given in Table 7-6. Currently, the single largest importation of foreign water is by the Bureau of Water and Power Resources. Water is brought into the basin via the Colorado Big Thompson Project and distributed by the Northern Colorado Water Conservancy District. As mentioned earlier,

Table 7-5. Transbasin Diversion Structures which Import Water to the South Platte River Basin (U.S. Army Corps of Engineers, 1977)

Transbasin Diversion Structure	Source		Destination		Years of Operation (water yrs)	Current Average Annual Imports (acre-feet)
Wilson Supply Ditch	NORTH PLATTE RIVER BASIN	Laramie River sub-basin	SOUTH PLATTE RIVER BASIN	Cache La Poudre River Sub-basin	1902-present	2,383
Columbine Ditch		" "			1921-1956	0
Creek Ditch		" "		"	1920-1956	0
Laramie Poudre Tunnel		" "		"	1914-present	15,630
Skyline Ditch		" "		"	1893-present	1,707
Lost Lake Outlet		" "		"	1988-1950	0
Cameron Pass Ditch		North Platte River-Mountains Sub-basin		"	1913-present	107
Michigan Ditch		" "		"	1905-present	1,190
Grand River Ditch	COLORADO RIVER BASIN	Colorado River Mountains Sub-basin		"	1892-present	21,523
Eureka Ditch		" "		Big Thompson River Sub-basin	1940-present	80
Alva B. Adams Tunnel		" "			1947-present	227,626
Moffat Water Tunnel		Fraser River Sub-basin		Boulder Creek Sub-basin	1936-present	59,332
Berthoud Pass Ditch		" "		Clear Creek Sub-basin	1910-present	612
Tunnel		Blue River Sub-basin			1971-present	48
Harold D. Roberts Tunnel		" "		North Fork South Platte Sub-basin	1964-present	28,654
Boreas Pass Ditch		" "		South Platte River-Mountains Sub-basin	1933-present	103
East & West Hoosier Pass Ditches		" "		"	1935-1940	0
Aurora Homestake Pipeline		Eagle River Sub-basin		"	1967-present	6,450
Cheyenne Pipeline		Little Snake River Sub-bas		Crow Creek Sub-basin	1965-present	7,315
Aurora-Homestake Pipeline	ARKANSAS RIV.BAS.	Arkansas River-Mountains Sub-basin		South Platte River-Mountains Sub-basin	1973-present	381
Total						373,122

Table 7-6. Summary of Present and Future Foreign Water Imports

Sub-Basin	Current Average Annual Imports (acre-feet)	Probable Future Average Annual Imports (acre-feet)	Net Future Average Annual Import Increases (acre-feet)
South Platte River - Mountains	6,934	35,825	28,891 1/
North Fork South Platte River	28,654	169,000	140,346 2/
Bear Creek	0	0	0
Clear Creek	660	660	0
Boulder Creek	59,322	77,322	18,000 3/
Saint Vrain Creek	0	0	0
Big Thompson River	227,706	275,706	48,000 4/
Cache la Poudre River	42,540	46,540	4,000 5/
Crow Creek	7,315	31,000	23,685 6/
TOTAL	373,121	636,053	262,922

1/ The Homestake Project Collection System - Furnishes Aurora with an additional 20,515 acre-feet per year through Aurora-Homestake Pipeline. Also, includes unused share of existing yield, 8,860 acre-feet.

2/ Development of abosolutely decreed Blue River rights owned by the Denver Water Department. Water would flow through the Harold D. Roberts collection system. Not included is 259,000 acre-feet of proposed expansion on Straight Creek, East Gore, Eagle-Pine, and Eagle-Colorado river systems.

3/ Expansion of Williams Fork collection system by Denver. Water would flow through Moffat Tunnel.

4/ Municipal sub-sdistrict of Northern Colorado Water Conservancy District would import 48,000 acre-feet per year through Alva B. Adams Tunnel of CBT project. Project is entitled to Windy Gap Project.

5/ Fort Collins will import additional water through Michigan Ditch to expanded Joe Wright Reservoir.

6/ Proposed expansion of Little Snake River system by City of Cheyene.

CBT water is not available for reuse. Therefore, out of the 373,121 acre-feet currently imported, only 145,415 acre-feet are available for reuse.

All proposed foreign water import projects shown in Table 7-6 are being undertaken by municipal entities. Only projects with a strong likelihood of being implemented by the year 2000 were included in Table 7-6. Increases in imported water using projects other than those outlined are considered to be highly uncertain due to competition from the Western Slope, environmental issues, and high costs. Net future increases in average annual imports are projected to be 297,610 acre-feet. The total quantity of water imports would be 670,721 acre-feet with 443,025 acre-feet being available for reuse projects along the Front Range.

The South Platte River, Mountains Sub-basin, would receive an additional 28,891 acre-feet through expansion and increased use of the Aurora-Homestake Pipeline. The Harold D. Roberts collection system can be expanded to yield an additional 140,346 acre-feet per year. This water would be brought into the North Fork of the South Platte River sbu-basin from the Blue River Basin via the Roberts Tunnel. An additional 53,678 acre-feet per year can be brought into the Boulder Creek sub-basin through the Moffat Tunnel from the Williams Fork Basin. The Windy Gap Project of the Northern Colorado Municipal Subdistrict would bring 48,000 acre-feet per year through the Alva B. Adams Tunnel of the CBT project. All four of these projects are expansions of existing systems.

The Cache la Poudre River sub-basin will begin receiving additional imports from the North Platte River Basin in 1980. These imports are to be stored in Fort Collins' recently completed Joe Wright Reservoir.

The Crow Creek River sub-basin will receive water from the Snake River sub-basin of the Colorado River for use by the City of Cheyenne.

7.3 Municipal Water Supplies and Demands

Municipal water supplies and demands have increased dramatically in the last several decades. Denver has met the demand for water by pursuing an aggressive policy of foreign water acquisition. The cities of Aurora and Cheyenne have followed similar policies, only much smaller in scale. The other Front Range communities have been acquiring water already being put to use in the basin by agriculture. This section reviews existing municipal water rights holdings, the make-up of these holdings, projected increases in foreign water imports, current water uses, and future water demands.

7.3.1 Municipal Water Supplies along the Front Range

As municipalities grow, they must either make more efficient use of their existing supplies or acquire other sources of water. Water reuse projects can utilize either of these options. Recycle reuse makes more efficient use of existing supplies while sequential reuse exchange can nearly double the yield of a new source of water. In order to determine the options available to a municipality, the existing supplies must be evaluated in terms of quantity, type of water right, and the origin of the water supply.

In Table 7-7, the present and projected water rights yield is given for each municipality. The water rights for each municipality are separated into categories suitable for water reuse

Table 7-7. Present and Projected Municipal Water Supply in Foreign, Storage, and Direct Flow Rights (U.S. Army Corps of Engineers, 1975; Denver Water Department, 1975)

City		Average Annual Water Yield Acre-Feet per Year				Drought Year Water Yield Acre-Feet per Year			
		Foreign	South Platte River Basin Water Storage Rights	Direct Flow	Total	Foreign	South Platte River Basin Water Storage Rights	Direct Flow	Total
Aurora	Present	15,310	18,500	12,300[a]	46,110	8,640	12,100	7,500[b]	28,240
	Projected	38,825	21,990	14,920	72,735	20,217[a]	12,190		
Denver	Present	228,322[d]	28,400	76,100	332,822	131,600[e]	5,360	46,500	183,460
	Projected	281,000[f]				157,200[g]			
Boulder	Present	11,763[h]	6,960	7,440	26,163	14,704[h]	4,640	4,360	23,704
	Projected	19,763[i]	17,726[j]			22,704			
Longmont	Present	4,606[h]	5,640	3,810	14,056	5,757[h]	3,670	2,480	11,907
	Projected	12,606[k]				13,757			
Loveland	Present	4,202[h]	0	4,208	8,410	5,252[h]	0	2,850	8,102
	Projected	8,202[l]				9,252			
Greeley	Present	11,070[h]	9,000	16,550[m]	36,620	13,839[h]	5,000	12,300[m]	31,139
	Projected	19,070				21,839			
Fort Collins	Present	10,175[h,o]	2,350[p]	16,275	28,800	11,718[h,q]	1,175[r]	15,107	28,000
	Projected	18,175[s]				19,718			
Cheyenne	Present	7,126	0	7,353[t]	14,479	7,126	0	4,512[t]	11,638
	Projected	31,000	0			18,600[u]			
TOTALS	Present	292,574	70,850	144,036	507,460	198,636	31,945	95,609	326,190
	Projected	428,641	85,106	046,056	660,403	283,287	32,035	95,609	410,931

Footnotes on following page.

Table 7-7. Continued.

Footnotes:

[a] Includes 6,050 acre-feet of groundwater

[b] Includes 4,560 acre-feet of groundwater

[c] 56% of average value

[d] Roberts System 169,000 AF + 59,322 AF from Moffat System

[e] Roberts System 103,000 AF + (59,322/112,000) AF (54,000) from Moffat (28,601)

[f] Roberts System 169,000 AF + 112,000 AF from Moffat System

[g] Roberts System 103,000 AF + 54,000 from Moffat System

[h] CBT water - not available for reuse

[i] CBT + 8000 AF from Windy Gap (1/6)

[j] Park Reservoir = 6,767 AF plus Barker Meadow - 4000 AF + 6960 AF

[k] Windy Gap - 8,000 AF + 4,606 AF CBT

[l] Windy Gap - 4000 AF + 4202 AF CBT

[m] Includes 3250 AF for dry year and 7500 AF for wet year of irrigation company stock

[n] Windy Gap 8000 AF + 11070 AF - CBT

[o] Michigan Ditch 4000 AF + 6175 AF - CBT

[p] Native storage in Joe Wright Reservoir

[q] Michigan Ditch - 4000 AF + 7718 AF - CBT

[r] Based on 50% of average year

[s] Includes 8000 AF of Windy Gap water transferred to Platte River Power Authority by Fort Collins but first use remains with Fort Collins

[t] Includes 3100 AF of groundwater

[u] Assumes dry year yield of 50% of average

[v] Direct flow and storage rights not increased unless a proposed project looks highly probable

evaluation. Municipal water rights often exceed the amount of water actually used. The additional water, however, is available for use so the water is included in the "present" average annual water yield. Projected water supplies include probable projects that require a significant investment to bring them into operation. The footnotes to the table provide detailed information on the assumptions made in developing data for the table.

Projects that were viewed as not being likely to be built because of environmental, legal, and cost problems were not included in the storage right projections. An example is Coffintop Reservoir which has been proposed by Longmont on Saint Vrain Creek. Although this project may eventually be constructed, it is unlikely because of its controversial nature and the availability of agricultural water rights.

Table 7-7 also contains data on projections of future municipal water supply acquisitions. Foreign water acquisitions are shown for each of the eight cities. Data on proposed foreign water projects is easier to obtain becasue conditional water rights must be applied for at the state level and be actively pursued in order to maintain their validity. The opportunity for the development of projects within the South Platte River Basin is limited due to the very high level of existing development. Plans of municipalities to acquire native storage rights and native direct flow rights need not be filed with the state. Municipalities purchase these rights according to their own individual plans. Since the rights already exist, the process of obtaining native basin water is a transfer from an existing use to another use within the basin.

Municipal water rights that are in excess of current needs are usually leased to agriculture. The excess rights serve as a reserve for drought years and provide water for future growth. Many municipalities, such as Fort Collins and Longmont, require the developers of new subdivisions to transfer three acre-feet of water per acre of development to the city or to make an equivalent payment.

Data from Table 7-3 is graphically displayed in Figure 7-3. The foreign water yields are shown for both an average year and a year during a drought cycle. The foreign water supply is given for the eight Front Range communities. The total drought year foreign water yield is currently 199,000 acre-feet and is projected to be increased to 283,000 acre-feet. The average year yield is 293,000 acre-feet projected to grow to 429,000 acre-feet per year. The projected increases in foreign yields are assumed to occur by the year 2000. Increased imports past the year 2000 are assumed to be highly uncertain and are shown using a dashed line.

Total municipal water supply for a drought year is shown as 326,000 acre-feet in 1975 and 411,000 acre-feet in the year 2000. The average year total municipal water supply is shown as 507,000 acre-feet in 1985 and 660,000 acre-feet in the year 2000.

In viewing Figure 7-3, it is important to note that municipal water supply sources are at all times composed of more than 60% foreign water. The high percentage of foreign water is a result of basin water having already been developed by agricultural interests. In recent decades municipalities, especially Denver, have sought out new sources of water in the Colorado River Basin. Now, the Colorado River Basin has become an

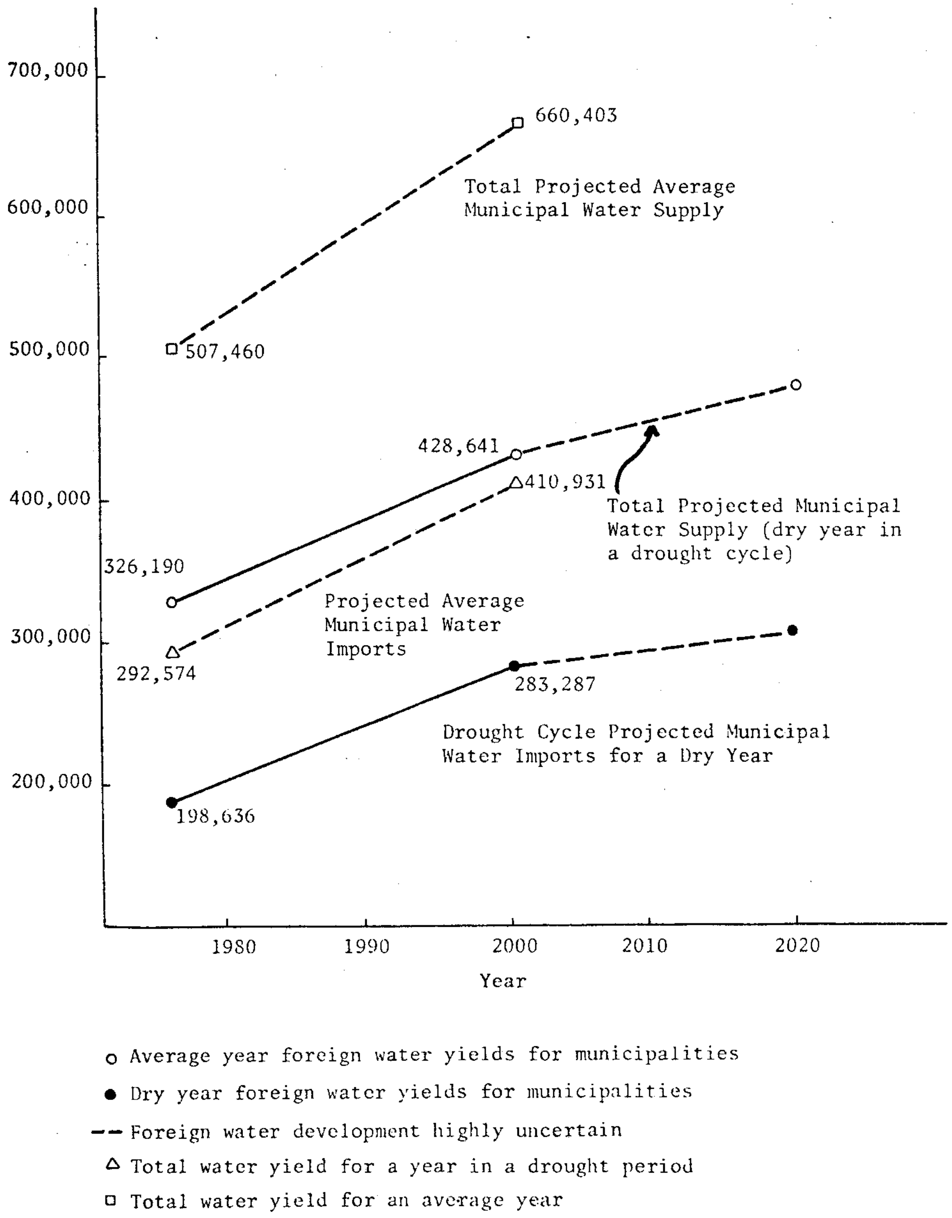


Figure 7-3. Projected total and foreign municipal water supplies.

expensive and difficult area from which to export water. The foreign water that has been imported can be an important working resource for developing water reuse projects.

7.3.2 Municipal Water Demands

Municipal use of water has been rising steadily as the Front Range cities have grown. In 1950 the population in the South Platte River Basin was 860,000; in 1960, 1,207,000; and in 1970, 1,551,000. The 1980 basin population is approximately 2,000,000 with projections for 3,000,000 in the year 2000 and 4,000,000 in the year 2020. Growth, unless accompanied by a decrease in per capita water consumption, means increased water demands.

As a base for water use in the Front Range municipalities, Table 7-8 was prepared based on data developed for the input-output model of the South Platte River Basin done by Colorado State University for the Corps of Engineers. The water diversion and return flows are shown for the seven major Front Range communities and the South Platte Transition sub-basin. The transition sub-basin includes Denver area communities such as Aurora, Thornton, and Westminister that furnish their own water supply. Total municipal water diversions along the Front Range amounted to 298,716 acre-feet in 1970. Of this amount, 212,258 acre-feet was returned to a surface water body. In 1975, 344,669 acre-feet was diverted and 245,000 acre-feet returned. Return flows averaged 71% of diversions for both years.

A return flow factor of 70% is used for this study, based on the 71% average obtained in 1970 and 1975. If lawn irrigation decreases in the future, the return flow percentage could increase. With higher

Table 7-8. South Platte Basin Summary of Selected Municipal Data for 1970 and 1975

Municipality	Year	Water Diversion (acre-feet)	Surface Water Return Flow (acre-feet)	GPCD$_a$[c]	GPCD$_b$[d]	Percent Return Flow[e]	Percent Industrial Use[f]
DENVER	1970	183,029	133,710	210	213	73.0	6.4
	1975	208,198	156,580	215	215	75.2	6.5
BOULDER	1970	15,294	13,305	181	204	85.4	4.5
	1975	16,532	14,106	181	181	85.3	4.2
LONGMONT	1970	8,641	6,653	262	333	70.8	9.8
	1975	9,600	6,643	272	297	66.4	6.6
LOVELAND	1970	5,493	3,418	294	303	61.0	15.9
	1975	7,215	4,014	274	280	54.6	12.0
FORT COLLINS	1970	12,051	9,219	230	249	74.6	8.4
	1975	16,074	12,664	222	235	78.3	1.0
GREELEY	1970	14,697	8,862	322	337	58.4	13.1
	1975	17,830	8,420	289	300	45.2	12.7
CHEYENNE	1970	8,811	6,801	266	266	55.9	16.2
	1975	10,920	7,639	262	262	57.8	16.6
OTHERS-Tansition[g]	1970	50,700	30,290	220	220	70.0[g]	
	1975	58,300	34,934	220	220	70.0[g]	
TOTALS	1970	298,716	212,258				
	1975	344,669	245,000				

[a] 1975 population is based upon the medium population series.

[b] 1975 population is based upon the medium population series.

[c] GPCD$_a$ = (Amount treated and delivered)/(Service population).

[d] GPCD$_b$ = (Amount diverted)/(Service population).

[e] Percent return flow - (STP return flow)/(Amount treated and delivered).

[f] Percent industrial use = (Industrial use)/(Amount treated and delivered).

[g] For 1970, an additional 50,400 AF was diverted from groundwater and 40,480 AF returned to groundwater. For 1975, an additional 58,300 AF was diverted from groundwater and 46,686 AF returned to groundwater.

return flow percentages, reuse systems become more desirable. This is especially true for sequential reuse exchange systems where make-up water must be found for consumptive use losses in the municipal system.

Future water demands are based on the population projections and per capita water use rates shown in Table 7-9. Data in this table provide a range of water need projections. The data in Table 7-9 are not, however, the highest projections available. Table 7-10 contains projections for water use and population based on Denver Water Department data. These projections are the highest available. Denver Water Department projections were made for Denver, Boulder, and Longmont. The most recent population projections from the Larimer-Weld Regional Council of Governments were coupled with 1975 per capita water use rates in Table 7-10 to yield high water need projections for Loveland, Greeley, and Fort Collins.

Increasing per capita water use rates used in Table 7-10 are not likely to occur. All of these cities, except Fort Collins, have adopted policies leading to water meter installation. The increasing costs of water combined with water metering will lead to decreasing per capita water consumption. The reason for calculating these high water needs is to show the highest possible municipal water demand in relation to water available for sequential reuse exchange.

A summary of municipal demand projections for communities along the Front Range is shown in Table 7-11. A graphical presentation of the same data is shown in Figure 7-4. Projections for the year 2000 vary from a low of 506,000 acre-feet to a high of 813,000 acre-feet. The year 2000 projection varies by 307,000 acre-feet between the high and

Table 7-9. Future Municipal Water Needs
(U.S. Army Corps of Engineers, 1977)

City		Year	Service Area Population	Average Per Capita Demand (gpcd)	Annual Demand (ac-ft)	Annual Return Flow (ac-ft)
Denver	High	2000	1,469,000	220	361,865	253,305
		2020	1,906,000	220	469,462	328,623
	Medium	2000	1,224,300	191	261,770	183,239
		2020	1,474,700	167	275,765	193,035
Boulder	High	2000	162,000	220	40,051	28,036
		2020	217,900	220	53,673	37,672
	Medium	2000	108,600	191	23,224	16,257
		2020	119,400	167	22,325	15,627
Longmont	High	2000	57,400	220	14,139	9,897
		2020	77,000	220	16,553	11,587
	Medium	2000	47,900	191	10,243	7,533
		2020	59,600	167	11,144	7,801
Loveland	High	2000	37,300	220	10,222	7,155
		2020	45,600	220	11,232	7,862
	Medium	2000	33,900	191	7,250	5,076
		2020	39,600	167	7,404	5,183
Fort Collins	High	2000	99,400	220	27,218	19,053
		2020	121,700	220	29,977	20,984
	Medium	2000	90,300	191	19,640	13,748
		2020	105,700	167	19,764	13,835
Greeley	High	2000	78,200	220	19,262	13,483
		2020	93,800	220	23,105	16,173
	Medium	2000	71,200	191	15,312	10,718
		2020	81,600	167	15,257	10,680
Cheyenne	High	2000	122,900	220	32,539	22,777
		2020	141,400	220	34,830	24,381
	Medium	2000	91,500	191	19,580	13,706
		2020	103,900	167	19,427	13,599
Others: Transition	High	2000	813,000	220	200,282	140,197
		2020	1,044,000	220	257,157	180,010
	Medium	2000	695,400	191	148,711	104,098
		2020	834,400	167	156,015	109,210
Others: Mountains	High	2000	72,600	220	17,883	12,518
		2020	89,200	220	21,972	15,380
	Medium	2000	68,000	191	14,542	10,179
		2020	80,800	167	15,108	10,576
Others: Plains	High	2000	199,500	220	49,141	34,399
		2020	243,700	220	60,028	42,020
	Medium	2000	186,000	191	39,776	27,843
		2020	218,400	167	40,886	28,585

Table 7-10. Maximum Potable Municipal Water Use Requirements to Year 2020

	1990	2000	2020
DENVER[a]	1,302,000 pop. 233 gpcd 340,000 AF	1,609,000 pop. 235 gpcd 423,000 AF	2,111,000[b] pop. 239 gpcd 565,000 AF
BOULDER[a]	132,000 pop. 185 gpcd 27,300 AF	164,000 pop. 190 gpcd 34,900 AF	228,000[b] pop. 200 gpcd 53,400
LONGMONT[a]	61,670 pop. 275 gpcd 19,000 AF	79,940 pop. 280 gpcd 25,100 AF	116,480[b] pop. 290 gpcd 37,800 AF
LOVELAND[c]	43,400 pop. 274 gpcd 13,320 AF[f]	60,900 pop. 274 gpcd 18,690 AF	95,900[d] pop. 274 gpcd 29,400 AF
GREELEY[c]	92,800 pop. 289 gpcd 30,040 AF	115,850 pop. 289 gpcd[e] 37,500 AF	161,950[d] pop. 289 gpcd 52,400 AF
FORT COLLINS[c]	112,500 pop. 222 gpcd 28,000 AF	149,400 pop. 222 gpcd[e] 37,150 AF	223,200[d] pop. 222 gpcd 55,500 AF
CHEYENNE	106,700[g] pop. 262 gpcd 31,310 AF	122,900 pop. 262 gpcd[e] 36,070 AF	141,400 pop. 262 gpcd 41,500 AF
TOTAL	488,970 AF	612,410 AF	835,000 AF

[a] Population projections and water use rates from the Denver Water Department (1975).

[b] The year 2020 population projections and water use rate calculated by adding differences between 2010 and 2000 to the year 2010.

[c] Population projections from Larimer-Weld Regional Council of Governments, personal contact with John Rutstein, Director, on May 6, 1980. Projections were updated in the fall of 1979.

[d] Year 2020 population projections calculated by taking the difference between the year 2000 and the year 1990 projection, multiplying by two, and adding result to year 2000 projections.

[e] Water use rates in gallons per capita per day based on 1975 use rates containted in the U.S. Army Corps of Engineers (1975).

[f] AF/year = gpcd x population x 365 days per year/325,851 gallons per AF.

[g] Population projections from U.S. Amry Corps of Engineers (1975).

Table 7-11. Summary of Municipal Demand Projections

		LOW[a]		MEDIUM[b]		HIGH[c]	
	Year	gpcd	AF/Year	gpcd	AF/Year	gpcd	AF/Year
DENVER	1975			215	208,198		
	2000	191	261,770	220	361,865	235	423,000
	2020	167	275,765	220	469,462	239	565,000
BOULDER	1975			181	16,532		
	2000	191	23,224	220	40,051	190	34,900
	2020	167	22,325	220	53,673	200	53,400
LONGMONT	1975			272	9,600		
	2000	191	10,243	220	14,139	280	25,100
	2020	167	11,144	220	16,553	290	37,800
LOVELAND	1975			274	7,215		
	2000	191	7,250	220	10,222	274	18,690
	2020	167	7,404	220	11,232	274	29,400
FORT COLLINS	1975			222	16,074		
	2000	191	19,640	220	27,218	222	37,150
	2020	167	19,764	220	29,977	222	55,500
GREELEY	1975			289	17,830		
	2000	191	15,312	220	19,262	289	37,500
	2020	167	15,257	220	23,105	289	52,400
CHEYENNE	1975			262	10,920		
	2000	191	19,580	220	32,539	262	36,070
	2020	167	19,427	220	34,830	262	41,500
OTHERS-TRANSITION	1975	220	118,553	220	118,553	220	118,553
	2000	191	148,711	220	200,282	220	200,282
	2020	167	156,015	220	257,157	220	257,157
TOTAL	1975		404,922		404,922		404,922
	2000		505,730		705,578		812,692
	2020		527,101		895,989		1,092,157

[a] Summary of medium projections from Table 7-9.

[b] Summary of high projections from Table 7-9.

[c] Summary using Denver Water Department and Larimer-Weld Regional Council of Governments population projections.

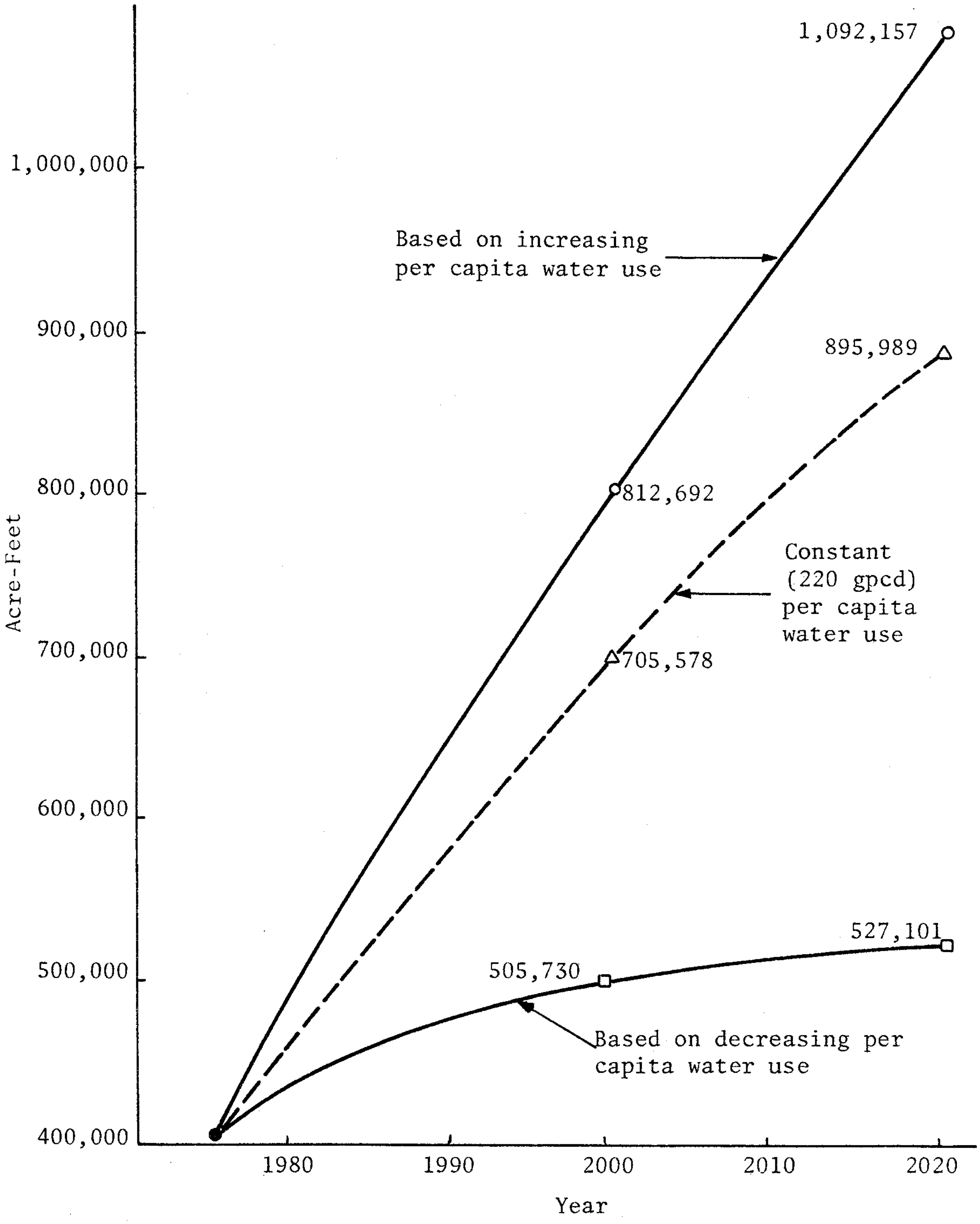


Figure 7-4. Front Range municipal water demands, 1975-2020.

and low figures. The high year 2000 figure is more than 100% higher than 1975 usage. A doubling of municipal water usage in 25 years is not likely to occur because of the increasing cost of municipal water supplies. The high figures are used in this research as the maximum possible level of municipal demand to evaluate reuse potential.

7.3.3 Reuse Potential of Foreign and Native Storage Rights

Data on native and foreign basin water supplies, municipal supplies and municipal demands has been presented thus far. Now, the potential of water reuse is evaluated for meeting increased municipal water demands. The return flows from foreign and native storage rights are compared with the water supply shortfalls found when subtracting future municipal demands from the projected water supply.

Tables 7-12 and 7-13 summarize Front Range municipal water supplies and demands. In Table 7-12, year 2000 native storage and native direct flow rights numbers are not intended to be accurate representations of the future conditions. Rather, native storage includes only storage projects deemed very likely to be constructed or acquired. The acquisition of municipalities of native direct flow rights has not been determined and may well be a function of reuse project implementation.

Data from Tables 7-12 and 7-13 are shown in Figure 7-5. In 1975, a potential shortfall of 81,000 acre-feet existed between supply and demand if a drought year had occurred. In the year 2000, a potential shortfall of 401,000 acre-feet exists between the high municipal demand and the droughtyear supply. The high demand exceeds the average supply by 152,000 acre-feet for the year 2000. By the year 2020, the high

Table 7-12. Front Range Municipal Water Supply: 1975 and 2000[a]

	Year	Municipal Water Supply	
		Dry (acre-feet)	Average (acre-feet)
Foreign Water	1975	198,636 (161,157)[b]	292,574 (245,700)[c]
	2000	283,287 (245,808)[b]	428,641 (381,794)[c]
Native Storage	1975	31,945	70,850
	2000	32,035[d]	85,106[d]
Native Direct Flow	1975	95,609	144,036
	2000	95,609	146,656[d]
TOTAL	1975	326,190	507,460
	2000	410,931	660,403

[a] Based on data from Table 7-9

[b] Foreign water supply excluding 37,479 acre-feet of CBT water.

[c] Foreign water supply excluding 46,847 acre-feet of CBT water.

[d] Year 2000 projections include only increases in water supply that are relatively certain. Acquisition of direct flow native water rights may actually be well in excess of these figures.

Table 7-13. Total Front Range Municipal Water Demands: 1975-2020[a]

Year	Low (acre-feet)	Medium (acre-feet)	High (acre-feet)
1975	404,922	404,922	404,922
2000	505,730	705,578	812,692
2020	527,101	895,989	1,092,157

[a] Based on data in Table 7-11.

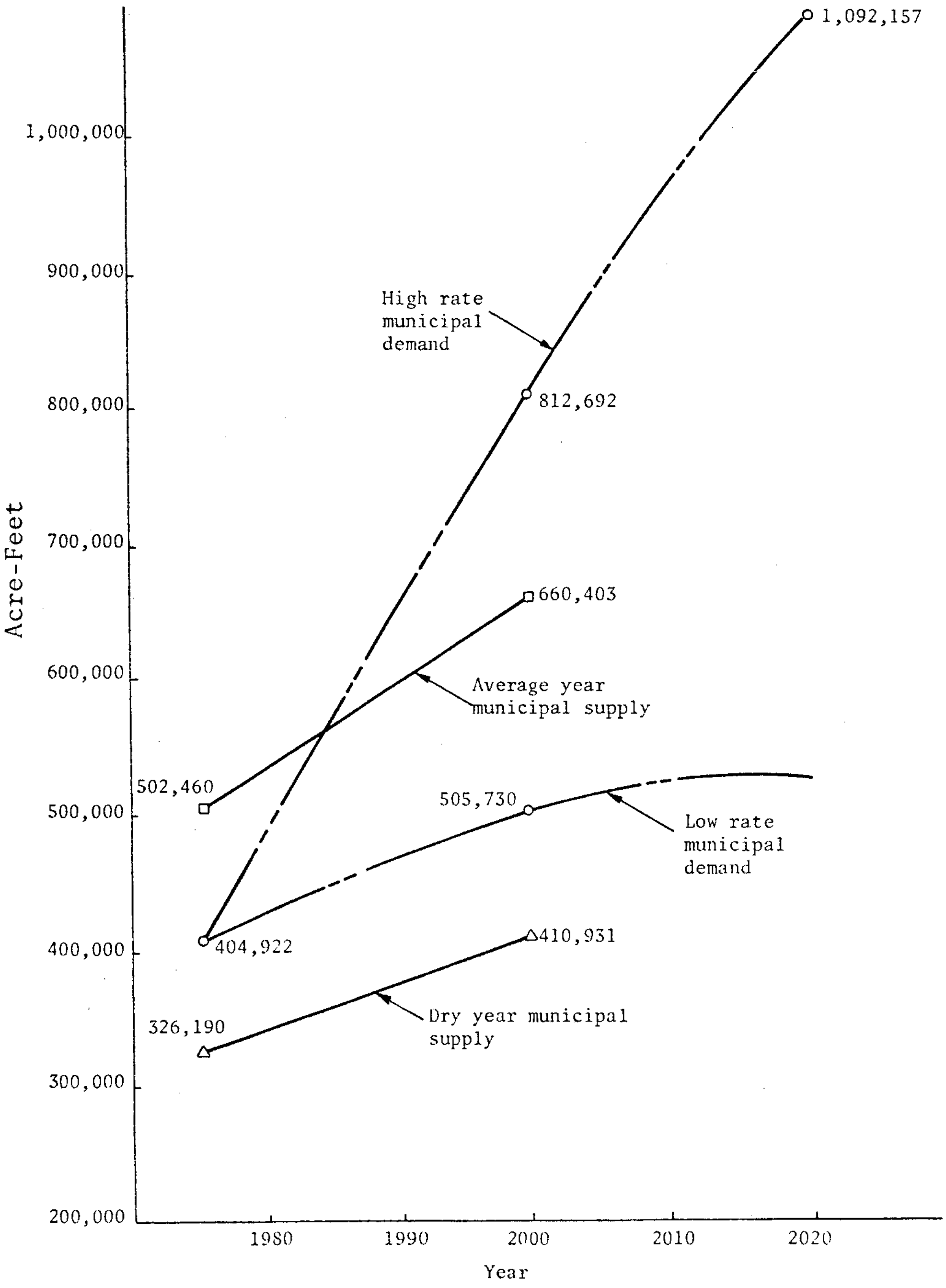


Figure 7-5. Front Range municipal water supply and demand: 1975-2020.

demand exceeds year 2000 drought year supply by 681,000 acre-feet and year 2000 average year supply by 432,000 acre-feet.

All of the demand-supply relationships for the years 1975, 2000, and 2020 are shown in Table 7-14. The numbers listed in this table show the Front Range municipal water supply needs, assuming that only the most feasible water import projects and native storage projects and acquisitions are constructed by the year 2000. The negative figures in Table 7-14 can be considered potential needs that might be met by utilizing water reuse alternatives. The "high" demand shortfalls are excessive due to the increasing per capita water use assumptions made for the demand calculations. These high demand shortfalls may not be very "realistic" but they do serve to show the potential of water reuse in meeting future municipal water demands.

Demand shortages are higher for drought years than average water supply years as shown in Table 7-14. The quantity of return flows available from foreign and native storage water supplies is also lower because of the limited supply during drought years. Figures 7-6 and 7-7 depict the dry year and average year shortfalls and surpluses and the return flows from foreign and native storage water. Return flows are based on a 70% return of the original water supply quantity.

Return flows from foreign water are high enough to meet drought year low demand shortages out to the year 2020 as shown in Figure 7-6. Either recycle reuse or sequential reuse exchange of return flows from the foreign water could be used to meet the shortfalls. Dry year, high demand shortages are far in excess of foreign and native water return flows for the years 2000 and 2020. For the year 2000, return flows from foreign and native dry year water supplies amount to 194,000 acre-feet while the

Table 7-14. Surplus or Shortfall of Demand Versus Supply for Front Range Municipal Water Supplies[a]

Year		Low (acre-feet)	Medium (acre-feet)	High (acre-feet)
1975	Dry	- 78,732[b]	- 78,732	- 78,732
	Average	+102,538[c]	+102,538	+102,538
2000	Dry	- 94,799	-294,647	-401,761
	Average	+154,673	- 45,175	-152,289
2020	Dry	-116,170	-485,058	-681,226
	Average	+133,302	-235,586	-431,754

[a] Based on Table 7-12 and 7-13.

[b] The minus sign indicates a shortfall, i.e., demand exceeds supply.

[c] The plus sign indicates a surplus, i.e., supply exceeds demand.

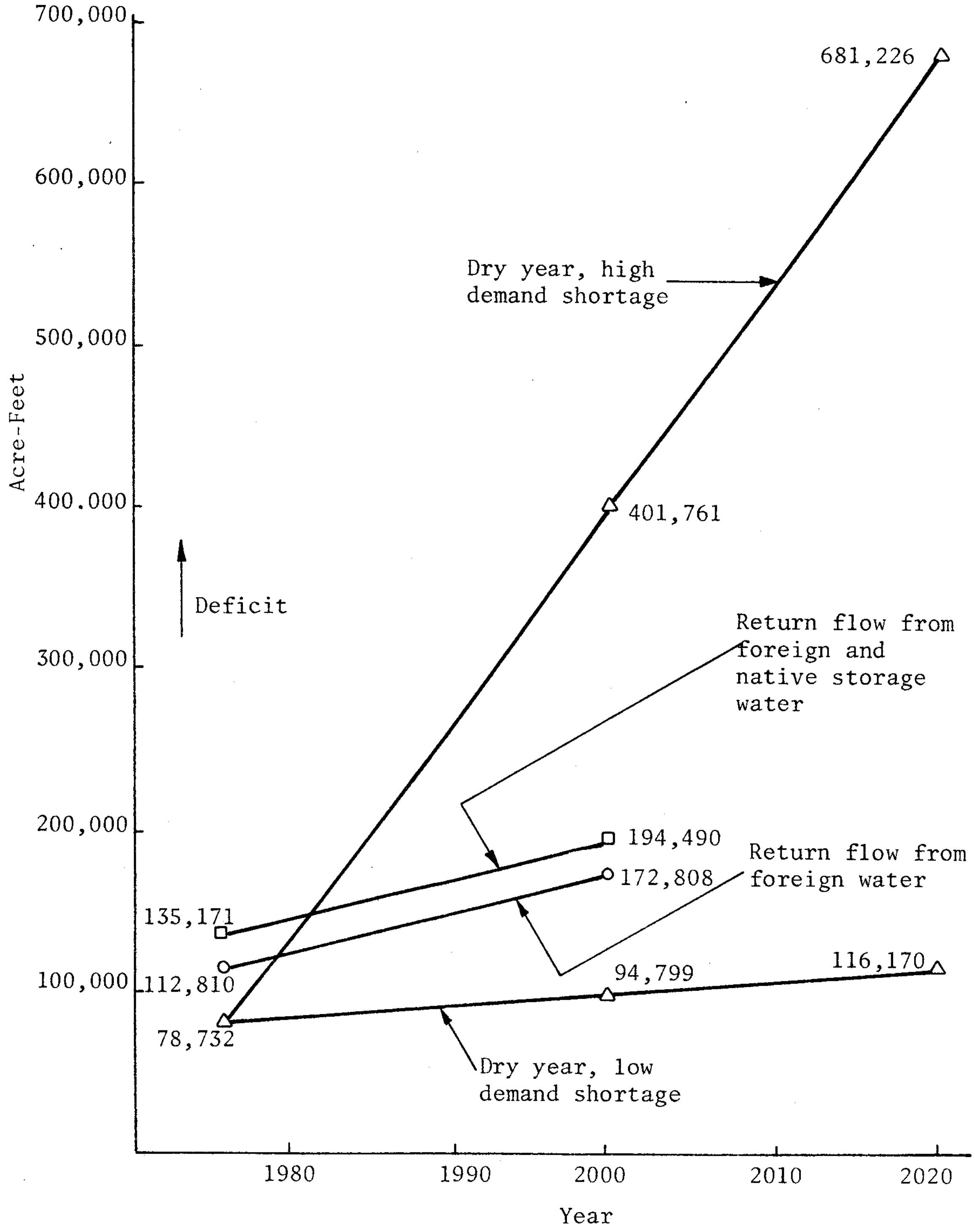


Figure 7-6. Potential of water reuse to meet dry year water demand shortfall (based on data from Tables 7-14 and 7-16.

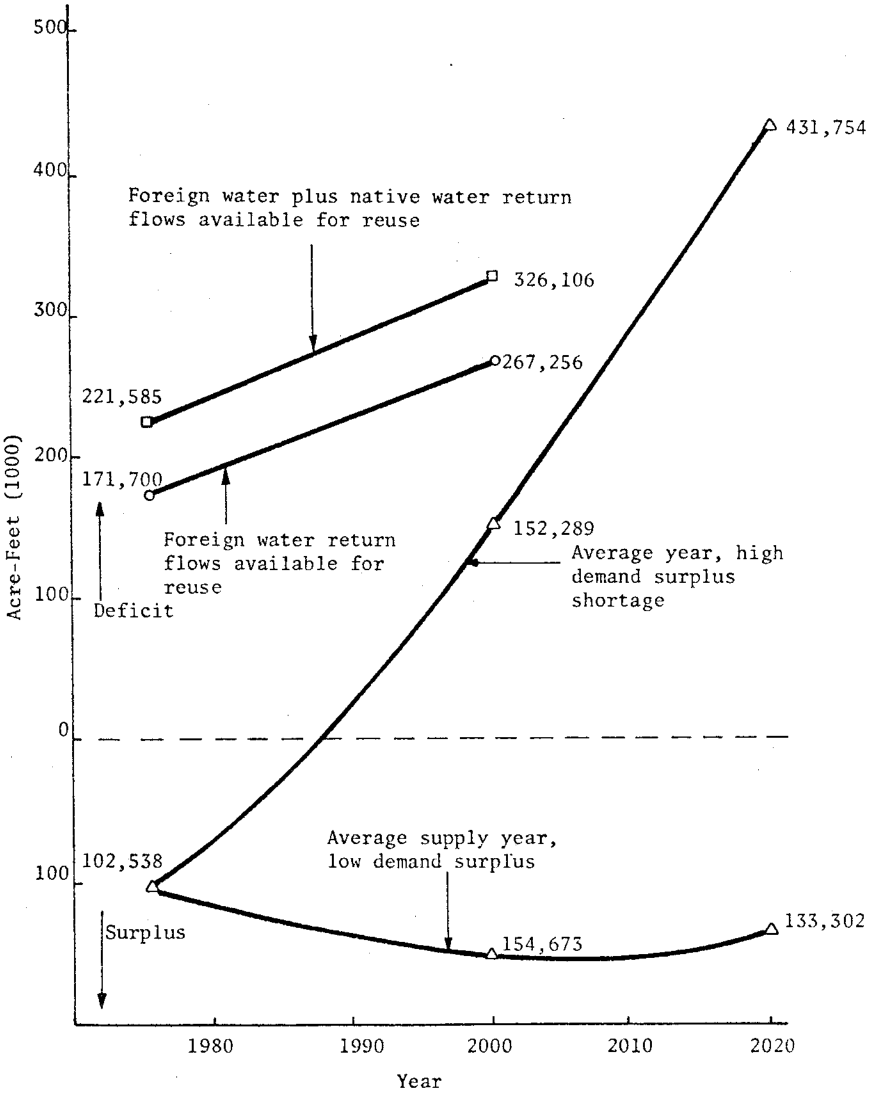


Figure 7-7. Potential of water reuse to meet average water demand shortfall for municipal water supply (based on data from Tables 7-14 and 7-16).

dry year high demand shortage is 402,000 acre-feet. The net shortfall is 208,000 acre-feet. For the year 2020, the high demand net shortfall is 487,000 acre-feet.

During the average water year, shown in Figure 7-7, reuse of return flows from foreign water would be adequate to meet the average year high demand water shortfall for the year 2000. The return flows for the year 2000 from foreign and native storage water is 326,000 acre-feet and the demand shortfall is 152,000 acre-feet for a net reuse surplus of 174,000 acre-feet. For the year 2020, the high demand shortage exceeds the foreign and native water storage return flow reuse potential by 106,000 acre-feet.

The reuse potential of return flows from foreign and native storage waters has been examined first because reuse of these waters presents the fewest legal problems. The owners of foreign and native storage waters can allocate the return flows in the manner most beneficial to the owner.

7.3.4 Reuse Exchange of Native Direct Flow Rights

When shortfalls occur beyond the reuse levels of foreign and native storage water return flows, sequential reuse exchange of native direct flow water can be used to make up the difference. A two-step check can be made by comparing the native water supply along the Front Range with the net remaining water shortfall: (1) the municipal ownership of native water supplies must be subtracted from the total native water supply, and (2) the municipal shortfall quantity is compared with the net native water supply. If the net native water supply is larger than the municipal shortfall, the potential exists for working out a sequential reuse exchange agreement with agricultural water rights owners.

Using data from Table 7-7, the municipal ownership of native direct flow water rights is 144,036 acre-feet for the average year and 95,609 acre-feet for the drought year. To these figures, 42,290 acre-feet should be added for the average year and 56% of 42,290 acre-feet or 23,690 acre-feet for the drought year. This is done to include municipalities in the South Platte Transition sub-basin other than Denver and Aurora, and to include mountain sub-basin municipalities. Total Front Range municipal ownership of native water rights for an average year is 257,000 and 151,230 acre-feet for a drought year.

The long-term average yield of the mountain sub-basins is given in Table 7-4 as 1,155,601 acre-feet. The drought year yield is 699,448 acre-feet. After subtracting out municipal ownership of native waters, 898,600 acre-feet for the average year and 548,220 acre-feet for the drought year remains. The net remaining native surface water supplies can then be compared with the high demand shortages. For the average water supply year, 898,600 acre-feet of water is available for exchange to meet the unsatisfied year 2020 demand of 106,000 acre-feet, or a ratio of 8.5 to 1 as shown in Figure 7-7. During the year 2000 drought, 548,220 acre-feet of water is available to meet sequential reuse exchange needs of 207,000 acre-feet. The ratio in the year 2000 is 2.6 to 1. In the year 2020, the 548,220 acre-feet is still available, but the high demand drought year deficit after reuse as foreign and native storage water return flows is 487,000 acre-feet as shown in Figure 7-6. The exchange ratio is 1.1 to 1.

The exchange ratio compares the amount of water theoretically available for exchange with the demand for exchange water. When the ratio is greater than 2.0, municipalities will encounter minor difficulties in overcoming pre-existing agreements between various water using entities and difficulties with physical transfer constraints. At a ratio of 1.1 to 1, it would be very difficult, if not impossible, to make the necessary exchange agreements without major modifications of the existing level and water management entities. A centrally controlled basin water management agency would be necessary to accomplish the high level of transfers and exchanges.

7.4 Summary

The sequential reuse exchange form of reuse appears adequate to meet all but the very highest long-range municipal water needs. The reuse of foreign and native water return flows is sufficient to meet the drought year, low demand shortages for both the years 2000 and 2020. Actual implementation of sequential reuse exchange in the basin would be a mixture of reuse forms. The comparison made here demonstrates that sequential reuse exchange can be used to meet all but the most severe drought demand scenarios.

CHAPTER 8

WATER REUSE POTENTIAL OF THE CACHE LA POUDRE RIVER BASIN

The Cache la Poudre River Basin (CLPRB) was selected for an in-depth analysis of its water reuse potential because of its diverse water uses, rapid rate of urban growth, increasing water demands, and the complex nature of its water system. The basin and its major communities are shown in Figure 8-1. The CLPRB is characteristic of Front Range sub-basins of the South Platte River Basin. The water supply originates in the mountains, is seasonal in character, and is subject to large fluctuations in annual yield. Originally, agriculture was the primary economic activity in the CLPRB. The agricultural economy has been supplanted by an urban one over the past thirty years and rapid urban growth is predicted to continue.

While the economy of the basin has shifted away from agriculture, over 90% of the water still belongs to agricultural users. Less than 10% of the CLPRB surface water resources receive first use by municipalities. Municipal demand for water, however, continues to grow and, consequently, water resources are being shifted from agricultural to urban uses. Planned sequential reuse of water has the potential to reduce the costs of acquiring water while maintaining a stable agricultural base.

The focus of this chapter is the development of water reuse alternatives for the cities of Fort Collins and Greeley. The development of

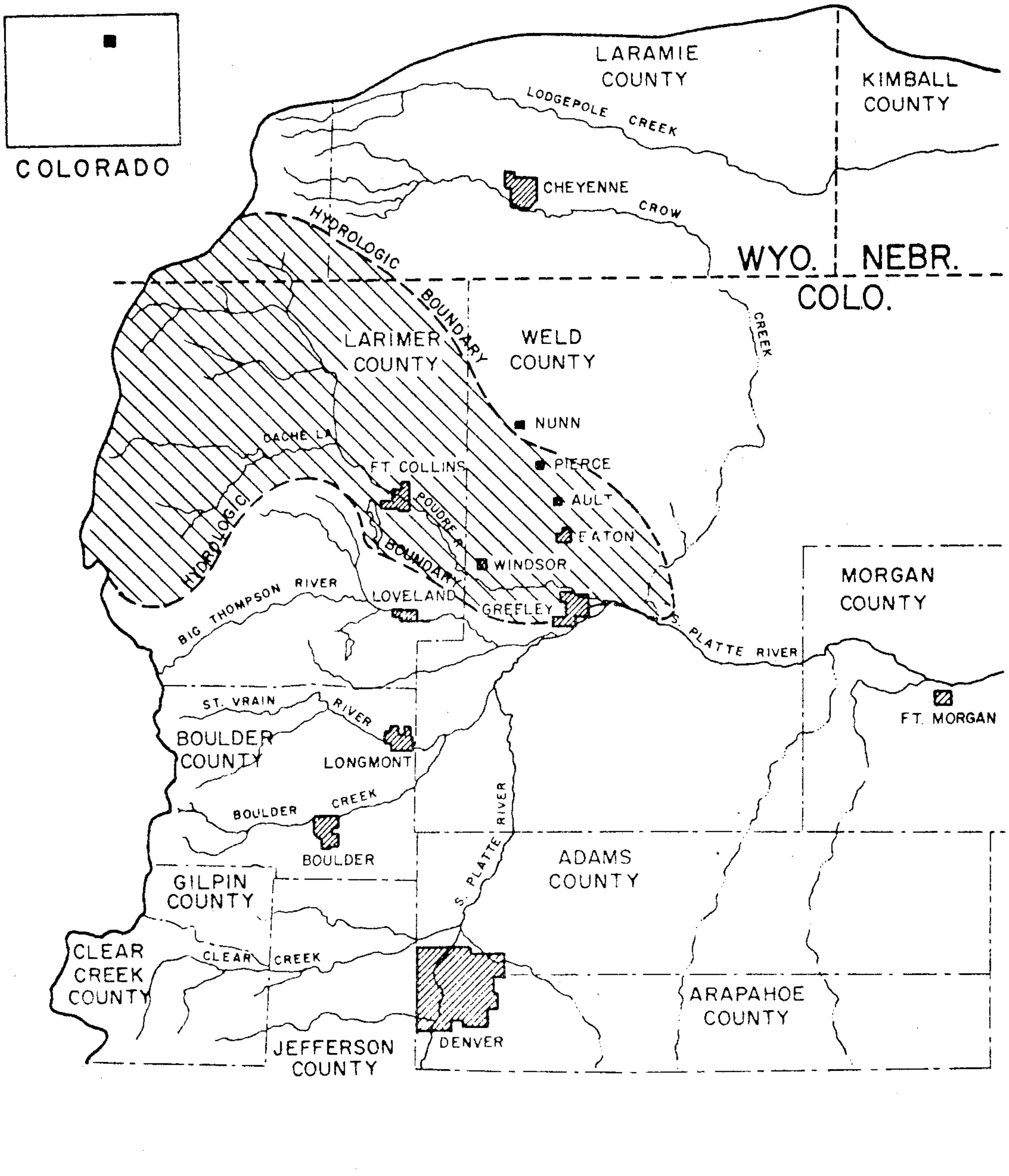


Figure 8-1. Location of the Cache la Poudre River Basin, Colorado.

these alternatives follows the reuse methodology set forth in Chapter 6 and draws on the information on water reuse forms, water quality law, and appropriate water law generated in earlier chapters.

The first two steps of the alternative development methodology consist of developing a comprehensive informational base for the water resources of the basin. This information was developed but has not been included in this volume. The determination of the ownership, distribution, and storage of the water resources in the basin is step three of the methodology. This is the starting point for this chapter.

The distribution, ownership, and storage of water in the basin controls, to a certain extent, the reuse alternative available to Fort Collins and Greeley. The information developed on these aspects of the water system is used in conjunction with the water resources of the two cities to develop the water reuse alternatives. The City of Fort Collins-Platte River Power (PRPA)-Water Supply and Storage water reuse exchange agreement serves as an integral part of several of the reuse alternatives. CBT and Windy Gap water is used as a tool in moving and storing water in locations advantageous to Fort Collins and Greeley. The alternatives developed herein are a demonstration of the reuse methodology and show the practical application of the theory developed in earlier chapters.

8.1 Characteristics and Water Supply of the Cache la Poudre River Basin

The general characteristics of the CLPRB are given in Table 8-1. The CLPRB is typical of other basins along the Front Range. The western half of the basin is mountainous and used for recreational activities,

Table 8-1. Characteristics of the Cache la Poudre River Basin (U.S. Geological Survey, 1977; U.S. Army Corps of Engineers, 1977)

Item	Description
Area	1,877 square miles - 50% plains; 50% mountains. 1,717 square miles in Colorado, 160 square miles in Wyoming
Elevation	Mountain peaks at 13,000+ feet on west side of basin Cache la Poudre River joins the South Platte River on the east side of the basin at an elevation of 4,610 feet
Precipitation	20-40 inches per year in the mountains. 12-16 inches per year in the plains
Major River	Cache la Poudre River (CLPR): total length is 85 miles; 50 miles from origin in Rocky Mountain National Park to its entrance onto the plains at the canyon mounth; 35 miles from canyon mounth to junction with South Platte River
Water Supply	427,700 acre-feet total average annual available surface water supply, including both native and foreign water 274,800 acre-feet average annual flows from Cache la Poudre River at the canyon mouth. 110,400 acre-feet per year of Colorado Big Thompson Project water imported from the Colorado River Basin by the Northern Colorado Water Conservancy District 42,500 acre-feet average annual yield of other foreign water imports.
Population	Approximately 140,000 in 1980
Major Cities	Fort Collins: population 69,000 in 1980; projected at 140,000 in the year 2000 Greeley: population of 60,000 in 1980; projected at 140,000 in the year 2000.
Major Activities	Light industry, agriculture, education
Irrigated Area	Approximately 250,000 acres
Counties	Larimer and Weld

while the eastern half is composed of flat semi-arid plains used for farming and ranching. Approximately 250,000 acres in the basin are irrigated with water from spring snowmelt from the mountains and foreign water imports. The spring runoff is either diverted and directly applied or diverted and stored in reservoirs for use later in the summer when mountain runoff is a small fraction of that in May and June.

The relatively flat north-south band of land between the Foothills and the plains is the scene of rapid urban growth along the Front Range. Fort Collins is similar to other Front Range communities such as Loveland, Longmont and Boulder. Greeley is located 30 miles to the east of Fort Collins near the junction of the Cache la Poudre River with the South Platte River. The Fort Collins economy is based on education, light industry and government. Greeley's economy, on the other hand, is primarily agricultural. Greeley is the trade center of Weld County which is one of the most productive agricultural counties in the United States.

The Cache la Poudre River Basin (CLPRB) has three sources of water supply: (1) native water, (2) Colorado Big Thompson (CBT) water, and (3) foreign water imports from the Laramie, Michigan, and Colorado river basins. CBT water, although foreign in origin, is classified separately because of the unique features of the water supply source. Table 8-2 summarizes the water supply data for the basin.

The schematic in Figure 8-2 shows the general location of the major water features of the CLPRB. Most of the native water of the basin originates in the mountainous western half of the CLPRB. All foreign water is imported into the basin along its western boundary. CBT water is brought in from the south along the foothills via the Charles Hansen

Table 8-2. Water Supplies of the Cache la Poudre River Basin

	Native acre-feet/year	Foreign acre-feet/year	CBT acre-feet/year	Total acre-feet/year
AVERAGE	274,800	42,500	110,400	427,700
MINIMUM	121,540	33,180[a]	133,920[c]	288,640
THREE-YEAR DROUGHT MINIMUM	164,400	38,290[b]	111,600[d]	314,290

[a] The lowest foreign water diversions during the 1953-1956 drought occurred in 1954 when foreign water diversions were 78 percent of average and the Michigan Ditch yielded no water due to maintenance problems [42,540 (.78) = 33,180].

[b] During any three-year period from 1953-1956, foreign water yields averaged at least 90 percent of the long-term average yield [42,540 (0.9) = 38,290].

[c] Assume 90 percent allotment during a one-year drought [310,000 (0.9)(0.43) = 133,920].

[d] Assume a 90, 75, and 60 percent allotment during a three-year drought [310,000 (0.75)(0.48) = 111,600 acre-feet].

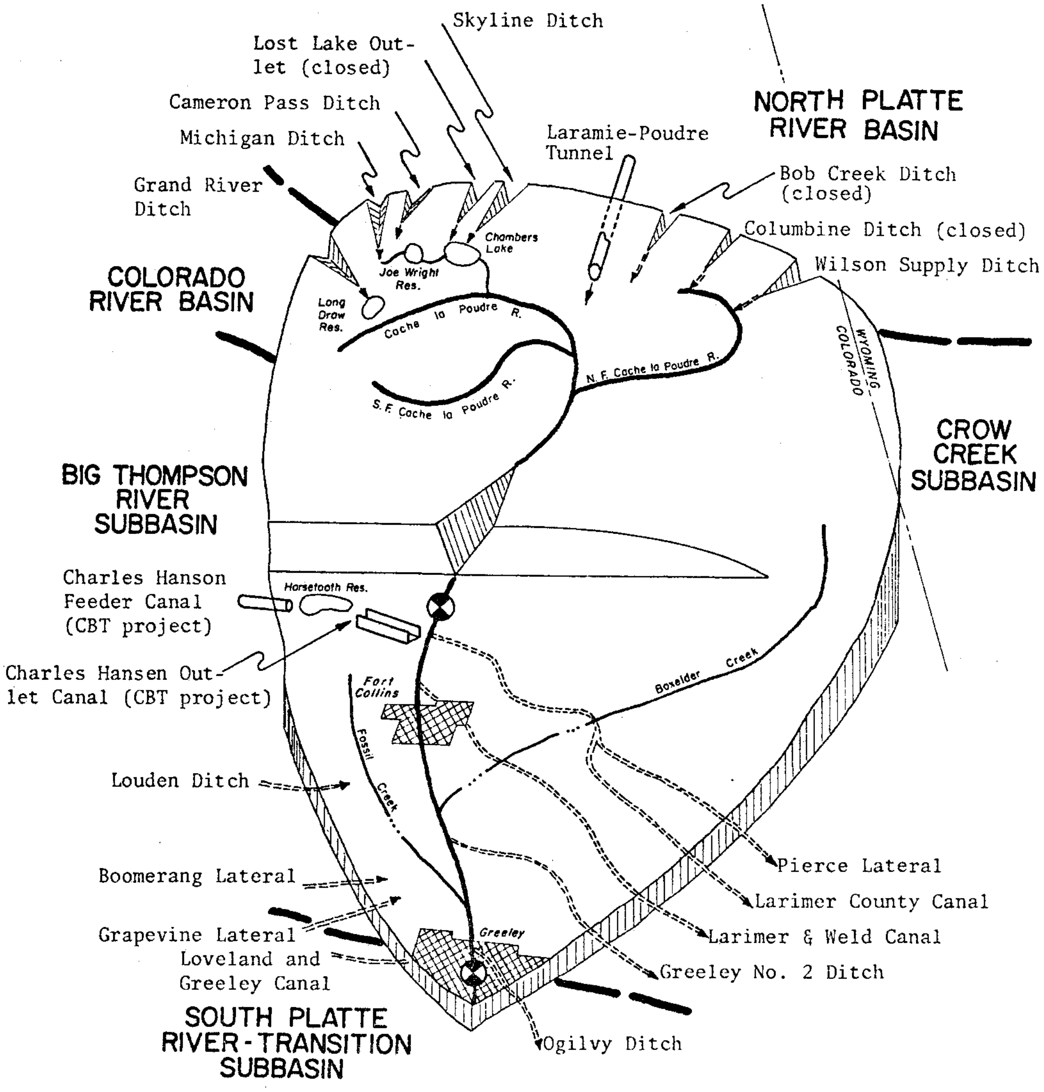


Figure 8-2. Schematic of the Cache la Poudre River sub-basin.

Feeder Canal from the Big Thompson River Basin. Almost all irrigation and municipal-industrial water use occurs on the plains in the eastern half of the basin.

The water quality of the raw water supply originating in the mountains is uniformly high. This high quality extends to native, foreign and CBT water in the CLPRB. The mountain water originates from snowmelt which has a total dissolved solids (TDS) level near zero. The mountain rocks are primarily granitic and impart very little dissolved solids to the water. Figure 8-3 depicts the TDS levels in the Cache la Poudre as the water moves downstream. By the time the waters reach the mouth of the canyon, the TDS level has increased to an average of 65 mg/ℓ. At the Fort Collins Wastewater Treatment Plant No. 2, river mile 43, the TDS level has climbed dramatically. At the junction of the Cache la Poudre River with the South Platte River, the average TDS level is 1210 mg/ℓ. The increase in TDS levels is due to the diversion of most of the stream flow above Fort Collins and streamflows from Fort Collins on downstream consisting mainly of return flows from agricultural irrigation.

8.2 Distribution, Storage and Use of Agricultural Water in the CLPRB

The Cache la Poudre River Basin has an extensive system of mountain and plains reservoirs and, on the plains, a complex system of irrigation canals interlinking the reservoirs. Plate 8-1 (see map pocket) is a schematic of the irrigation system while Figure 8-4 is a scale map of the same system. Table 8-3 gives the names, capacities and ownership of the reservoirs.

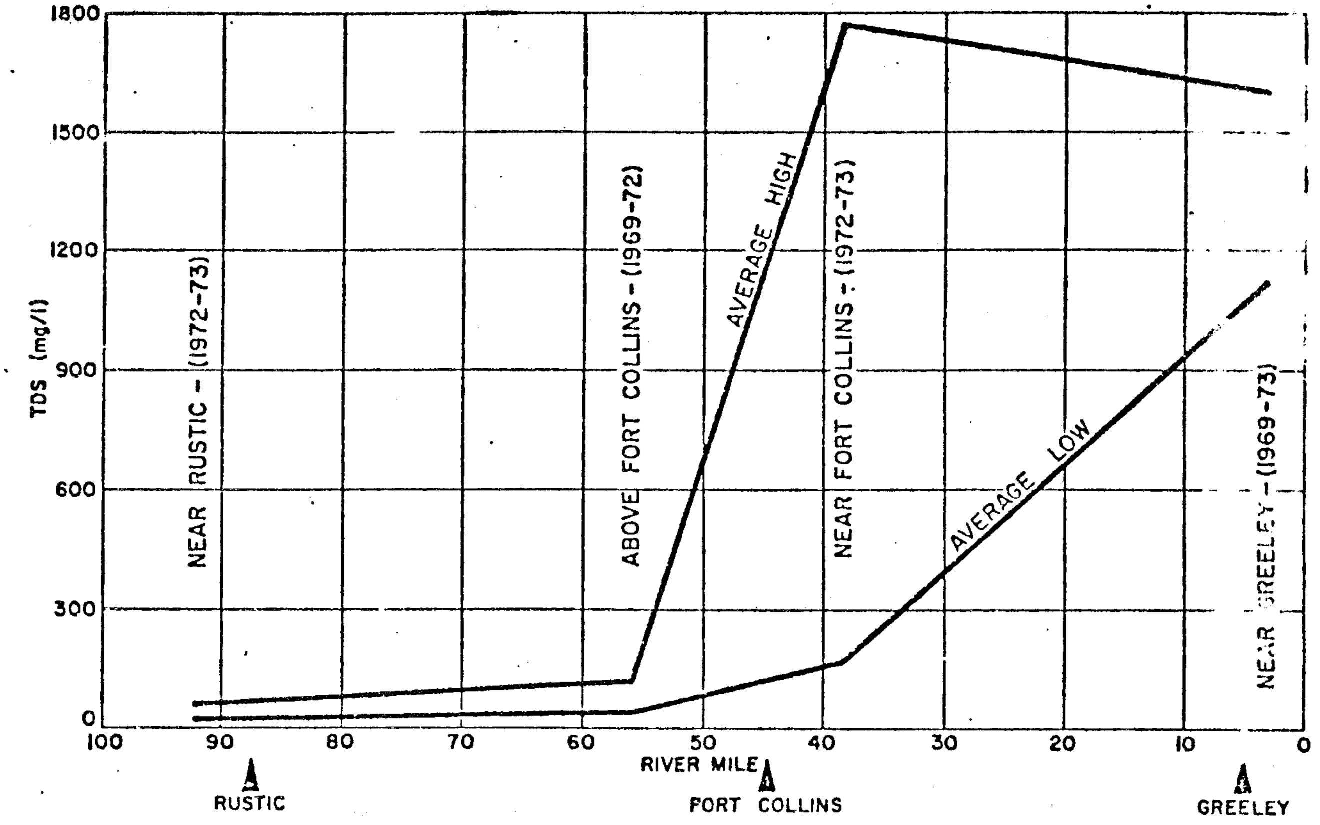


Figure 8-3. Total dissolved solids profile, Cache la Poudre River (Colorado Department of Health, 1974).

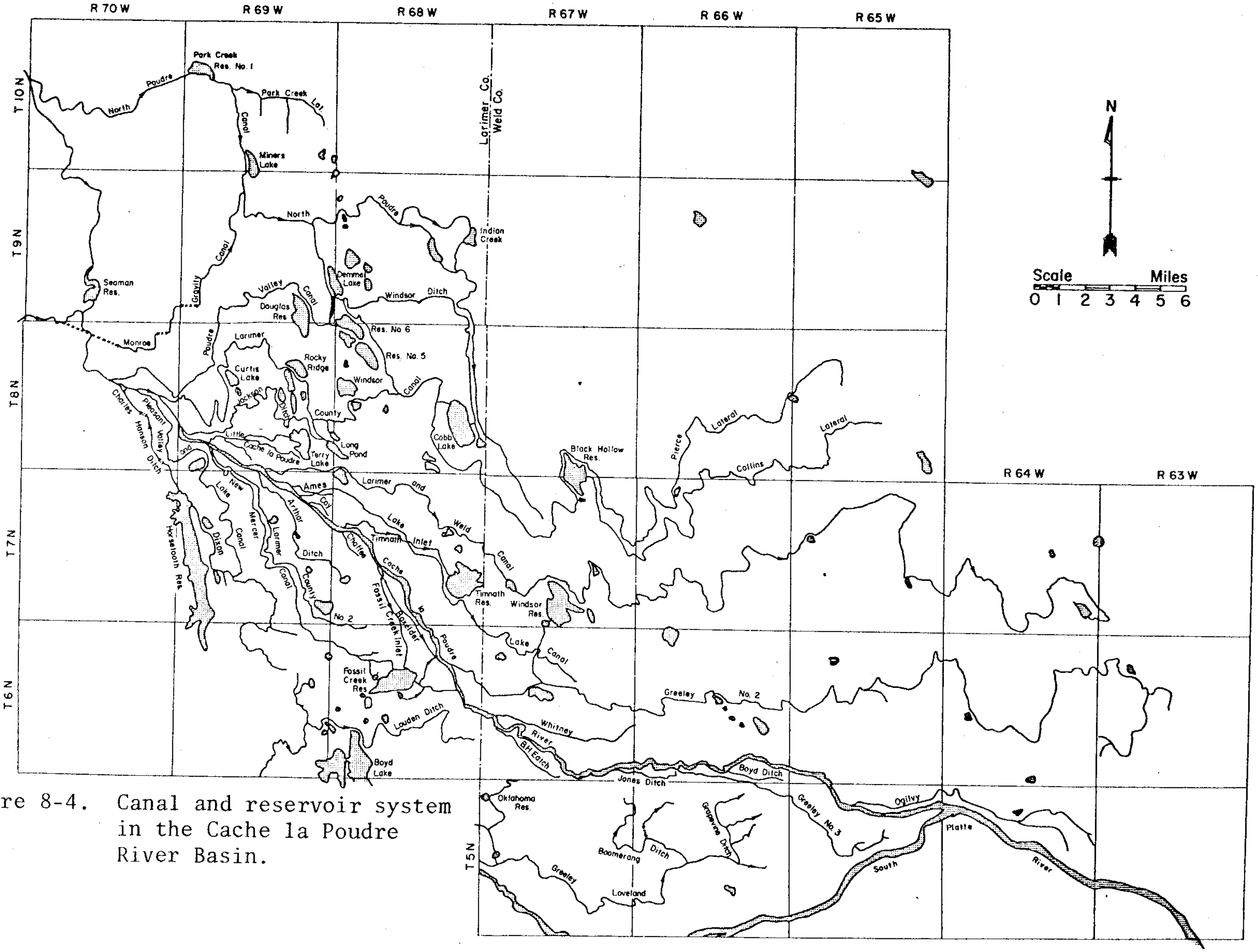


Figure 8-4. Canal and reservoir system in the Cache la Poudre River Basin.

Table 8-2. Major Reservoir Characteristics for CLPRB (Neutze, 1980; Evans, 1971; Klooz, 1981)

Reservoir/Lake	Owner	Surface (acres)	Evaporation (feet)	Evaporation (acre-feet)	Safe Capacity (acre-feet)
Chambers Lake (M)	WSSC	227	2.6	590	8,824
Comanche Res. (M)	Greeley	41	2.6	107	2,256
Long Draw Res. (M)	WSSC	332	2.6	863	10,519
Barnes Meadow (M)	Greeley	81	2.6	211	2,349
Joe Wright (M)	Fort Collins	---	2.6	---	7,161
Hourglass (Big Beaver)(M)	City of Greeley		2.6		1,693
Peterson Res. (M)	City of Greeley		2.6		892
Eaton (Worster) Res. (M)	Divide Canal & Res. Co.*		2.6		3,749
Horsetooth (M)	USBR	1,389	3.5	4,862	151,752
Halligan (M)	North Poudre	135	2.6	351	6,428
Seaman Res. (M)	Greeley	101	2.6	263	5,008
Claymore Lake	Pleasant Valley	74	3.5	259	978
Black Hollow	WSSC	377	3.5	1,320	7,486
Terry Lake	Larimer & Weld Res. Co.	395	3.5	1,383	8,028
Cob Lake	Windsor RC	568	3.5	1,988	22,300
North Poudre 5	North Poudre	305	3.5	1,068	7,217
North Poudre 6	North Poudre	107	3.5	375	4,500
Long Pond	WSSC	219	3.5	767	4,766
Fossil Creek	North Poudre	475	3.5	1,663	11,100
Timnath Res.	Cache la Poudre Res. Co.	523	3.5	1,831	10,070
No. 8	Windsor RC	501	3.5	1,754	13,727
Douglas Res.	Windsor RC	457	3.5	1,600	8,834
Windsor Res.	Windsor RC	752	3.5	2,632	17,689
Curtis Lake	WSSC	110	3.5	385	1,259
North Poudre 2	North Poudre	208	3.5	728	3,714
North Poudre 3	North Poudre	41	3.5	144	2,760
North Poudre 4	North Poudre	91	3.5	319	1,386
North Poudre 15	North Poudre	241	3.5	844	5,517
Clark's Lake	North Poudre	145	3.5	508	871
Indian Creek	North Poudre	143	3.5	501	1,906
Kluver Res.	WSSC	84	3.5	294	1,231
Rocky Ridge	WSSC	196	3.5	686	4,493
WSSC 3	WSSC	181	3.5	634	4,888
WSSC 4	WSSC	75	3.5	263	1,371
Wood	Wood Lake Farm Co.	160	3.5	560	2,608
Park Creek	North Poudre	189	3.5	662	7,320
Warren Lake	Warren Lake Res.	123	3.5	431	2,089
Windsor Lake	New Cache la Poudre Irr. Co.		3.5		1,275

The eleven mountain reservoirs have a total safe capacity of 200,630 acre-feet, of which 151,750 acre-feet is attributable to Horsetooth Reservoir. The other ten mountain reservoirs have a capacity of 48,880 acre-feet. There are 27 major plains reservoirs with a total capacity of 159,383 acre-feet. In addition to the reservoirs listed in Table 8-3, there are 53 minor reservoirs, of which six are located in the mountains. These minor reservoirs have less than 5,000 acre-feet total capacity and are not included in the numerical data given above.

The irrigation system is an interlocking network of reservoirs and canals. The system has the appearance of a maze because it was built up gradually without an integrating master plan. The bottom lands next to the river were the first to be irrigated, followed shortly thereafter by the irrigation of the bench land above the river bottoms.

The first example of bottomland irrigation occurred at the town of LaPorte in 1860. Vegetables, small fruit, native hay, and oats were raised. The first canal system to divert water from the Cache la Poudre River and apply the water to lands other than those adjoining the river was built by Union Colony in 1870. This canal is currently known as the Greeley No. 2 Canal. This was followed by the construction of Greeley No. 3 by Union Colony. The next large canal constructed was the Larimer and Weld Canal built in 1878-1881. The Larimer County Canal and North Poudre Canal were in operation by 1882. A list of the water rights on the Cache la Poudre River is given in Evans (1971).

Most of the canals operating below higher canals receive a significant portion of their water by collection of tailwater runoff from the canals lying above (Evans, 1971). Many of the lower canals would encounter operational difficulties if the lands above their canals were not irrigated.

Klooz (1981) in his input-output model reuse study for the CLPRB determined that 449,600 acre-feet of water were diverted for agricultural use in 1979. This figure is close to the average annual surface water diversions to cropland of 436,700 acre-feet used by Evans (1971) for his digital computer program. Table 8-4 shows the diversion by ditch company for 1979 and the year 2020. In 1970 the total irrigated acreage was 247,285 acres. Of this amount, 100,000 acres was in corn, 50,000 acres in alfalfa, 23,000 acres in sugar beets, 14,000 acres in hay, and 14,000 acres in Barley. A summary of Evans' results is given in Table 8-5.

Groundwater pumpage from the 1400 agricultural irrigation wells in the CLPRB is linked with the quantity of virgin flow available each year in the CLPRB. Figure 8-5 shows the relationship between the virgin flows and the average annual KWH per pump in the CLPRB. Groundwater is used to supplement surface water during dry years. During wet years, surface water is used in place of groundwater because of the high costs associated with groundwater pumping. The number of KWH used for pumping is nearly double during a dry year compared to that used during an average year.

8.3 Exchanges of Water

Three types of exchanges taking place in the CLPRB are: (1) exchanges between stockholders in a mutual irrigating company, (2) exchanges between mutual ditch companies, and (3) exchanges of CBT water. For the purpose of this study, the last two types are the most important.

Table 8-4. Water Demands of the Agricultural Sector (Klooz, 1981)

Use System	Water Demand	
	2020 acre-feet/year	1979 acre-feet/year
North Poudre Irr. Co.	85,824	92,230
Cache la Poudre Irr. Co.	10,911	11,982
Pleasant Valley Lake	11,511	12,758
Other Irrigation Companies above Fort Collins	18,717	15,466
Windsor Res. and Canal Co.	31,547	32,348
Water Supply and Storage Co.	71,844	79,627
Larimer & Weld Irr. Co.	82,035	90,922
Larimre County UWUA	24,209	NA
Lake Canal Co.	10,452	11,584
CLP Res. Co.	8,920	9,886
New Cache la Poudre	32,027	36,616
Greeley No. 3	10,765	11,931
Other Irrigation Companies below Fort Collins	24,852	27,494
Weld County UWUA	22,556	NA
Ogilvy Ditch	15,267	16,921
TOTALS	461,437	449,578

Table 8-5. Mean Monthly and Mean Annual Water Budget for the CLPRB

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual
1	River Inflows	4,400	2,400	1,800	1,800	1,800	2,200	5,700	44,300	88,600	38,300	14,600	6,900	212,800
2	Tributary Inflows	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Diversions to Cropland	9,400	1,300	1,100	1,000	1,000	1,300	4,500	50,600	89,600	58,100	36,100	22,200	276,100
4	Direct Reservoir Use	1,000	0	0	0	0	0	500	4,600	4,900	13,800	16,400	12,700	53,900
5	CBT Direct Use	1,000	0	0	0	0	0	700	8,700	6,000	21,800	31,700	15,100	85,000
6	Direct Imports	0	0	0	0	0	0	0	2,300	8,000	12,500	3,900	500	27,200
7	River Exchange	400	0	0	0	0	0	0	-900	-2,300	-4,900	-2,900	0	-10,600
8	Reservoir Exchange	200	0	0	0	0	0	100	0	3,500	800	400	0	5,000
9	River to Storage	3,700	100	0	100	0	100	4,900	10,200	14,700	600	100	800	35,300
10	CBT to Storage	3,500	0	0	0	0	0	0	0	0	0	0	1,800	5,300
11	Imports to Storage	0	0	0	0	0	0	0	200	900	0	0	0	1,100
12	Total Diversion to Cropland	13,400	2,500	1,900	1,500	1,000	3,300	9,200	87,800	134,500	140,500	147,800	85,900	629,300
13	Surface Water to Cropland	12,000	1,300	1,100	1,000	1,000	1,300	5,800	65,300	109,700	102,100	85,600	50,500	436,700
14	Amount to Root Zone	4,900	600	500	400	400	600	2,400	27,700	46,600	43,400	36,400	21,400	185,300
15	Pumped Water to Cropland	1,800	0	0	0	0	0	3,100	16,300	24,800	38,400	43,800	34,300	162,500
16	Amount to Root Zone	1,100	0	0	0	0	0	1,900	9,800	14,900	23,100	26,300	20,600	97,700
17	Precipitation on Cropland	17,700	8,400	5,000	4,700	5,500	14,700	23,600	46,100	35,500	26,500	24,200	23,800	235,700
18	Total Amount to Root Zone	23,700	9,000	5,500	5,100	5,900	15,300	27,900	83,600	97,000	93,000	86,900	65,800	518,700
19	Cropland P.C.U.	31,000	5,500	2,700	1,900	2,700	6,200	17,700	39,700	92,500	116,200	113,700	67,800	497,600
20	Cropland Consumptive Use	30,900	4,100	2,300	1,600	2,500	5,700	15,900	38,900	84,800	90,600	93,000	52,900	423,200
21	Accumulated Soil Moisture	118,200	39,000	38,600	38,700	37,400	37,500	38,200	57,500	61,000	60,500	56,800	34,000	617,400
22	Soil Moisture Depletion	0	5,200	5,700	5,600	6,900	6,700	6,100	3,700	17,000	34,400	55,000	77,700	224,000
23	Consumptive Use Deficiency	100	1,400	400	300	200	500	1,800	800	7,700	25,600	20,700	14,900	74,400
24	Consumptive Use Surplus	8,500	1,500	1,500	600	500	5,200	5,400	28,500	9,800	7,100	7,000	6,200	81,800
25	Total Return Flows	84,100	3,100	1,100	2,800	2,800	3,500	44,200	148,200	142,300	132,400	129,800	67,300	761,600
26	Cropland Return Flows	19,100	1,200	1,100	1,000	900	1,500	9,300	30,800	25,600	20,800	22,700	11,400	145,400
27	Conveyance Losses	1,700	200	200	200	100	200	900	9,800	16,500	15,300	12,800	7,600	65,500
28	Additions to Ground Water	55,000	-2,300	-100	600	300	-2,000	25,000	99,300	90,100	72,600	74,500	36,500	449,500
29	Domestic Use and W.S. Evap.	9,500	4,200	2,000	1,400	1,900	4,700	10,700	19,700	25,800	34,900	28,700	17,500	161,000
30	Supply to Wetlands	75,800	-500	1,200	1,700	1,300	-200	35,100	131,700	119,000	99,300	102,800	51,500	618,700
31	Precipitation on Wetlands	1,200	600	300	300	400	1,000	1,600	3,200	2,500	1,800	1,700	1,700	16,300
32	Wetland Consumptive Use	1,700	600	200	100	100	300	800	1,600	3,300	5,900	5,600	3,600	23,800
33	Use from Ground Water	2,500	600	200	100	100	300	3,800	17,900	28,100	44,300	49,400	37,900	186,300
34	Surface Outflows	-2,500	4,000	3,000	2,600	2,200	4,500	3,400	-12,300	-6,100	-51,400	-57,900	-35,100	-145,600
35	G.W. Outflows and/or Change	35,900	-3,500	-1,200	-400	-600	-3,500	15,700	68,500	64,500	51,800	51,800	25,100	304,100

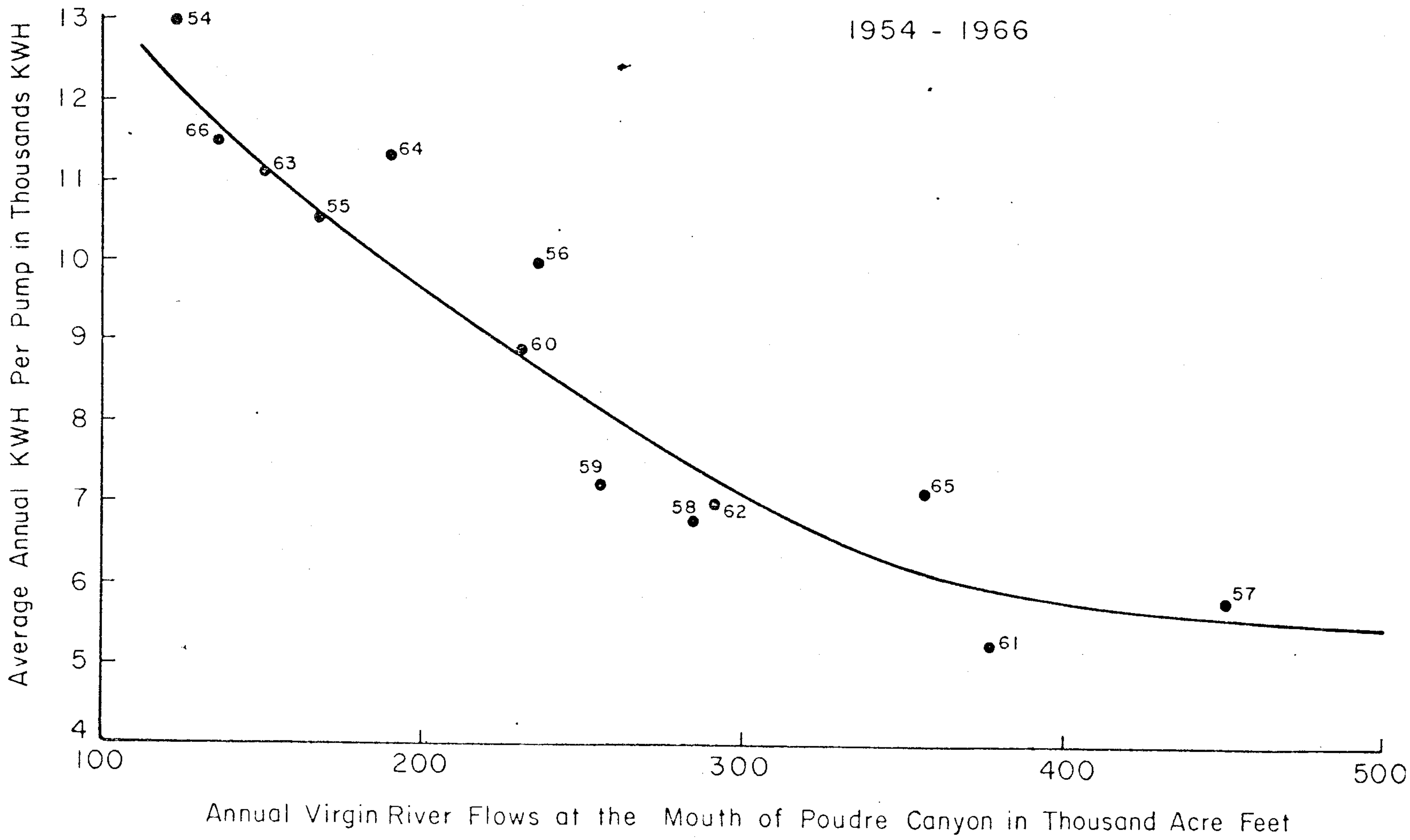


Figure 8-5. Annual virgin flows versus average annual KWH per pump from 1954 to 1966.

The early ditch companies had only direct diversion rights and very little or no storage. As the water resources of the CLPRB were developed, storage reservoirs were built to capture the heavy spring runoff for use later in the summer when stream flows were low. The older ditch companies with very early water rights (high priority) were interested in ensuring their late summer water supply while ditches with low priority rights were interested in having at least a reasonable chance of getting water. Many of the reservoirs are actually located below the lands irrigated by the ditch company owning the reservoir.

The exchange system operates in this manner. When river flows are high in the early spring, all ditch companies will be able to divert water. Those with storage rights are entitled to fill their reservoirs as long as water is available to water rights holders putting their water to immediate or direct use (direct flow right owners). When the river flow drops, the ditch company with junior water rights will have to stop diverting. Storage reservoirs were built at elevations lower than lands actually irrigated by the companies building the reservoirs so that an exchange could be worked out with a senior diverter whose lands could be irrigated by the reservoirs. The ditch company with the junior water right is allowed to divert at its upstream headgate using the senior water right while an equal amount of water can be released on demand into the canal of the senior water rights holder. The exchange is, therefore, advantageous to both parties.

Evans (1971) has an excellent explanation of the exchange system that is presented below:

The priorities of the ditches named are, in general, in the order in which they occur from the downstream to the upstream end. This order in priorities is one of the prime factors which led to the conception and subsequent development of the exchange practice. That is, a ditch lying below a reservoir usually has a more senior appropriation than the owners of the reservoir. This permits the owners of the lower canal to use the reservoir water on a demand basis, while the reservoir owner can divert an equal amount at his diversion works, but on an "at the time the water is available" basis.

As a case in point, when the flow of the river is such that the Larimer and Weld Canal is entitled to only 19.66 cfs, Greeley Canals No. 2 and No. 3 still have a high quantity of water available. The Windsor Reservoir is owned by a subsidiary company of the Larimer and Weld Canal. However, the Larimer and Weld Canal is unable to use the facility as it lies below the ditch. The Greeley No. 2 however, can use the reservoir water. Therefore, an exchange is negotiated so that Windsor Reservoir turns water into the Greeley No. 2 Canal upon demand, and the Larimer and Weld can divert water through their headgate to which the lower canal was entitled.

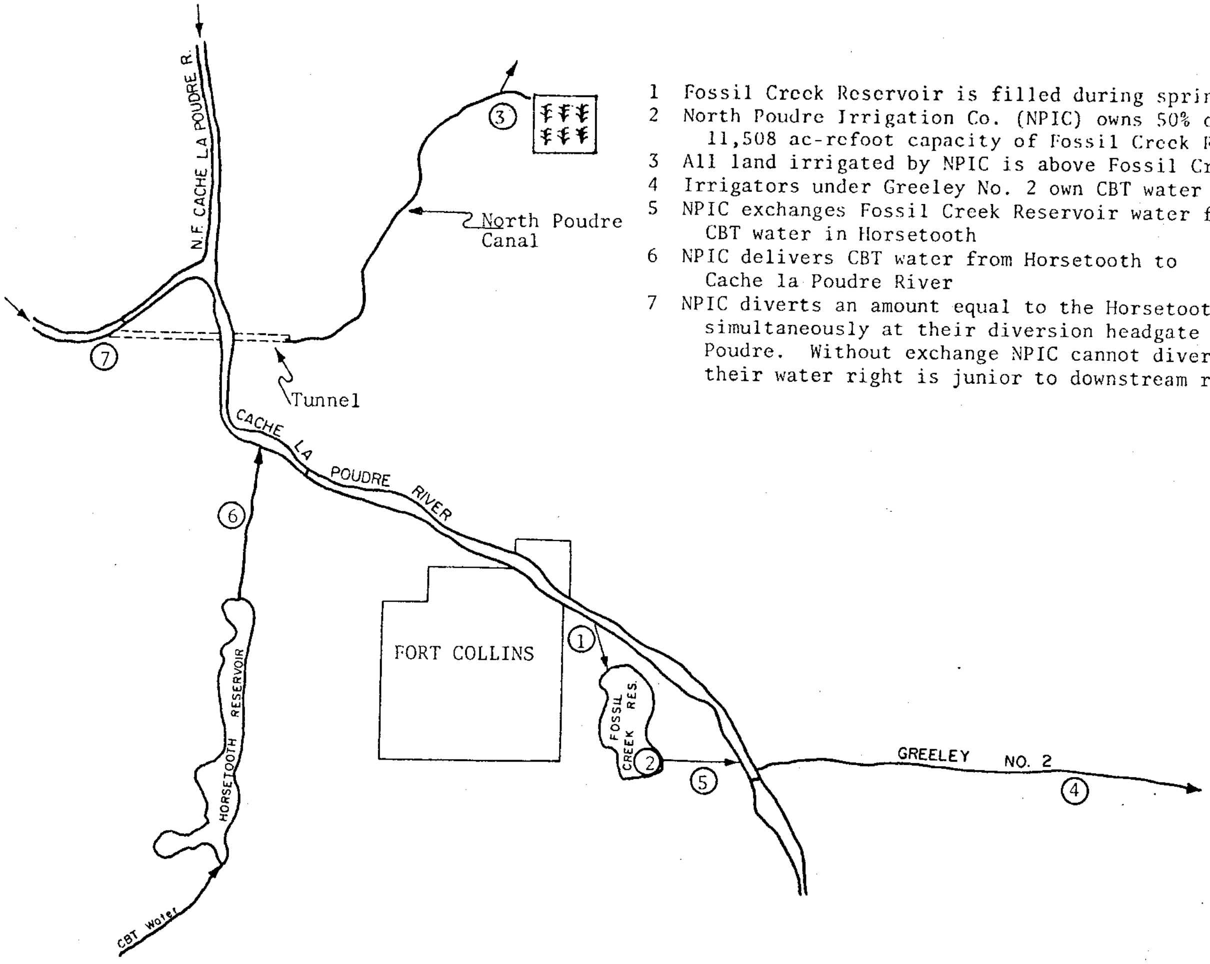
The same method of operation works with the North Poudre Canal and the ditches below by assuming, of course, that the North Poudre Canal's plains reservoirs contain water for exchange. All canals below it have rights senior to its own and, therefore, have water when the North Poudre appropriation does not allow it to divert. The case of the North Poudre Canal is especially apt as there are no reservoirs above its ditches at all, except for some upstream storage.

When the exchange practice was first strated, the North Poudre Canal diverted from the North Fork of the Cache la Poudre River and could get no more water in exchange than was carried by that branch and the mountain storage above their headgate, no matter how much it could supply through its reservoirs to the lower canals. With the construction of the Colorado-Big Thompson Project, which included construction of the Munroe Gravity Canal in 1951, and with the North Poudre Canal obtaining 40,000 units of C-BT water, these early exchange problems have almost been eliminated.

Another explanation of the exchange system is contained in Bittinger's report (1974):

> Two types of exchanges are utilized in the Cache la Poudre basin. For purposes of this report, these are called direct-flow exchanges and reservoir exchanges.
>
> Direct-flow exchange. A direct-flow exchange involves a direct-flow right on the river. The typical direct-flow exchange occurs when water available under a direct-flow held by a downstream appropriator is instead diverted by an upstream appropriator, with that appropriator simultaneously providing the downstream appropriator with an equivalent flow of water (adjusted for travel time and losses, if any) from a reservoir.
>
> Reservoir exchange. A reservoir exchange does not involve a direct-flow right, and therefore does not require a simultaneous use of water by both parties.
>
> Timing considerations and assumptions. Exchanges can only be executed at certain times, i.e., (1) when river conditions are such that the water is legally and physically available at the proper points, (2) when other water rights will not be adversely affected and (3) when all parties to the exchange are in need of water or otherwise agreeable to the exchange. Thus, the timing of availability of foreign water, and foreign water effluent, in comparison to river conditions and water demands, is of importance to the question of reuse.

The North Poudre Irrigation Company exchange system described by Evans is depicted in Figure 8-6. An exchange of this type would have been impossible to make prior to the construction of the North Poudre Canal. Exchanges similar to this one can be used by the City of Fort Collins. Reusable wastewater from the wastewater treatment plant can be exchanged for CBT water in Horsetooth Reservoir.



1 Fossil Creek Reservoir is filled during spring runoff
2 North Poudre Irrigation Co. (NPIC) owns 50% of the 11,508 ac-refoot capacity of Fossil Creek Reservoir
3 All land irrigated by NPIC is above Fossil Creek Res.
4 Irrigators under Greeley No. 2 own CBT water
5 NPIC exchanges Fossil Creek Reservoir water for CBT water in Horsetooth
6 NPIC delivers CBT water from Horsetooth to Cache la Poudre River
7 NPIC diverts an amount equal to the Horsetooth release simultaneously at their diversion headgate on the Poudre. Without exchange NPIC cannot divert because their water right is junior to downstream rights

Figure 8-6. North Poudre Irrigation Company exchange system.

8.4 Role of CBT and Windy Gap Water in Water Reuse Planning

The Northern Colorado Water Conservancy District (NCWCD) and the water that it distributes from the CBT project are important resources for water reuse planning. Between 97,000 and 149,000 acre-feet per year (48% of the CBT project output) are delivered into the CLPRB each year (Northern Colorado Water Conservancy District, 1979). Horsetooth Reservoir, located just west of Fort Collins, stores water from the CBT project. Almost all water delivered into the CLPRB from the CBT project passes through Horsetooth Reservoir. A complete description of the NCWCD, the CBT project and the related Windy Gap Project are given in Appendix A8-1.

The Windy Gap Project is being planned by the Municipal Subdistrict of the NCWCD. The project would utilize CBT project facilities for the delivery of an additional 48,000 acre-feet per year of Colorado River Basin water into the SPRB. In the CLPRB, the Platte River Power Authority (PRPA) and the City of Greeley own 16,000 and 8,000 acre-feet, respectively, of Windy Gap water. Project deliveries should start in 1984.

CBT and Windy Gap water each have unique characteristics that make their use valuable aids in developing water reuse alternatives. These unique characteristics are summarized below. Some advantages are:

1. CBT and Windy Gap waters provide flexibility due to the ease with which the shares can be sold, transferred, assigned or leased.
2. Horsetooth Reservoir provides storage for use of the water during periods of high demand and low stream flows, i.e., late summer and early fall.

3. The storage is relatively high up in the CLPRB in relation to the water demand. Very little water demand exists in the mountainous portions of the basin. Horsetooth Reservoir is located directly west and above Fort Collins. Water can flow by gravity to the areas of demand.
4. Approximately 96,000 units of CBT water are currently owned by agricultural interests in the CLPRB. A significant percentage of the CBT water has the potential of being exchanged into Horsetooth Reservoir for municipal wastewater return flows. Exchanges between municipal, agricultural, and industrial users can be mutually beneficial to all parties involved.
5. Water exchanged into Horsetooth can be treated as foreign water if the exchange is based on non-CBT foreign water.
6. Windy Gap water can be reused without regard to return flows.

Some disadvantages are:

1. Return flows from CBT water cannot be reused by the original allottee.
2. Both CBT and Windy Gap water are expensive. The cost of Windy Gap water is currently projected to have an annual price of $163 per acre-foot. At $2000 per unit of CBT water, the annual cost is $193. Figure 8-7 shows the geometric growth of the cost of CBT water.
3. Windy Gap water allotments must be removed from CBT facilities (Horsetooth) prior to the use of CBT water.
4. CBT water cannot be used after October 31 of each year and the allotted water remaining after this date is forfeited to the NCWCD.

CBT water can be used as a tool in making water reuse exchange agreements work. Use of CBT water avoids the long, drawn-out and

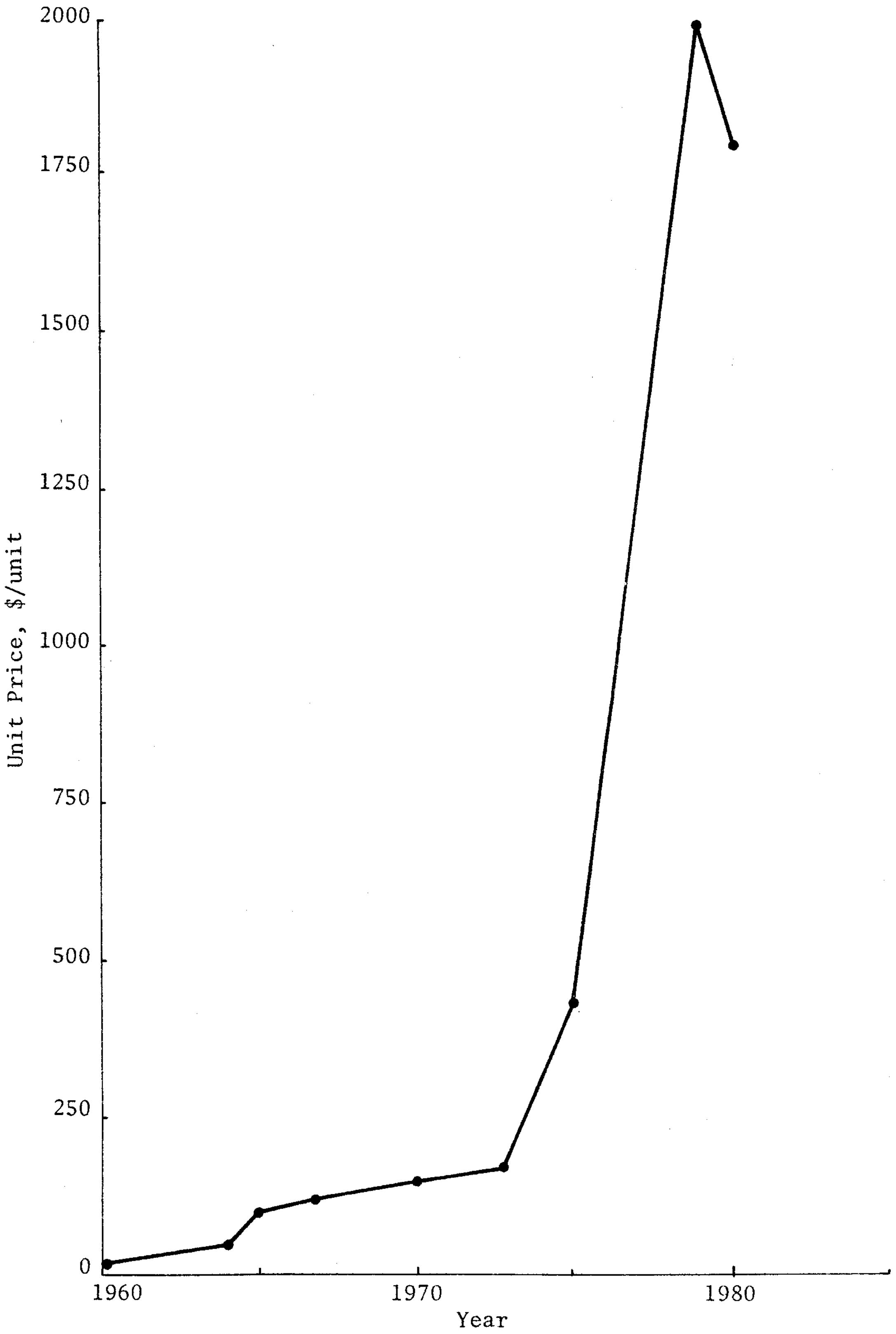


Figure 8-7. Average market price, CBT allotment.

expensive court battles that are associated with changing points of diversion and use. Windy Gap water is the most flexible water available for reuse planning. The restriction on the time of use (prior to CBT water) is the major handicap for reuse planning with Windy Gap water.

8.5 City of Fort Collins

Fort Collins is a city of 67,000 people located next to the foothills along the Front Range. The Cache la Poudre River runs through Fort Collins as it winds its way to the southeast towards Greeley and the South Platte River. Fort Collins is an expanding "water demand Center" for the basin. Because of its central location, it is ideally suited for reuse exchange planning.

8.5.1 Water Supply

Fort Collins obtains its water supply from the Cache la Poudre River CBT water units, and foreign water imports. Table 8-6 shows the ownership of water by the city. The city owns five direct flow rights with priority numbers 1, 5, 6, 12, and 14 for a total of 20.28 cfs. The dependable yield of these rights is 11,300 acre-feet per year. The recently completed Joe Wright-Michigan Ditch system should have an average yield of 4,800 acre-feet per year. The city also owns 10,477 shares of CBT water and 6,400 acre-feet of irrigation company water. The total average yield is 30,500 acre-feet per year (City of Fort Collins, 1980a). All of these waters are usable at one of the city's two water treatment facilities. The city also owns 7,490 acre-feet of water that cannot currently be treated at either water treatment plant because the points of diversion are downstream of the plant intakes.

Table 8-6. Raw Water Owned by the City of Fort Collins (City of Fort Collins, 1980b)

Source	Conversion Factor (Ac-Ft/sh)	As of March 1, 1970		As of January 1, 1980	
		Shares	Ac-Ft	Shares	Ac-Ft
Available for Treatment					
Poudre River Direct Flow	--	--	11300	--	11300
Joe Wright-Michigan Ditch System	--	--	0	--	4800
NCWCD (CBT)	.76[a]	9238	7000	10477	8000
North Poudre Irrigation Co.	5.98[a]	505.7	3000	839.75	5000
Water Supply and Storage Co.	107 x .8	0	0	16.9	1400
Subtotal			21300		30500
Other Raw Water Sources					
Arthur Irrigation Co.	3.442	125.2	430	108.2	370
Larimer Co. Canal No. 2	42.687	8.6	370	37.3	1590
New Mercer Ditch Co.	30.236	8.9	270	18.0	540
Pleasant Valley & Lake Canal Co.	39.74	45.2	1800	112.0	4450
Warren Lake Reservoir Co.	10.00	10.1	100	36.4	360
Mountain & Plains Irrigation Co.	1.72[a]	31.0	50	0	0
Lake Canal Co.	30.0[a]	0	0	6.0	180
Subtotal			3020		7490
TOTAL			24300		38000

[a] Approximate average yield.

8.5.2 Water Demand

In 1950 the population of Fort Collins was 19,000 people and treated water use was 5,920 acre-feet. By 1970, the population of the city had increased to 44,000 and the service area population to 48,400. Total treated water in 1970 was 11,257 acre-feet or double that of 20 years earlier. In 1980, with the city population at 67,000 and a service area population of 73,700, the treated water use was approximately 18,000 acre-feet. The average per capita per day water use since 1960 has been 222 gallons.

The projected city population for hte year 2000 is 150,000 and the service area population is projected at 165,000. In Figure 8-8 the year 2000 water demand is projected to be 41,000 acre-feet without metering and 35,400 acre-feet with metering. Return flows were approximately 12,400 acre-feet in 1980 and are projected to be 27,000 acre-feet without and 22,000 acre-feet with metering in the year 2000 (City of Fort Collins, 1980b).

The demand projection without metering uses a demand in the year 2000 of 222 gpcd. The metered demand projection assumes a water use reduction of 13%. The metered reduction in demand is not based on price elasticity, but rather on eliminating excess lawn watering. The decrease in lawn watering would be from 39 inches per season to 25 inches per season. By the year 2000, a 14 inch per year decrease in lawn watering would amount to 5,300 acre-feet decrease in water demand and return flows.

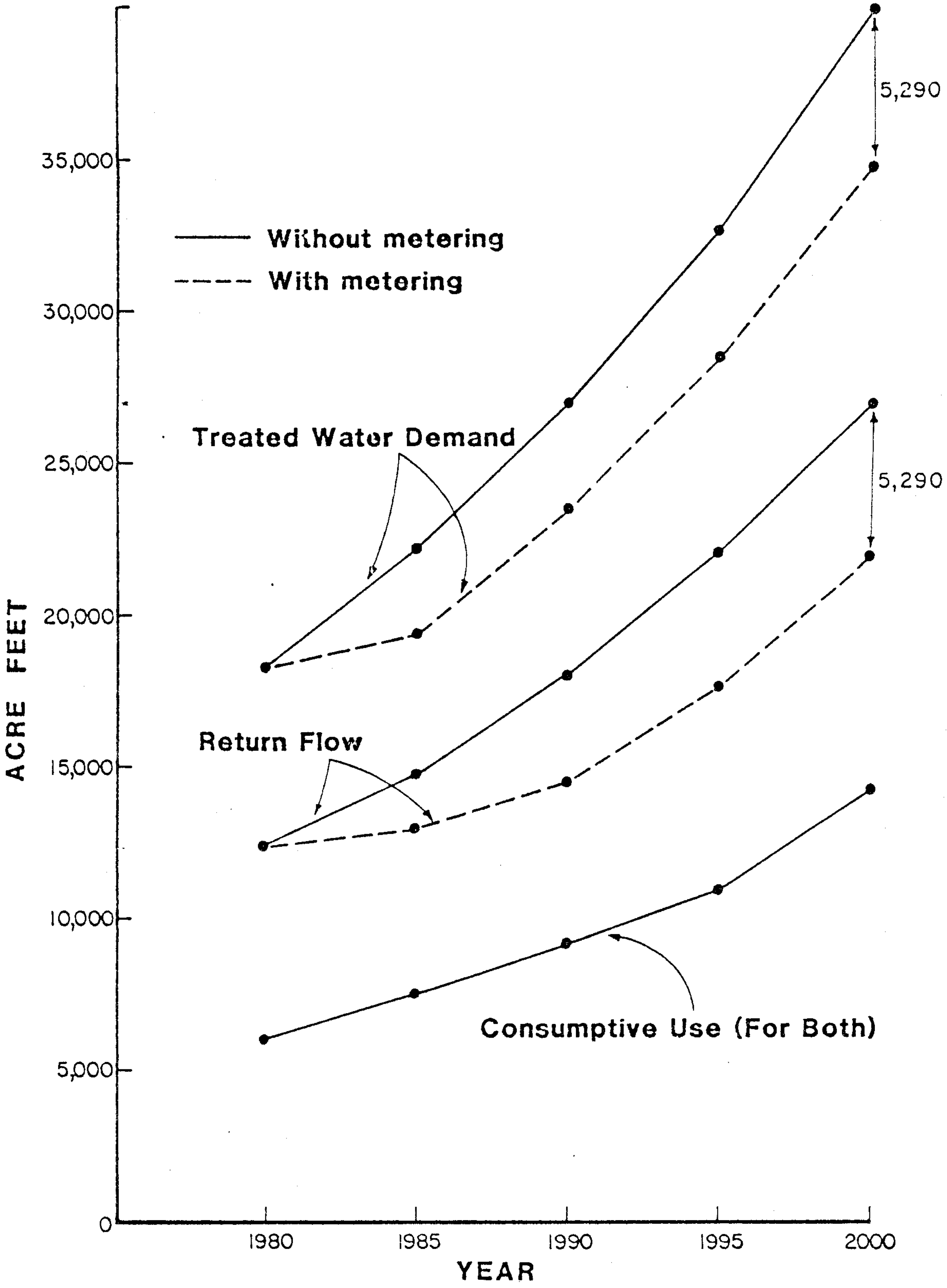


Figure 8-8. Water demand and return flows for the City of Fort Collins (City of Fort Collins, 1980b).

8.5.3 Water Treatment Facilities

In the City of Fort Collins the first central water supply came from a small water wheel powered plant on the Larimer No. 2 Canal near the intersection of Overland Trail and Bingham Hill Road. This plant was abandoned in 1909 when the Poudre Canyon Treatment Plant was built.

Currently, the city operates two water treatment facilities, as shown in Figure 8-9. The Poudre Canyon Treatment Plant (WTP No. 1) is located a few miles upstream of the canyon mouth and has a peak treatment capacity of 20.0 mgd. The Soldier Canyon Treatment Plant (WTP No. 2) is located at the base of Soldier Canyon Dam and takes CBT project water from Horsetooth Reservoir. The plant was expanded in 1980 to a treatment capacity of 34.0 mgd with the potential for 10 mgd incremental expansions up to 64 mgd.

8.5.4 Wastewater Treatment Facilities

Fort Collins has two secondary sewage treatment plants. The older plant (STP No. 1) is a trickling filter-activated sludge plant with an average design flow of 5.0 mgd. STP No. 2 is an activated sludge facility constructed in two phases. The first unit is a 4.5 mgd plant that began operation in 1968. The second unit has an 18 mgd average design flow and became operational in 1977. Another expansion of STP No. 2 is planned. The expansion would duplicate the second unit and would increase the total capacity of STP No. 2 to 40.5 mgd when used as activated sludge or 28.5 mgd if used as an extended aeration plant. Extended aeration is used to convert ammonia to nitrate, a less toxic form of nitrogen. An interceptor sewer connects STP No. 1 with STP No. 2.

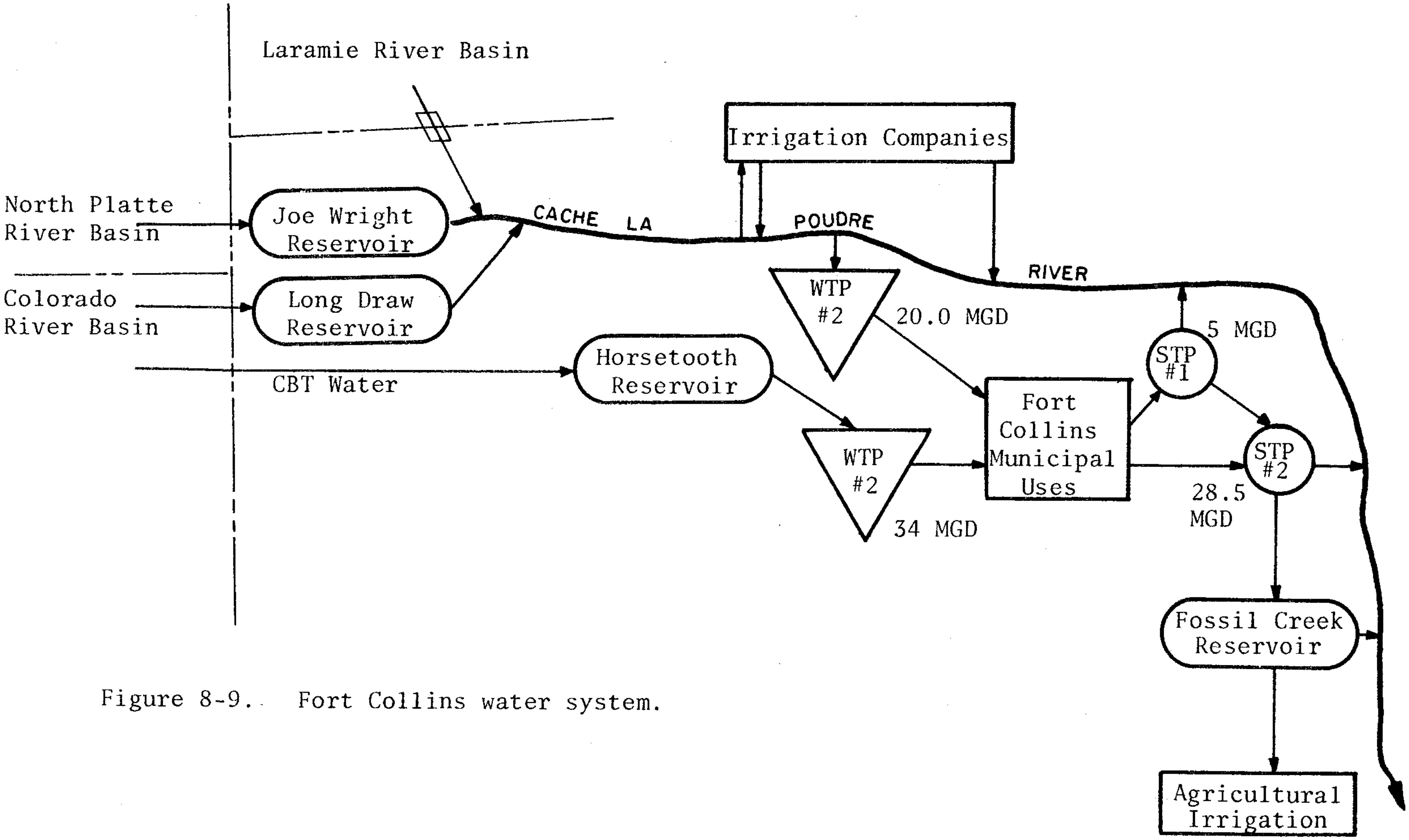


Figure 8-9. Fort Collins water system.

The ratio of return flows versus the potable water supplied varies widely over the year. Flows entering the WWTPs are higher during the summer than the winter due to infiltration of groundwater into the sewer lines. The return flows as a percentage of treated water suplied to the city are lower during the summer and high during the winter as shown in Table 8-7. Almost all water is used inside during the winter months while large quantities are used for landscape irrigation during the summer. Most of the water used for landscape irrigation never returns to the sanitary sewer system. In 1975, the city treated and delivered 15,179 acre-feet of water and the city's WWTPs treated and discharged 11,880 acre-feet to the Cache la Poudre River. The return flows were 78% of the water delivered in the city.

The quality of the Fort Collins wastewater treatment plants is excellent. The biochemical oxygen demand (BOD) is usually less than 20 mg/ℓ and the suspended solids for 1979 averaged less than 10 mg/ℓ (City of Fort Collins, 1980c). The raw water has a TDS level of 60 mg/ℓ while the effluent TDS averaged 336 mg/ℓ from STP#2 and 540 mg/ℓ from STP#1 in 1979. The flow weighted average for 1979 was 400 mg/ℓ TDS or an increase of 340 mg/ℓ for a single use in the city. The quality of treated wastewater from the city of Fort Collins is fine for use on irrigated agricultural crops. The levels for all toxic substances are low or non-existent.

Agricultural reuse of STP No. 2 effluent occurs at this time. The current reuse is unplanned in the sense that it occurs due to water rights priorities on the river. Historically, wastewater discharged from Fort Collins STP No. 1 into the Cache la Poudre River was diverted

Table 8-7. Percentages of Return Flows from Delivered Water for Fort Collins (Bittinger, 1975)

Month	Percentage of Return Flows
January	98.5
February	98.5
March	98.5
April	74.2
May	72.5
June	48.6
July	39.9
August	42.4
September	52.7
October	70.6
November	98.5
December	98.5

downstream into the Fossil Creek Reservoir Inlet Canal. When STP No. 2 was constructed, the outfall was constructed so that treated wastewater could be discharged to the canal as well as the Cache la Poudre River.

8.5.5 Fort Collins-PRPA-WS&SCo Reuse Exchange Agreement

The Platte River Power Authority (PRPA) is an entity created by the four member cities of Fort Collins, Loveland, Longmont, and Estes Park to furnish electric power to the member cities (see Appendix A8). PRPA currently has a 250 MGW coal-fired electric generation plant under construction 18 miles to the north of Fort Collins at a site called Rawhide. PRPA also owns rights to 16,000 acre-feet of Windy Gap water. In the event that the Windy Gap Project was not completed in time (1984) to supply the Rawhide Power Plant with 4,200 acre-feet of water per year, PRPA entered into a contractual agreement with the City of Fort Collins and the Water Supply and Storage Company (WS&SCo) to supply the needed water by using the treated wastewater of Fort Collins.

8.5.5.1 Basic Proposal. Reuse of Fort Collins' wastewater for cooling purposes at Rawhide is simple in principle and complicated in execution. Figure 8-10 is a schematic of the physical system while Figure 8-11 depicts the exchange calculations needed to make new foreign water available for reuse.

The goal behind the reuse agreement is the delivery of 4,200 acre-feet per year to the Rawhide Power Plant lake to make up for water lost through evaporation from the lake. The source of the water is effluent from Fort Collins STP No. 2. This effluent must be pumped 18 miles north to Rawhide. Because downstream water rights exist for return flows from native water used by Fort Collins, these return flows must

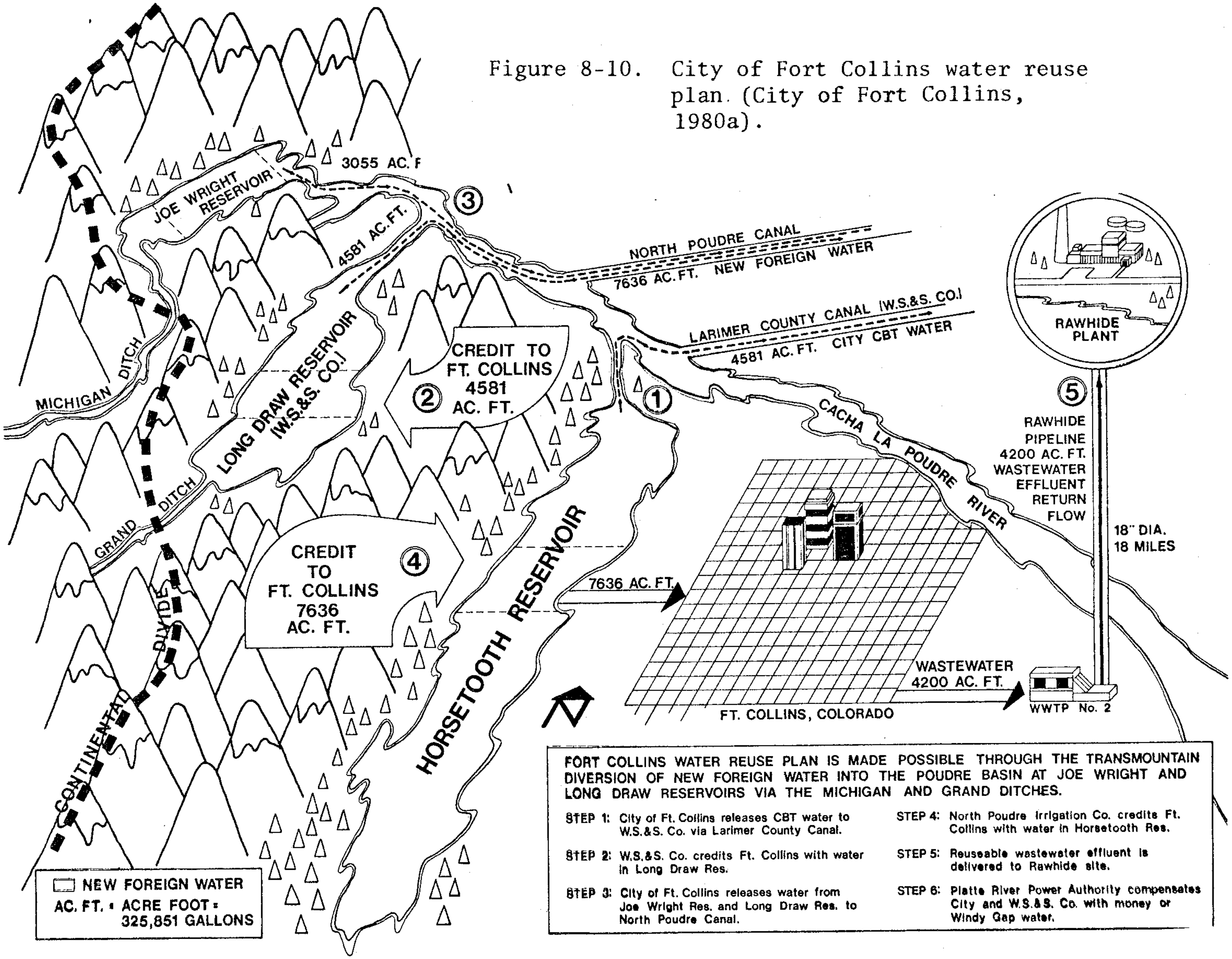


Figure 8-10. City of Fort Collins water reuse plan. (City of Fort Collins, 1980a).

FORT COLLINS WATER REUSE PLAN IS MADE POSSIBLE THROUGH THE TRANSMOUNTAIN DIVERSION OF NEW FOREIGN WATER INTO THE POUDRE BASIN AT JOE WRIGHT AND LONG DRAW RESERVOIRS VIA THE MICHIGAN AND GRAND DITCHES.

STEP 1: City of Ft. Collins releases CBT water to W.S.&S. Co. via Larimer County Canal.

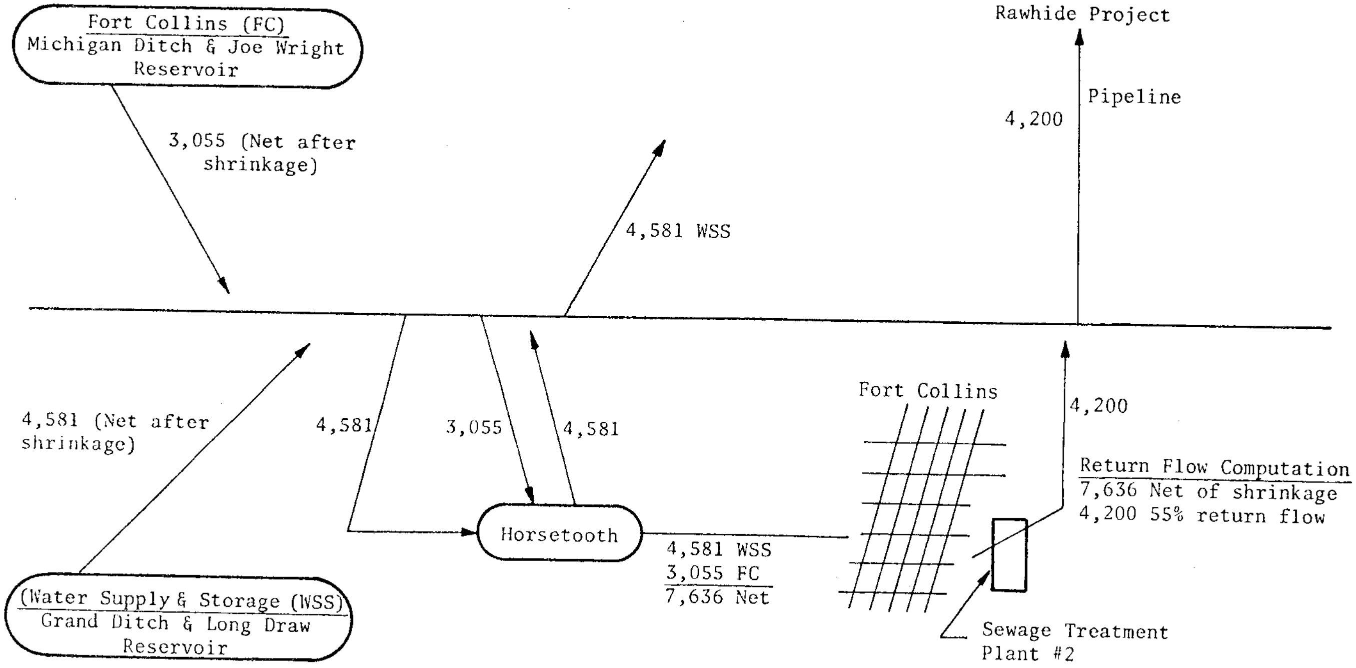
STEP 2: W.S.&S. Co. credits Ft. Collins with water in Long Draw Res.

STEP 3: City of Ft. Collins releases water from Joe Wright Res. and Long Draw Res. to North Poudre Canal.

STEP 4: North Poudre Irrigation Co. credits Ft. Collins with water in Horsetooth Res.

STEP 5: Reuseable wastewater effluent is delivered to Rawhide site.

STEP 6: Platte River Power Authority compensates City and W.S.&S. Co. with money or Windy Gap water.



Source	Volume, AF		Processing Charge 25% (of 4,581)		Total Contribution (AF/percentage)	Allocation of 4,200 of Windy Gap (percentage/AF)
Fort Collins	3,055	+	1,145	=	4,200/55%	55%/2,310 AF
Water Supply & Storage Co.	4,581	-	1,145	=	3,436/45%	45%/1,890 AF
Total	7,636				7,636/100%	100%/4,200 AF

Figure 8-11. City of Fort Collins water reuse exchange calculations.

be discharged to the Poudre. Therefore, a new source of reusable return flow had to be found. The most convenient source was foreign water.

8.5.5.2 Old and New Foreign Waters. The parties to the reuse exchange agreement make the distinction between old and new foreign water for purposes of this agreement. Old foreign water is considered to be foreign water which has been imported into the CLPRB for many years. The return flows from old foreign water have been used for an extended time period by downstream appropriators. New foreign water is defined as water that has been developed in recent years or will be developed in the future. Therefore, return flows from new foreign water are either a very recent addition to the stream or are as yet nonexistent. The distinction between old and new foreign water was made as a friendly gesture to promote cooperation between Fort Collins-PRPA and agricultural water users in the CLPRB. The state water law, as reviewed by Ward Fischer, makes no distinction between old and new foreign waters (Fischer, 1974). The old foreign water return flows could be discontinued at any time without legal recourse by downstream users. This, however, would not have proved mutually advantageous to the parties in the agreement.

8.5.5.3 Exchange Agreement. New foreign water has been developed by Fort Collins and WS&SCo that nets an estimated 7,636 acre-feet per year. Under the terms of the agreement, Fort Collins releases 4,581 acre-feet from Horsetooth to WS&SCo's Larimer County Canal. In exchange, WS&SCo credits an equal amount of water to Fort Collins in Long Draw Reservoir. This new foreign water, plus foreign waters from Joe Wright Reservoir, can then be exchanged with irrigation companies such as North Poudre who have rights to CBT water for their CBT water stored in Horsetooth Reservoir. The exchange is accomplished by releasing new foreign water stored in Joe Wright and Long Draw Reservoirs in exchange for CBT water stored in Horsetooth. The most likely company is the North Poudre Irrigation Company because of their ownership of 40,000 CBT units.

The City of Fort Collins acquires rights to 7,636 acre-feet of water in Horsetooth through this exchange. Although the water in Horsetooth is actually CBT water, foreign water was used to make the exchange into Horsetooth and the CBT water can now be treated as foreign water and the return flows reused. Fort Collins uses water from Horsetooth for municipal purposes when water demand is in excess of direct flow rights owned by the city on the Cache la Poudre River. Water from the Cache la Poudre is treated at WTP No. 1. Return flows during the spring and summer amount to 55% of the water used by the city. The return flows are treated at the WWTP and subsequently pumped directly to Rawhide or stored in Fossil Creek Reservoir for pumping later in the year (City of Fort Collins, 1978).

Treated wastewater would be stored in Fossil Creek Reservoir during summer months when the volume of new foreign water return flows is high. The stored water is then pumped to Rawhide during the winter when new foreign water return flows are low. This allows the pipeline to be sized smaller because the line is used near capacity on a year-round basis.

<u>8.5.5.4 PRPA Compensation to Fort Collins WS&SCo</u>. PRPA must compensate Fort Collins and WS&SCo for water delivered to the Rawhide Pipeline intake. The compensation is as follows:

Without Windy Gap: until December 31, 1985 - $25/acre-foot
from January 1, 1985 on - $95.50/acre-foot

With Windy Gap:

1. PRPA delivers 4,200 acre-feet/year of Windy Gap water to Fort Collins.
2. Fort Collins delivers to Rawhide Pipeline intake 4,200 acre-feet per year.
3. Return flows from Windy Gap water are subject to a succession of uses. The return flows from Fort Collins' use of Windy Gap water remain the property of PRPA.
4. Fort Collins will deliver to WS&SCo a "water company percentage" of the 4,200 acre-feet contributed by PRPA. This amounts to approximately 1,890 acre-feet per year.

$$\text{Water company \%} = \frac{0.75 \times \text{acre-feet/year from water company}}{\text{total of all water contributed by water company and Fort Collins}}$$

The Fort Collins-PRPA-WS&SCo reuse exchange agreement makes water available for two additional users: the City of Fort Collins and WS&SCo. Without the reuse exchange plan, PRPA would have had to purchase agricultural water rights to meet its needs in the first few years of operation. Fort Collins and WS&SCo would have been without 2,310 and 1,890 acre-feet per year of additional water. The reuse exchange plan is beneficial to all parties involved and increases the usefulness of the water by being put through a high value sequential use pattern.

8.5.6 Water Reuse Opportunities for Fort Collins

This section reviews seven reuse options that are available to the City of Fort Collins. These seven reuse options and eleven others are given in Table 8-8. Six of these options involve Fort Collins using the water sequentialy--first use for domestic purposes and a second use for some other purpose such as agricultural irrigation. The seventh option is potable reuse. Potable reuse is the most costly, least acceptable reuse option currently available to Fort Collins. With the large quantity of high quality water currently receiving first use in agriculture, reuse exchange alternatives are readily available to the city. The reuse exchange alternatives are less sophisticated technologically, but require more legal, organizational, and political cooperation.

Before examining specific reuse alternatives, the reuse spectrum available to the city should be displayed. The two key elements in the spectrum are the primary water sources available to the city and the reuse options for the return flows. Water quantity and quality are dependent on the specific water source and reuse option and are an inherent part of each alternative. The third factor is the method of water transfer between the water available for reuse at the wastewater treatment plant and the point of intended reuse. In alternatives where the wastewater is exchanged, the exchange water must also be made available for treatment at one of the city's water treatment plants.

Table 8-8 lists Fort Collins' primary water sources, reuse options, transfer mechanisms, and several possible combinations of water sources and reuse options. Reuse options for the various water sources are limited by state water law and pre-existing commitments such as PRPA's

Table 8-8. Reuse Spectrum for the City of Fort Collins

Primary Water Source	Transfer Mechanism*	Reuse Options for Return Flows
I New foreign water	1. Discharge to stream for downstream diversion	A. Sequential reuse exchange with agriculture
II Windy Gap water	2. Pump upstream to 2nd user	B. Successive reuse exchange with PRPA
III Old foreign water	3. Exchange for CBT water	C. Sequential reuse with city
IV Storage water	4. Exchange for storage water	D. Potable reuse within city
V Southside Ditch water	5. Exchange for Windy Gap water	
VI Native direct flow water owned by the city	6. Discharge to stream in exchange for alluvial groundwater pumping	
VII Native direct flow and storage water owned by agriculture	7. Retention within city use system	

Primary Water Source	Reuse Options
I	A, C, D
II	A, B, C
III	A, C, D
IV	A, C, D
V	A, C, D
VI	C, D
VII	A

*The use of more than one transfer mechanism may be required for reuse options involving water exchange.

Windy Gap project involvement. The number of possible combinations of water sources, transfer mechanisms and reuse options is quite large. Only seventeen combinations are listed in Table 8-8. Of these seventeen, seven have been selected for use in this study.

The seven reuse options evaluated are as follows:

1. Reuse of excess Windy Gap water owned by PRPA;
2. exchange of return flows from the city for irrigation company water;
3. reuse exchange of return flows from Southside ditches;
4. reuse of return flows from the import of additional North Platte River Basin water;
5. reuse of return flows from old foreign water currently imported by CLPRB irrigation companies;
6. exchange reuse of native water between the city and irrigation companies similar to the Northglenn-FRICO reuse plan; and
7. reuse of return flows within the city.

A summary of water reuse exchange quantities is given in Table 8-9.

8.5.6.1 Windy Gap Water and Reuse Exchange. In the Fort Collins-PRPA-WS&SCo reuse exchange agreement, Fort Collins will receive 4,200 acre-feet of Windy Gap water in payment for the 4,200 acre-feet of foreign water delivered each year to PRPA. Fort Collins must repay WS&SCo with 1,890 acre-feet of water delivered to the WS&SCo headgate. The water does not necessarily have to be Windy Gap water but could be from another source such as CBT or direct flow rights on the Poudre. According to the agreement, PRPA retains the right to the Windy Gap return flows but consents to Fort Collins' use of the return flows until

Table 8-9. Sources of Reusable Water Available to the City of Fort Collins[a]

Source of Water	Quantity Available for Dirst Use (Ac-Ft/year)	Quantity of Return Flow (Ac-Ft/year)	Net Maximum Water Yield to City Through Reuse (Ac-Ft/y)	Reuse Sequence
Joe Wright	3,055	4,200[b]	2,310	PRPA-Rawhide-WS&SCo reuse agreement for power plant cooling
Long Draw	4,581			
Windy Gap: Min.	8,000	4,400[b] to 7,880[c]		PRPA owns Windy Gap water; city gets first use; agriculture gets 2nd use until PRPA needs 2nd use for energy generation
Max.	11,800[e]	6,490[b] to 11,620[c]	11,800 (11,620)[f]	
Southside Ditches	16,500	9,075[b] to 16,250[c]	16,250	First use by city; 2nd use for agriculture with exchange for CBT water or 2nd use in city
Additional Foreign Imports				
Michigan River	1,000-1,500	550[b] - 1,478[c]	1,478	Same as Southside Ditch water, above
Laramie River	2,000-4,000	1,100[b] - 3,950[c]	3,950	
Old Foreign Water	38,500 (30,000 WS&SCo)	21,175[b]	21,175	A number of different systems for 1st use by city; 2nd use by agriculture
Native water	11,300	8,418[d]	8,418	1st use by city; 2nd use within city
TOTAL			65,381[g]	

---

[a] Table does not include native water that is owned by agriculture and could be exchanged with city for municipal wastewater.

[b] Based on 55% return flow (summer).

[c] Based on 98.5% return flow (winter).

[d] Based on 74.5% annual average return flow (year-round).

[e] Excludes water payback of 4,200 ac-ft from PRPA for existing reuse agreement.

[f] Up to 11,620 ac-ft of additional return flow water could be available to city for reuse exchange until PRPA constructs additional power units.

[g] Does not include the 11,620 ac-ft/year Windy Gap figure.

PRPA needs them for increased electric energy production. The following quote from Article V-C(iii) makes this point clear (City of Fort Collins, 1978):

> ...allow Platte River to make beneficial use of the return flow waters from Windy Gap Project waters to be furnished here under when such waters are needed and usable for increased electric energy production at the Rawhide site or elsewhere, and allow Fort Collins to make use thereof in the interim.

Using the standard 55% return flow figure, 2,310 acre-feet of return flow would be available for reuse or exchange until PRPA builds the second unit at Rawhide. If use of the 4,200 acre-feet could be delayed until late fall or winter, return flows increase up to 98.5% as shown earlier in Table 8-7.

If all Windy Gap water was used during the months of November through March, 98.5% or 4,140 acre-feet of return flow would be available for reuse. The problem of using Windy Gap water prior to CBT water would not be encountered by Fort Collins because the city is, in effect, leasing the water and not subject to the same constraints as the owner.

The City of Fort Collins also has the right of first refusal for 8,000 acre-feet of Windy Gap water the city assigned to PRPA. Return flows from this water are subject to reuse. Although PRPA can require return of the 8,000 acre-feet of Windy Gap water when needed for power generation, the return flows from the 16,000 acre-feet would be a minimum of 8,800 acre-feet (55%) if used during the summer or 11,920 acre-feet (74.5%) if used evenly over the year. Approximately 12,600 acre-feet of water would be needed for the operation of all three Rawhide units. The return flows available to Rawhide after first use by Fort

Collins would be a minimum of 8,800 acre-feet plus 4,200 acre-feet from the existing agreement, or a total of 13,000 acre-feet. This quantity is sufficient to meet all of PRPA's cooling water needs.

Two problems are encountered at this point with the reuse scheme: (1) all water must be used or removed from Horsetooth Reservoir by November 1 of each year or the water is lost, and (2) winter is the period of lowest water demand. Winter return flows would be more useful if they could be stored for use during periods of heavy demand such as late summer. Therefore, storage may be needed for both the raw water and the return flows.

The time constraint problem at Horsetooth Reservoir could be handled by either persuading the NCWCD to modify its storage policy or providing storage for Windy Gap water outside Horsetooth Reservoir. Modification of NCWCD district policy on winter storage is currently being pursued by the Fort Collins Water Board for CBT water. The extension of any policy modification on CBT water to Windy Gap water would be useful to the city.

The provision of storage outside of Horsetooth could be accomplished in one of three ways: (1) exchange of water with an irrigation company, (2) construction of a new reservoir or enlargement of an existing reservoir, and (3) use of either shallow or deep aquifers for storage. Exchange with an irrigation company would involve the release of Windy Gap water during the summer to an irrigation company for reservoir storage credit. The reservoir water could then be released or exchanged to provide water in Horsetooth Reservoir the following spring. The city is already considering the expansion of North Poudre Reservoir

No. 6 located approximately seven miles north of Fort Collins. Water from Horsetooth can be discharged to the Poudre Valley Canal which in turn discharges into Reservoir No. 6. The reservoir could be expanded to increase storage by an additional 4,360 to 6,500 acre-feet. Another choice is storage by exchange in the proposed Rockwell or Sheep Creek high mountain reservoirs.

The third choice is storage of the water in shallow or deep aquifers. If suitable aquifers located within a reasonable distance could be found, the capital construction cost could be quite low. Water could be injected or allowed to infiltrate into the groundwater table for storage and withdrawn at times when return flows are highest. Aquifers have two advantages: (1) they are not subject to evaporation, and (2) the problems of coordinating the first use of water with the second use are greatly simplified. In addition, reservoir capacity is made available for capturing spring runoff. Storage in alluvial aquifers hydraulically connected to the Poudre River would be subject to the adjudication process to ensure no injury was done to other appropriators.

Once the Windy Gap water has been used by the city, the return flows are available for pumping to Rawhide. Fossil Creek Reservoir could be used as a storage reservoir for equilization of flows to be pumped. Prior to full utilization of Windy Gap water return flows at Rawhide, however, other exchange arrangements would have to be made with irrigation companies. The following section addresses the history and nature of water exchange in the CLPRB and its application to water reuse.

8.5.6.2 Exchange of Return Flows for Use of High Quality Water. The use of water exchanges has been practiced since before the turn of the century as described in Section 8.3. The water exchanges enable the entities involved to make more efficient use of river water. Fort Collins is in a position where water exchanges can be used to secure water for treatment above its water treatment plants.

Once the water is used by the city, the return flows must either be exchanged, stored, or put to use. These options are very similar to those needed to store Windy Gap water after November 1. The downstream location of the WWTP outfall makes the exchange and/or storage more difficult if pumping is to be minimized.

The most convenient and least expensive alternative is to exchange the Windy Gap return flows for CBT water in Horsetooth. The most suitable irrigation canals with CBT water are the Lake Canal, Greeley No. 2, and Larimer and Weld Canal. Lake Canal irrigators have approximately 3,200 CBT units and Greeley No. 2 irrigators (owned by the New Cache la Poudre Irrigating Company) have 11,000 CBT units. The Larimer and Weld Canal irrigators had 28,500 CBT units in 1980. Both the Larimer and Weld Canal and Lake Canal would require pumping of the reusable wastewater up to the canals as shown in Figure 8-12.

One problem encountered with exchange with these ditches is reservoir capacity. Storage of winter return flows could reduce storage for spring runoff. The irrigation companies need water in late summer. Exchanging CBT water for return flows in the spring that reduce the amount of spring runoff that can be stored is not useful to irrigation companies. In this case, the city would have to use Windy Gap water during the summer so that return flows could be exchanged for CBT units.

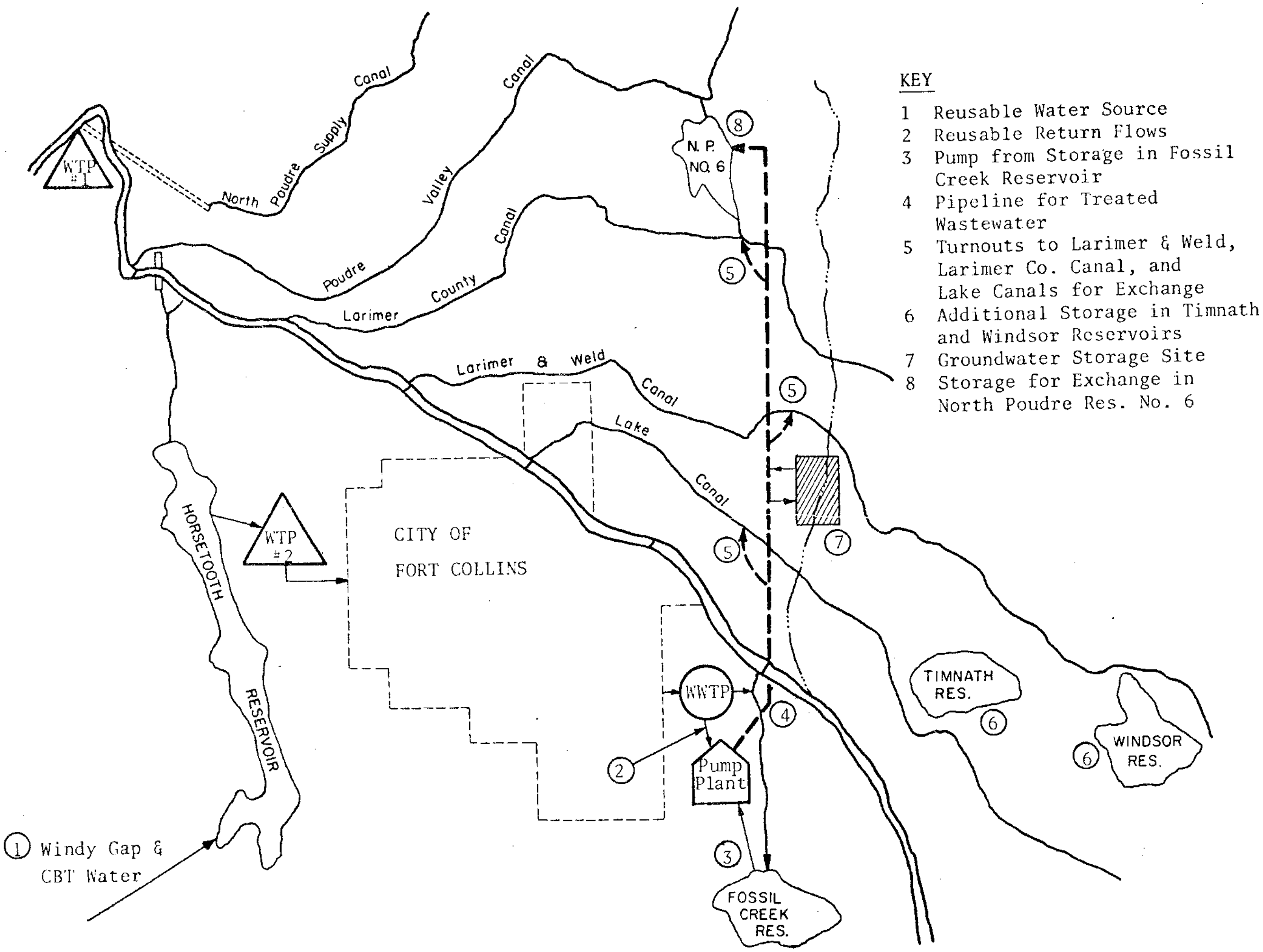


Figure 8-12. Reuse exchange facilities for Fort Collins.

The already existing exchanges of CBT water between the ditch companies is another obstacle to be overcome in reuse exchange plans. As an example, the North Poudre Irrigation Company owns 50% of Fossil Creek for CBT water owned by irrigators on the Greeley No. 2 canals. This pre-existing agreement makes it difficult for the city to exchange wastewater effluent with Greeley No. 2 for water in Horsetooth.

Exchange during the winter into a high mountain reservoir may also be difficult because the winter low flows are diverted by intervening ditches. Water stored at a high mountain reservoir in an exchange with a downstream ditch might well be judged harmful to the intervening appropriators. Pumping return flows upstream to one of these ditches and then exchanging to a high mountain reservoir such as the proposed Sheep Creek or Rockwell reservoirs could prove feasible.

Storage of reusable return flows could be accomplished by enlarging an existing reservoir for storage of the return flow. Fossil Creek Reservoir is the most obvious candidate for expansion. Treated wastewater from Fort Collins STP No. 2 is routinely diverted and stored in this reservoir. Two other choices are Timnath and Windsor reservoirs. Bittinger (1974) estimated that Fossil Creek, Timnath and Windsor reservoirs could be increased 1500, 1500, and 3800 acre-feet, respectively.

Fossil Creek Reservoir can also be used for storage without modification. During the late summer and winter months storage levels are low. Return flows from STP No. 2 could be stored in the reservoir during the late summer and fall for pumping up to Rawhide during the winter. This would leave the reservoir open for storage of spring runoff.

The other possibility for storage is the use of groundwater aquifers. Water could be allowed to recharge groundwater aquifers through the use of filtration galleries or by well injection. Injection would be the only feasible method for using deep nontributary aquifers. As stated earlier in this section, any use of hydraulically connected tributary groundwater would require adjudication. A groundwater simulation model can be used to determine the effects of the recharge on groundwater flows to the river. Deep well injection of treated wastewater effluent generally means additional treatment is required for both operational and health reasons. Deep wells also have the disadvantage of relatively high power requirements.

Pump-back systems can be used to transport the reusable wastewater upstream to irrigation ditches that have water rights more amenable for exchange. The Larimer and Weld Canal has 28,500 CBT units owned by irrigators along the canal and the pump-back distance is 3.2 miles from STP No. 2 and 6.8 miles from Fossil Creek Reservoir. Exchanges with this canal would be dependable in both wet and dry years and are unaffected by flow in the Poudre River. Storage could be provided at either the WWTP No. 2 area or at one of the existing reservoirs along the canals, such as Windsor or Timnath Reservoirs. Figure 8-12 depicts the general layout of such a system. Bittinger (1974) had the following to say about a pump-back system:

> A variation of the pump back system is to make use of alluvial sands and gravels in Boxelder Creek. The Larimer and Weld and Lake Canals both cross this alluvium bed. High capacity wells could pump from the Boxelder alluvium deposits into either canal and the return flows from the WWTP No. 2 discharged into the Poudre. The timing of the pumping and discharge would have to be investigated.

Another variation suggested by Bittinger is to make use of a large sand and gravel pit between the Larimer and Weld and Lake canals. Water could be pumped from the gravel pits instead of using wells and sunk into the alluvium.

The exchange of reusable water with agricultural ditches was examined in detail for the City of Fort Collins by M.S. Bittinger and Associates, Inc. in 1974. An analysis was made of the exchange potential of reusable return flows from Fort Collins for CBT credit in Horsetooth. Exchanges are analyzed for both downstream and upstream ditch companies. The Bittinger analysis is not repeated here and should be referred to for details.

8.5.6.3 Southside Ditches. The City of Fort Collins has four southside ditches, shown in Figure 8-13, that pass through the community. These ditches from east to west are: the Arthur Ditch, Larimer County No. 2, New Mercer Canal, and the Pleasant Valley and Lake Canal. The lands irrigated under these canals are gradually being turned into subdivision developments. The city has a policy of requirng three acre-feet of water for each acre of development. Most of the water rights transferred to the city have come from one of the southside ditches. The average annual deliveries of these ditches is approximately 33,200 acre-feet. This figure does not include CBT water delivered or exchanged. Figures for each of the ditches are shown in Table 8-10.

A study of ditch consolidation for the Southside ditches is currently underway. Since the city will eventually acquire most of the Southside ditch water rights, it will be able to make use of these waters for municipal uses. Some ditch water will continue to be used for irrigation for many years into the future. This water will not be

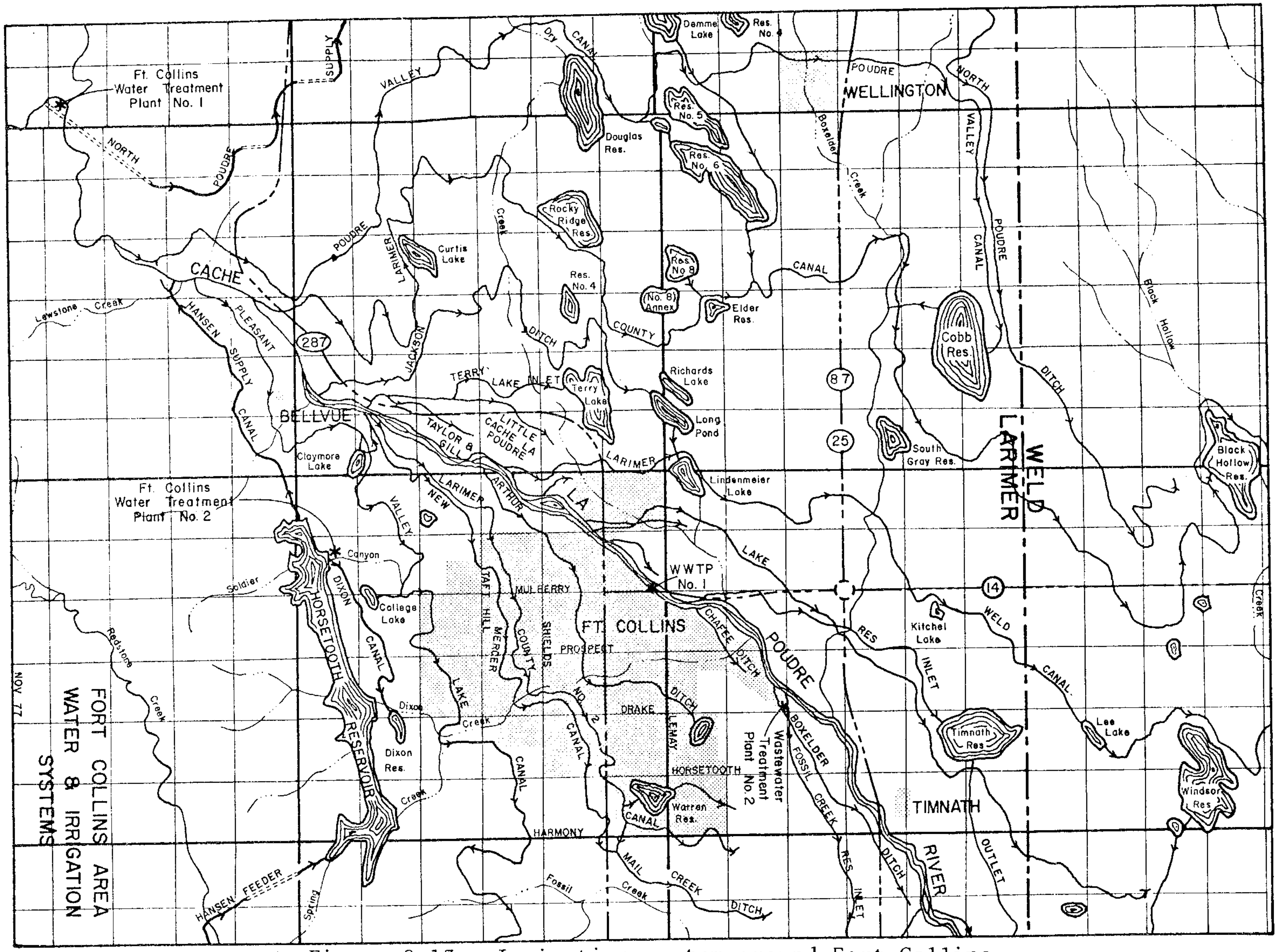


Figure 8-13. Irrigation system around Fort Collins.

Table 8-10. Southside Ditch Diversions and Fort Collins Ownership (City of Fort Collins, 1980a)

	Average Annual Diversions (acre-feet)	Percent Owned by Fort Collins
Pleasant Valley and Lake Canal	15,000	43.4
New Mercer Canal	5,000	12.6
Larimer County No. 2 Canal	7,700	25.4
Arthur Canal	5,500	7.2

available for city use unless the city condemns the remaining water through the exercise of its powers of eminent domain. Currently, the Southside ditch diversions are located below both of the water treatment plants. Ditch consolidation could change the points of diversion. When the water use is changed from agricultural to municipal the water court could reduce the total quantity of water available to the city. Only the quantity of water consumptively used historically for irrigation could be available for transfer. The city could also argue in water court that the same lands are being irrigated and return flows are as high if not higher when urban landscape is irrigated.

If only the historic consumptive use (15,00-20,000 acre-feet per year) is transferred, the city should be able to make sequential uses of the return flows. The consumptive use is the water that is completely lost to the basin through evaporation. The city should be entitled to full use of return flows because no harm would be done to downstream water rights holders. The city could make either recycle reuse or sequential reuse water.

Provided the city can reuse return flows from the Southside ditches, the city could treat the return flows in the same manner as return flows from Windy Gap. Eventually, return flows from PRPA's Windy Gap water would have to be transferred back to Rawhide as the additional power units are constructed. Return flows from the Southside ditch water could be phased in at approximately the right time to replace the return flows that must be sent to Rawhide. The use of Windy Gap and Southside ditch water would be complementary in terms of timing and use of the same system for reuse.

Storage prior to use could be accommodated through the rehabilitation of North Poudre Irrigation Company (NPICo) Reservoir No. 6, shown in Figure 8-12. Approximately 6,500 acre-feet of additional capacity can be added to this reservoir. The reservoir is also adjacent to the Rawhide reuse pipeline. This opens options for storage and exchange of water between Fort Collins, PRPA, and NPICo.

8.5.6.4 Import of New Foreign Water. The North Platte River Decree limits the quantity of water that can be exported out of the basin in Colorado. After completion of Michigan Ditch improvements, imports will still be 1,000 to 1,500 acre-feet per year less than decree limits. If senior water rights were acquired in North Park, the additional water could be imported into the CLPRB. The costs associated with such a project are unknown at this time, but should be low because the importation system is already in place.

An average of 17,826 acre-feet per year is exported from the North Platte River Basin. The Laramie River Decree limits exports to 19,875 acre-feet per year which is 2,049 acre-feet per year less than the decree limit. Water rights could be purchased from Laramie River irrigators and the additional water imported into the CLPRB.

Another possibility is the purchase of senior water rights in the Laramie River Basin so that additional water could be diverted from Sand Creek via the Wilson Supply Ditch. Sand Creek diversions are not included in the Laramie River Decree export limits. The yield of the 35 cfs of senior rights is not known but would probably be between 2,000 and 4,000 acre-feet per year (35 cfs diverted for 60 days yields 4,166 acre-feet).

The total imports from the North Platte River Basin could be increased by 5,000-7,500 acre-feet per year without constructing new import facilities. Return flows from this water belong to the importer and are subject to reuse and exchange.

8.5.6.5 Use of Old Foreign Water. Prior to the Michigan Ditch-Joe Wright expansion and the increase in Long Draw Reservoir capacity, 38,500 acre-feet of water were imported into the CLPRB each year. Approximately 30,000 acre-feet of this amount belongs to the Water Supply and Storage Company. Return flows from this foreign water have historically been allowed to accrue to downstream water users. This water may be available for reuse even though the importer (WS&SCo) has never made any effort or plans to put the return flows to use in the past.

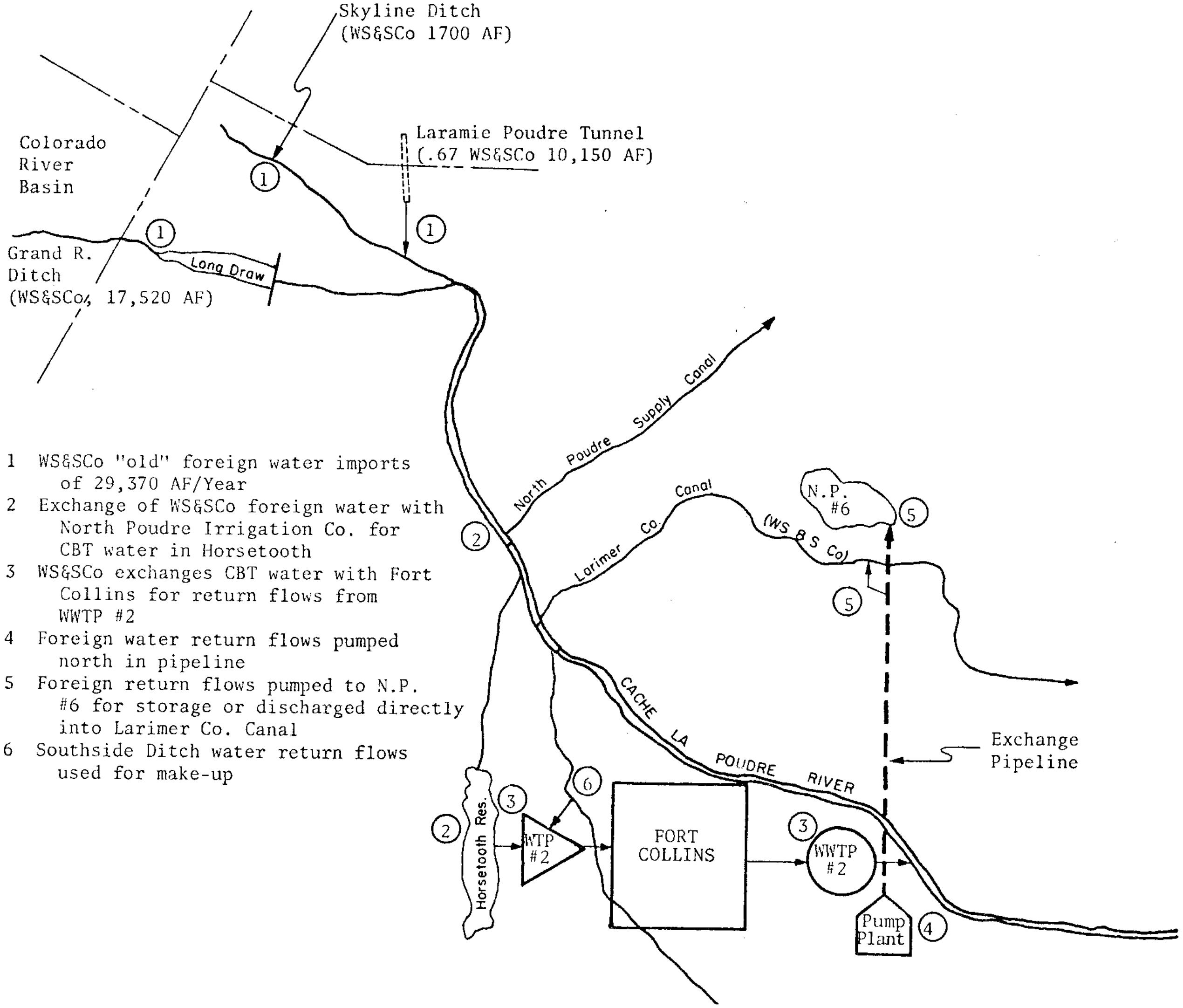
The city could enter into an agreement with WS&SCo whereby the city would use the foreign water first and that the return flows from the old foreign water be treated and returned to WS&SCo or some other company for reuse. The foreign water could also be exchanged for CBT water in Horsetooth.

Legally, such an agreement would undoubtedly be challenged in court by junior appropriators dependent on the historic return flows from the foreign water. Strong arguments can be made for both sides. Since foreign water imports can be stopped at any time without the importers being held responsible for longstanding appropriations of return flows by junior appropriators, it is a logical extension that the place of use or quantity of return flow can be altered at any time without legal liability. On the other side, a change in the location and type of use is not the same as stoppage of imports and dependent appropriators would be injured by such a plan. In the end, only the water courts can decide the outcome.

A modification of the system proposed above could eliminate objections by downstream water users. The plan, outlined below, would maintain return flows in the same historical pattern but take advantage of the foreign water for exchange with CBT water in a manner similar to the Fort Collins-PRPA-WS&SCo reuse exchange agreement.

A mutually advantageous system for both Fort Collins and WS&SCo might be set up as shown in Figure 8-14 and described below:

1. WS&SCo delivers foreign water to the North Poudre Irrigation Company (NPICo). NPICo is the owner of 40,000 CBT units.
2. NPICo credits WS&SCo with CBT water in Horsetooth in an equal amount. WS&SCo is now credited with CBT water that is in essence foreign water. The exchange for foreign water credit in Horsetooth is very similar to the Fort Collins-PRPA-WS&SCo river agreement.
3. WS&SCo then leases the foreign credit CBT water to Fort Collins for use in the municipal system.
4. Fort Collins uses the water in its municipal system. Payment to WS&SCo for their part in the exchange is made by making up consumptive use from return flows from Southside ditch water or unused shares of WS&SCo stock, plus a bonus of extra water or a cash payment.
5. The return flows are then pumped or exchanged back to WS&SCo for use. The enlarged North Poudre Reservoir No. 6 is used for storage.



1 WS&SCo "old" foreign water imports of 29,370 AF/Year
2 Exchange of WS&SCo foreign water with North Poudre Irrigation Co. for CBT water in Horsetooth
3 WS&SCo exchanges CBT water with Fort Collins for return flows from WWTP #2
4 Foreign water return flows pumped north in pipeline
5 Foreign return flows pumped to N.P. #6 for storage or discharged directly into Larimer Co. Canal
6 Southside Ditch water return flows used for make-up

Figure 8-14. Reuse exchange of "old" foreign water.

If the CBT water resulting from the foreign water exchange could be used during the winter, spring or fall months, the return flow percentage would be high. Irrigators below WS&SCo would have no basis for complaints if WS&SCo actually received an equal or larger quantity of water in return for allowing Fort Collins first use. Fort Collins could use water from the Southside ditches or other water as make-up. The returns would be at least 2 to 1 and might be as high as 4 to 1 for each acre-foot of consumptive use made up by Fort Collins. In effect, Fort Collins would receive four acre-feet of water for each acre-foot delivered to WS&SCo.

Another variation would involve diversion and treatment of WS&SCo foreign water at the Fort Collins WTP No. 1 on the Poudre and then a reuse return system similar to the alternative outlined above. The foreign water could also be diverted to WTP No. 2 through a new pipeline hooked up to the PV&LC Co. If the water came from storage, other water rights holders would not be injured.

8.5.6.6 Exchange Reuse of Native Water. Exchange reuse of high quality mountain water involves the transfer of the first use of water from a lower quality early priority water rights appropriator to a high quality user searching for the least cost alternative to meet water demands. In the CLPRB, 90% of high quality raw waters are used first by the high priority agricultural user and then sequentially reused by other agricultural users. Fort Collins could enter into an agreement with one of the upper ditch companies whereby the city gets first use of the water and the ditch company second use. Consumptive use would have to be made up plus some form of compensation for the right to have first use of the water. The consumptive use could be made up with water currently owned by the city or water purchased from another irrigation company. This type of arrangement involves changing points of diversion. The arrangement is somewhat similar to that on Northglenn-FRICO exchanges. If the Northglenn case could be used as a weather vane, extensive litigation might be involved. Any plan wherein one irrigation company will benefit at the perceived expense of antoher will cause conflict and make implementation difficult. Still, with good coordination and proper handling, most of the roadblocks to such a plan can be removed to the benefit of all parties involved.

8.5.6.7 Reuse of Native Water Within the City. Reuse of native water within Fort Collins would provide a large source of water for the city. Historically, Fort Collins has used 11,300 acre-feet per year of direct flow rights from the Poudre and discharged the treated wastewater back to the Poudre. Downstream junior appropriators have become dependent on the return flows. As discussed in Section 4.12, if a municipality retains possession of its wastewater by not discharging to a receiving body or stream but retaining the water within the system for reuse, the municipality may have the right to reuse the water. The dependent appropriators might not have any rights to the continuation of the historic native water return flows. The return flows could be used for landscape irrigation or at some point in the future, recycled for direct potable use in the city's system. Since the direct flow rights of the city are used year-round, approximately 8,400 acre-feet per year of return flows would be available for reuse. Any attempt to implement such a system might destroy relations between the city and agricultural water users in the basin.

8.5.7 Role of Reuse in Meeting Water Demand

Water demand for the year 2000 for the city of Fort Collins has been projected at 41,000 acre-feet. The current water supply available for treatment is 30,500 acre-feet and the total supply is 38,000 acre-feet. The total quantity of water available from water reuse is 65,380 acre-feet per year as shown in Table 8-9. This figure does not include sequential reuse of native water through exchange with irrigation companies. There is no shortage of water reuse options available to the City of Fort Collins. If so desired, the city could meet all forseeable water demands for at least 50 years into the future using water reuse exchange options.

8.6 City of Greeley

The City of Greeley is located on the east side of the CLPRB very close to the junction of the Cache la Poudre and South Platte Rivers, as shown in Figure 8-1. The 1980 population of Greeley was approximately 65,000. The population projection for the year 2000 predicts a population of 140,000.

The service area population in 1979 was 76,086. The service area population is high because Greeley supplies water to Evans (4,000), Windsor (4,500) and several other small service areas. Greeley also supplies water to Kodak and Monfort (prior to its 1980 closing) (City of Greeley, 1980).

8.6.1 Water Supply

Greeley obtains its water supply from three sources: (1) direct flow and storage rights in the CLPRB, (2) CBT project water, and

(3) irrigation company stock in the Bigh Thompson River Basin. Table 8-11 is a summary of the water resources currently available to Greeley. In addition to the resources in Table 8-11, Greeley also owns 8,000 acre-feet of water in the Windy Gap Project. Windy Gap water is not likely to become available for use prior to 1984.

Greeley's water policy has been to increase the supply available at its Boyd Lake treatment plant. This is being accomplished through acquisition of CBT water, a large holding in the Greeley-Loveland Irrigation Company, and participation in the Windy Gap Project. Existing water rights holdings in the CLPRB have not been expanded in recent years.

8.6.2 Water Demand

In 1979 Greeley and its service area customers used 20,000 acre-feet of water. In 1975 and 1970 the figures were 17,600 and 13,700 acre-feet, respectively (City of Greeley, 1980) as shown in Figure 8-15. Projected water demand for the year 2000 is 44,500 acre-feet based on a service area population of 140,000. Per capita use in 1979 was 218 gpcd while the five-year average is 231 gpcd. The projected year 2000 water usage is based on a per capita demand of 284 gpcd. The accuracy of such a high per capita water demand increase is questionable but is used to provide a high level demand adequate for use in this paper.

8.6.3 Water Treatment Facilities

The City of Greeley has three water treatment facilities. One is located on the Cache la Poudre River northwest of Fort Collins at a small community named Bellvue. The other two plants are located near Boyd Lake to the east of Loveland. The location of the water treatment

Table 8-11. Water Resources of Greeley (City of Greeley, 1980)

High Mountain Lakes			Capacity (acre-feet)
Seaman			5,008
Hourglass			1,693
Commanche			2,256
Twin Lakes			301
Barnes Meadow			2,349
Peterson Reservoir			892
TOTAL STORAGE			12,499
Direct Diversion from Cache la Poudre River			
Priority No. 6	March 1862	12.5 cfs	3,620
Priority No. 6.5	August, 1862		5,430
			9,050
Colorado Big Thompson Water (18,452 units)			
Maximum			18,452 (1.0 AF/share)
Minimum			11,070 (0.6 AF/share)
Irrigation Company Stock			
Greeley-Loveland	(190.5 shares 33AF/share)		6,273
Seven Lakes	(36 shares 20 AF/share)		720
Lake Loveland	(13 shares 40 AF/share)		520
			7,513
Total Maximum Water Available to Treatment Plants			47,514
Total Minimum Yield[a]			34,400
Other Ditch Company Water Rights[b]			
Greeley No. 3			3/8 shares of Direct Rights
Greeley Irrigation Company			21 shares
Sand Creek Lateral Irrigation Company			8 shares
Delta Irrigation Company			3 shares
New Cache la Poudre Irrigation Company			4 shares (River)
Cache la Poudre Reservoir Company			8 shares (Reservoir)

---

[a] Based on storage yield of 5,000 acre-feet, CBT yield of 0.9 acre-feet per unit, irrigation stock yield of 3,250 acre-feet and direct flow rights yield of 9,050 acre-feet.

[b] Water not available to filter plants.

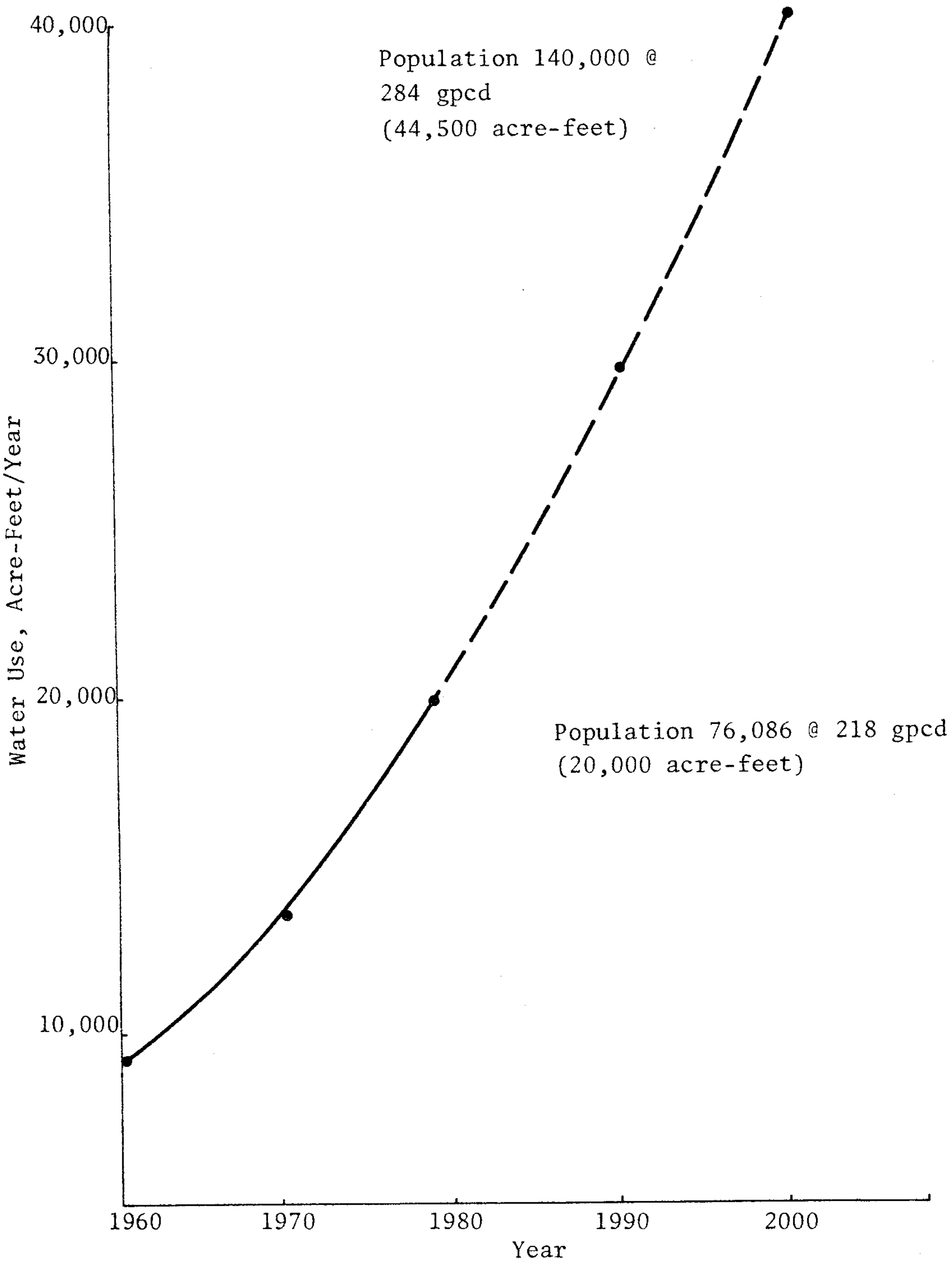


Figure 8-15. Water demand schedue for the City of Greeley.

facilities and Greeley's high mountain reservoirs are shown in Figure 8-16.

The Bellvue water treatment plant was built in 1901 and currently has a capacity of 18.0 mgd. The Boyd Lake Water Treatment Plant No. 2, the older of the two plants, was completed in 1969 and has a capacity of 10.0 mgd. Boyd Lake Water Treatment No. 1 was completed in 1976 and has a treatment capacity of 20.0 mgd. The total treatment capacity available to Greeley is 48 mgd.

8.6.4 Wastewater Treatment Facilities

Greeley has two wastewater treatment plants. The First Avenue Wastewater Treatment Plant is located on the Cache la Poudre River on the east side of Greeley. The facility had an average daily flow of 7.76 mgd in 1979 which translates to 118 gpcd. The second treatment facility is the Love Tree Industrial Wastewater Treatment Plant which treated Monfort Packing Plant waste until 1980. The 1979 flow through this plant was 0.96 mgd (U.S. Army Corps of Engineers, 1977).

The city is preparing to construct a new land treatment facility at a site four miles east of Gill. The planned land treatment process would reduce the historic per capita return flows from the sewage treatment process. No decision has been made concerning the water rights issue of downstream junior appropriators who have become dependent on return flows from the First Avenue Wastewater Treatment Plant.

The return flows for the City of Greeley and Monfort totaled 9,770 acre-feet in 1980. Of this amount, 8,770 acre-feet originated at the First Avenue Wastewater Treatment Plant. The return flows amount

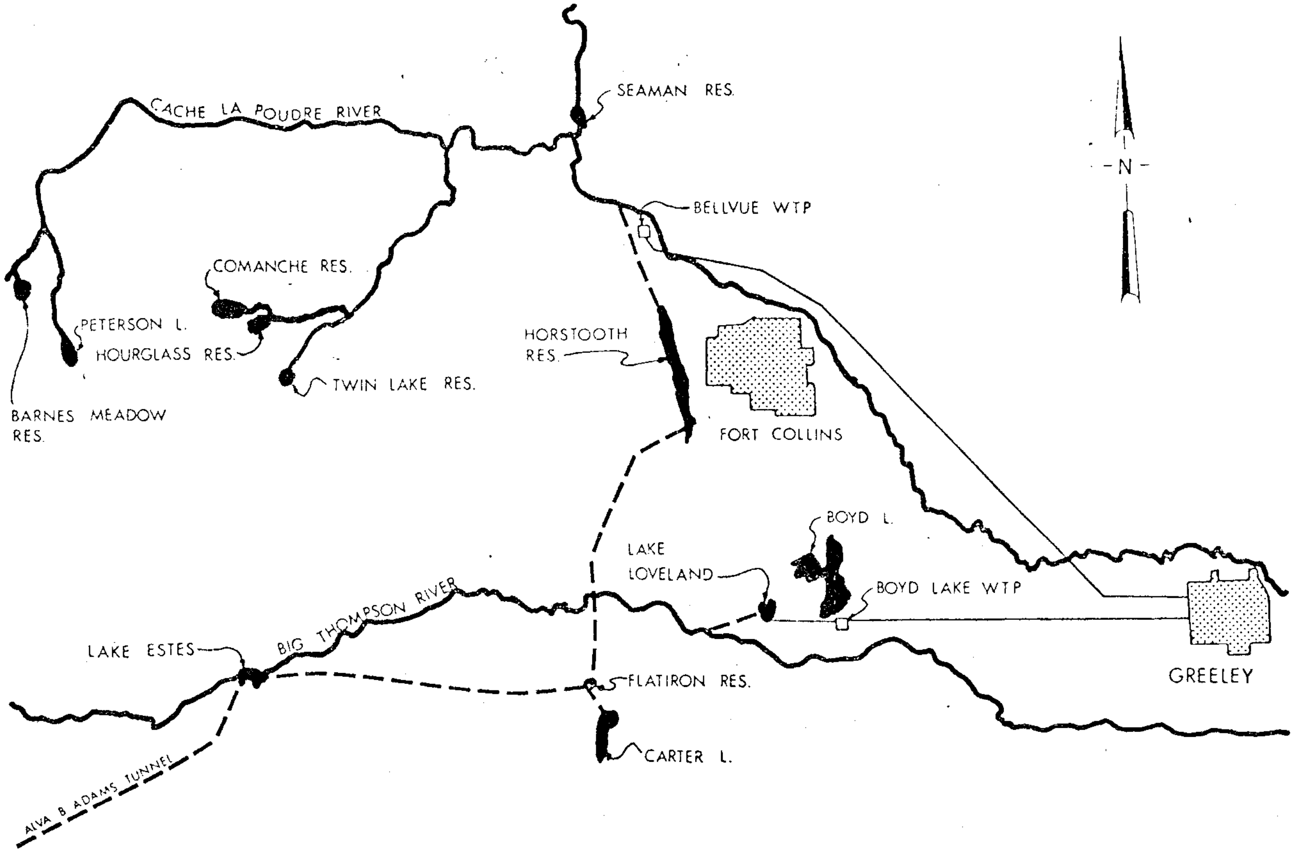


Figure 8-16. City of Greeley water supply system (Greeley, 1976).

to 52.5% of the 18,590 acre-feet treated each year at the Greeley water treatment plants. In 1980, 3,930 acre-feet of water was sold to municipalities and industries outside of Greeley. When the outside water sales are taken into account, the return flows from Greeley in 1980 averaged 60% of the municipal water use. The monthly return flow rates for 1979 are shown in Table 8-12.

The water quality of the Greeley WWTP discharge has been poor over the last several years. The First Avenue WWTP is overloaded and there have been operational problems. BOD and suspended solids (SS) levels are consistenlty higher than the 30 mg/ℓ BOD and 30 mg/ℓ SS permit requirements. The TDS levels in Greeley's raw water are approximately 100 mg/ℓ. The TDS level in the WWTP effluent averages 540 mg/ℓ (Environmental Protection Agency, 1972).

8.6.5 Water Reuse Opportunities

The City of Greeley currently has no foreign water from which return flows are reusable. As discussed earlier, Greeley's return flows from CBT water cannot be reused. Although Greeley has several high mountain reservoirs in the CLPRB, none of them store water imported from another basin. Greeley does have an 8,000 acre-foot share of Windy Gap water. Return flows from this source will be available for reuse or exchange in any manner that Greeley chooses. The single limiting constraint is that the Windy Gap water must be used prior to Greeley's CBT water each year. This limitation presents problems for timing of exchanges when water demand is high late in the summer. Greeley's ownership of large quantities of CBT water means Greeley must use the Windy Gap water early in the year when exchange for agricultural water is the least desirable.

Table 8-12. Monthly Return Flow Rates for Greeley, 1979
(City of Greeley, 1980)

	Water Treated acre-feet	Water Sold Outside Greeley[a] acre-feet	Water Use in Greeley acre-feet	Wastewater at First Ave. WWTP[b] acre-feet	Return Flow as % of Treated Water %
Jan.	714	297	417	733	100
Feb.	884	297	587	653	100
March	990	297	693	628	91
April	1320	328	992	608	61
May	1430	328	1102	818	74
June	2255	328	1927	820	43
July	3187	393	2794	780	28
Aug.	2147	393	1754	780	44
Sept.	2103	393	1710	726	43
Oct.	1747	293	1454	761	52
Nov.	895	293	602	718	100
Dec.	916	293	623	742	100
Total	18588	3933	14655	9767	

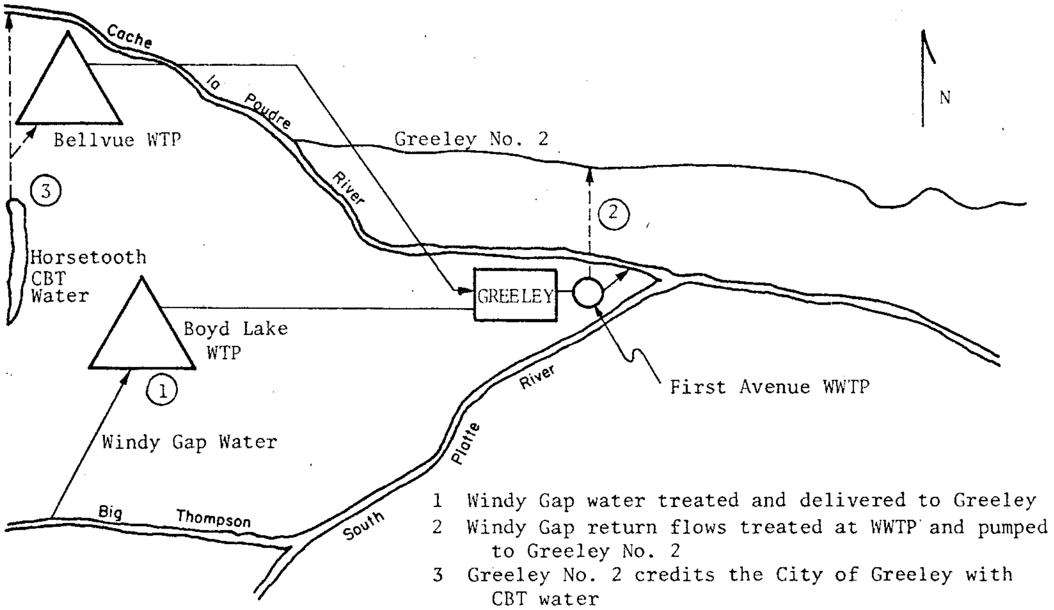
[a] Data given only by quarters.

[b] Groundwater infiltration has not been taken into account.

Greeley's location in the CLPRB presents problems in terms of water reuse exchange. Because Greeley is located at the very downstream end of the CLPRB, exchange of wastewater upstream is made difficult. Most of the irrigation water received in the Greeley area is the result of return flows from agricultural use upstream. These return flows are of relatively low quality because of their high TDS levels. Direct use of these high TDS waters presents quality problems for domestic consumption. In addition, Greeley's water treatment facilities are over 25 miles to the west. If the wastewater return flows cannot be exchanged upstream, exchange for water in the Greeley vicinity would mean construction of a new treatment facility built especially for this purpose or a pipeline back to one of the existing water treatment facilities. There are, however, a few opportunities that could prove useful for exchange reuse.

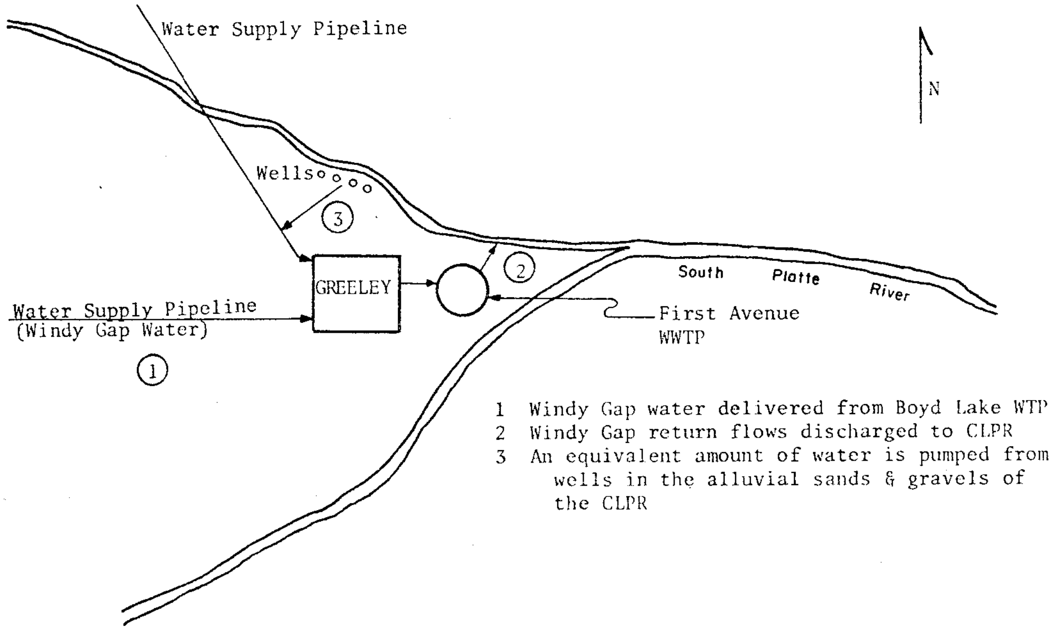
8.6.5.1 Exchange with Greeley No. 2. The New Cache la Poudre Irrigation Company owns Greeley No. 2 Canal to the north of Greeley. Irrigators under Greeley No. 2 own 11,049 CBT units. A pipeline approximately four miles long could pump reusable wastewater, such as Windy Gap return flows, from the Greeley STP to Greeley No. 2 in exchange for CBT water that could be treated at either of the Greeley water treatment plants as shown in Figure 8-17(a). Greeley might be able to use one of its three water supply pipelines from the Bellvue Plant to pump back to Greeley No. 2 to the point where the lines cross the ditch.

8.6.5.2 Exchange for Groundwater. Prior to 1907 Greeley's water supply was taken from infiltration wells in the gravel bed of the Cache la Poudre River a short distance above the business section (City of greeley, 1952). Greeley could use a similar system to meet peak demands



1 Windy Gap water treated and delivered to Greeley
2 Windy Gap return flows treated at WWTP and pumped to Greeley No. 2
3 Greeley No. 2 credits the City of Greeley with CBT water

(a) Exchange with Greeley No. 2



1 Windy Gap water delivered from Boyd Lake WTP
2 Windy Gap return flows discharged to CLPR
3 An equivalent amount of water is pumped from wells in the alluvial sands & gravels of the CLPR

(b) Exchange for groundwater

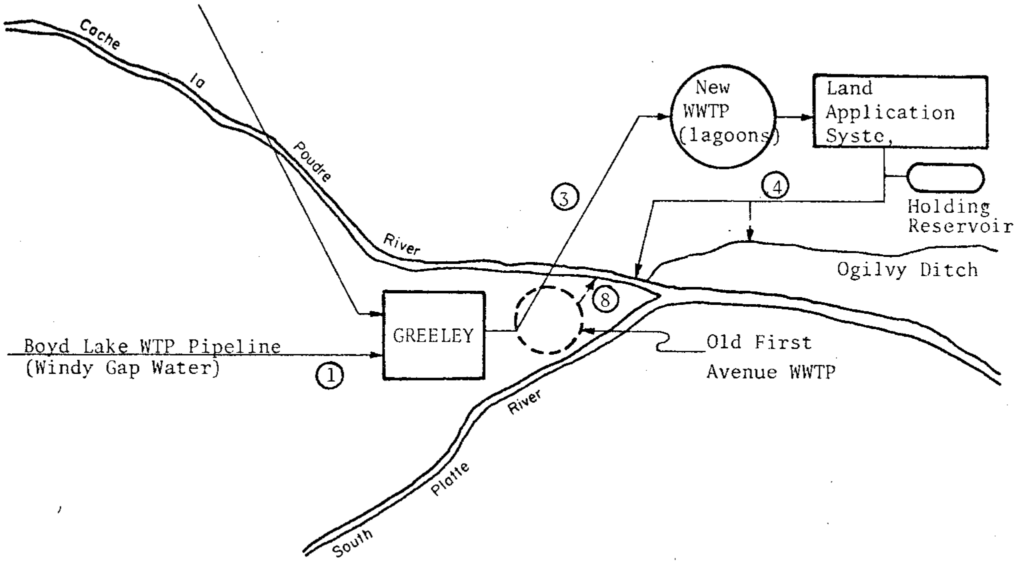
Figure 8-17. Greeley reuse alternatives.

during the summer. Wells could be sunk into the alluvial aquifer along the Poudre and reusable return flows from the wastewater treatment facility could be used to replace water withdrawn from the aquifer as shown in Figure 8-17(b). The water pumped from the sand gravel aquifer would be high in total dissolved solids (1,500 mg/ℓ) and would have to be mixed with treated water from either the Boyd Lake or Bellvue treatment plants. Water from these plants has a TDS of less than 100 mg/ℓ.

Coordination of foreign water use and water demand might create operational problems. Windy Gap water must be used prior to CBT water. Greeley might be obliged to use Windy Gap during periods of relatively low demand making mixing of high TDS well water with mountain water a problem. Storage of some type could resolve the mixing problem.

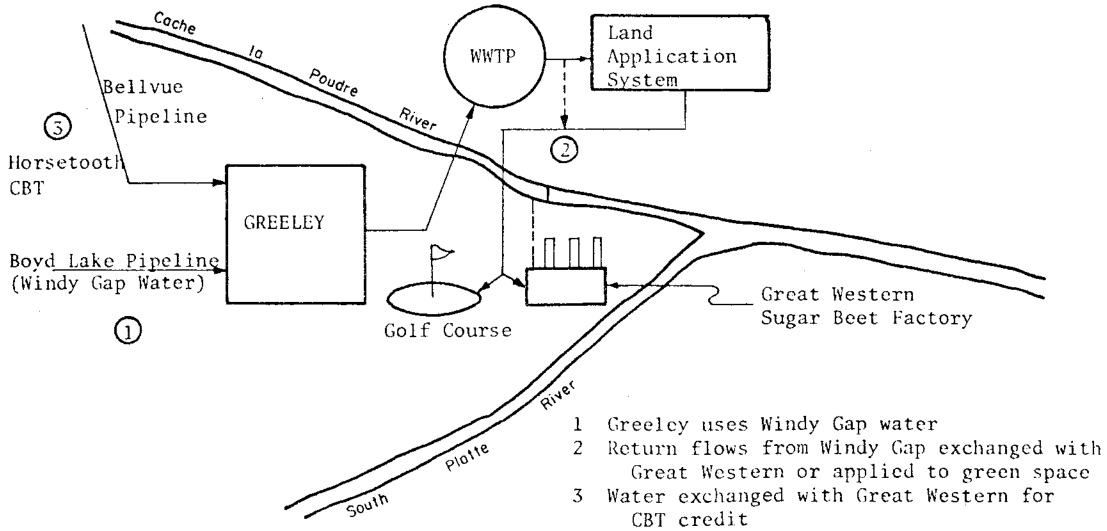
8.6.5.4 Land Treatment Reuse Makeup. Greeley is currently going ahead with a land treatment plan for treating municipal wastewater. Consumptive use will be higher with the land treatment plant than with the conventional mechanical wastewater treatment plant in use at present on the First Avenue site. Greeley might be required by the Water Court to maintain its historic return flow quantities from CBT and native waters. Olgivy Ditch diverts treated wastewater from the Poudre River just below the First Avenue Wastewater Treatment Plant. If this were to occur, Greeley could use Windy Gap water return flows to make up the difference in consumptive use between the two systems. The schematic in Figure 8-17(c) illustrates the land application plan.

8.6.5.5 Sequential Reuse Within Greeley. Another potential use of foreign water reusable return flows is for industrial use. Great Western Sugar Company owns 3,598 units of CBT water. Water is currently



1 Water from Windy Gap delivered along with CLPRB and Ditch Co. water.
2 Water formerly treated at First Avenue WWTP and diverted by Ogilvy Ditch
3 Wastewater now pumped to land application system that consumptively uses water as part of treatment process
4 Return flows from land application supplemented with Windy Gap return flows and discharged to either the CLPR or directly to Ogilvy Ditch

(c) Land treatment



1 Greeley uses Windy Gap water
2 Return flows from Windy Gap exchanged with Great Western or applied to green space
3 Water exchanged with Great Western for CBT credit

(d) Exchange with Great Western

Figure 8-17. Continued.

diverted just above the First Avenue WWTP outfall. Water diverted at this point is lower in quality than Greeley's treated wastewater meeting NPDES permit discharge requirements. Great Western Sugar could use the Greeley reusable return flows in exchange for CBT water that Greeley could treat at their Boyd Lake Water Treatment Plant as shown in Figure 8-17(d). Once again, timing of supply with the reusable water demand might necessitate storage.

The other option is to irrigate golf courses and open space with the Windy Gap return flows. Storage of the return flows does not pose as serious a problem with this option because return flows from Windy Gap water would be available for use during most of the landscape irrigation season.

8.6.5.6 Other Options. The other options, such as exchange of high quality water currently receiving first use in agriculture for wastewater flows may not be cost effective for Greeley. A lengthly return pipeline would have to be constructed for pumping effluent back to the users of the high quality mountain waters. Local exchange is difficult because of the low quality of the water and remote location of the water treatment facilities.

8.6.6 Role of Reuse in Meeting Water Demand

Greeley owns rights to 8,000 acre-feet of Windy Gap water. Return flows from this water could amount from anywhere between 4,000 and 8,000 acre-feet of water per year depending on the season during which it is used. Given current Windy Gap water use restrictions, the Windy Gap water must either be stored outside the CBT system or used early in the summer. Four water reuse options have been outlined: (1) the Windy Gap water can be exchanged for CBT water with the Greeley No. 2 Canal or Great Western Sugar, (2) the return flows can be exchanged for groundwater from the Poudre for meeting peak demands during the summer, (3) return flows from Windy Gap can be used to make up for increased consumptive use if the proposed land application system is built and the Water Court rules that historical return flows must be maintained, and (4) the return flows can be sequentially reused in Greeley.

Given the existing Windy Gap storage restrictions, storage either before or after use will be needed to make full use of the return flows from Windy Gap water. Other reuse exchange options are not readily applicable due to Greeley's location in the downstream end of the river basin.

Greeley has an available water supply of 34,400 acre-feet during a drought year, and an average year supply of approximately 40,000 acre-feet. Year 2000 maximum demand is 44,500 acre-feet. Return flows from the Windy Gap water could be used to make up the difference between demand and supply if a workable reuse system can be designed and implemented.

8.7 Summary

The methodology presented in Chapter 6 has been used to formulate water reuse exchange alternatives for the cities of Fort Collins and Greeley. The alternatives have been built around the sequential reuse/foreign water exchange and the sequential reuse/native water exchange forms discussed in Chapter 2. These reuse forms have evolved to fit the characteristics of the South Platte River Basin and their use in the CLPRB was designed to produce alternatives that mesh well with the existing water use system and can be competitive with the more traditional water supply and wastewater treatment alternatives.

The costs of water reuse can vary widely depending on the type of water reuse employed. Potable water reuse, as proposed by the Denver Water Department, has been estimated to cost $2.15 per 1,000 gallons for a 10 mgd plant (Culp-Wesner-Culp, 1979). A reuse exchange project such as Greeley's exchange alternative with Great Western Sugar could cost as little as $.60 per 1,000 gallons based on $.474 per 1,000 gallons for wastewater treatment and $.127 per 1,000 gallons for water treatment (Culp-Wesner-Culp, 1979). The costs of water produced from these reuse projects could vary from $2.15 to $0.60 per 1,000 gallons. Potable water reuse, as shown above, is 3.6 times more expensive than reuse exchange.

The costs of most water reuse alternatives fall in between these two extremes. For example, the cost of enlarging North Poudre Reservoir No. 6 by 5,400 acre-feet to facilitate reuse exchanges has been estimated at $2,008,000. If an average of 4,000 acre-feet per year could be exchanged, the annual cost per 1,000 gallons would be $0.16 (8%, n=20). The current annualized cost of purchasing one unit of CBT water is roughly $.90 per 1,000 gallons ($2,000/unit @8% for n=20). The total cost of each of these alternatives is $0.76 and $1.50 per 1,000 gallons, respectively. Both are less expensive than potable reuse. Many of the CLPRB reuse exchange projects are less expensive than purchasing additional CBT units.

The next step in the planning process would be the integration of the water reuse alternatives into the comprehensive water resources planning process. This would involve a benefit-cost analysis of the water reuse alternatives in comparison with the other alternatives that achieve the same purposes. The economic methodology for comparing alternatives was presented in Chapter 5. Each of the alternatives should also be analyzed for their performance in meeting non-economic objectives such as environmental quality. Once each of the alternatives has been evaluated according to their performance in meeting the objectives, the information can be presented to the decision makers.

The water reuse alternatives developed in this chapter are only a few of the many combinations possible. The development of any one alternative brings to light information that can be used in the development of other water reuse alternatives. The challenge in water reuse planning will be developing alternatives that are beneficial to all parties involved and that make efficient use of the existing water resources systems.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

Water reuse exchanges have the potential to become the water resource planner's most useful tool in the next phase of municipal water supply development in Colorado. Since the opening of the western frontier to settlement in the 1860's, the emphasis in the water resources field has been on the development of dependable water supplies for agriculture. The development of municipal water supplies played a relatively minor role. Now, continued rapid urban growth has forced municipal water planners to turn to agricultural water supplies as a source of water. Water reuse exchange projects between municipalities and agricultural water owners provide a cooperative way to meet the water needs of both.

9.1 Conclusions

The objectives of this research were to develop a theory of water reuse and to demonstrate how the theory is applied through case studies. In meeting these objectives, the following conclusions were reached:

1. The development of water reuse alternatives requires an in-depth knowledge of the basin water system, users and uses.
2. Water reuse terminology found in the literature is limited to specific applications. Definitions of the same or similar terms

terms often overlap or are incomplete. A comprehensive set of water reuse definitions has been synthesized from the literature and is presented in Chapter 2.

3. Based on a review of federal and state water quality laws, it is evident that financial and regulatory incentives encourage the selection and development of water reuse projects, particularly in the area of new sewage treatment projects.
4. Colorado's appropriative water law provides the basis for workable water reuse exchange systems but does not address many specific water reuse issues. The ownership of foreign water rights places a municipality in a very favorable reuse exchange position.
5. The economic evaluation of water reuse plans for municipalities is usually done using cost-effectiveness analysis. The supplementary use of benefit-cost analysis has technical advantages over using only cost-effectiveness analysis.
6. The water reuse potential demonstration for the South Platte River Basin indicates there is ample opportunity for Front Range municipalities to develop water reuse alternatives.
7. In the Cache la Poudre River Basin, the City of Fort Collins has excellent water reuse exchange opportunities while those for Greeley are more limited due to its physical location at the lower end of the basin.

In the sections that follow, each of these conclusions is developed more fully.

9.1.1 Development of Water Reuse Alternatives

The development of water reuse exchange alternatives should be built around the acquisition and application of information on basin water resources and their uses and users. This is necessary because water exchange reuse schemes involve complex engineering, legal and organizational problems. Water reuse exchange does not, however, require the technologically sophisticated treatment systems associated with potable water reuse. In developing water reuse exchange alternatives, water planners must work closely with agricultural water organizations if workable reuse exchange alternatives are to be found.

9.1.2 Establishing a Uniform Terminology

The water resources literature has not established a uniform water reuse terminology. Many definitions exist for the same or similar water reuse terms. In Cahpter 2 key reuse terms are defined based on concepts of water use, water user, and intent to reuse water. Branching and set theory are used to classify the water reuse terms. The establishment of a uniform terminology is important to the development of a comprehensive theory of water reuse.

9.1.3 Water Quality Legislation and Water Reuse

The Federal Water Pollution Control Act and the Clean Water Act Amendments contain both planning and project funding incentives for water reuse. In addition to the federal incentives, the State of Colorado gives priority points for funding of water reuse projects.

These points significantly increase the chances of a publicly owned wastewater treatment project receiving federal and state funds. These water reuse incentives have been effective at encouraging municipalities to consider and in some cases adopt water reuse alternatives.

Public health issues have been raised by water reuse projects involving publicly owned treatment works. Neither the State of Colorado nor the EPA have specific biological standards for protecting public health on water reuse projects. Fecal coliform standards are set on a case-by-case basis. In the Northglenn water reuse case, the EPA and State of Colorado required different fecal coliform standards for the same discharge. The enactment of uniform standards would eliminate much of the controversy and uncertainty associated with the reuse of municipal effluent.

9.1.4 Appropriative Water Law

Appropriative water law provides the mechanisms needed to facilitate water reuse planning. A few of the more important mechanisms are: (1) system of water rights ownership, (2) methods for the sale, transfer and change in use of water rights, and (3) a classification of rights and their restrictions for direct flow, storage and foreign waters. It also protects, within certain limits, downstream appropriators of return flows.

Legislative water law does not deal with many of the specific problem issues that are bound to arise in the near future. A few of these problems are: (1) the reuse of old foreign water, (2) reuse of return flows from native storage water rights, (3) recycle reuse of native direct flow rights within a municipality, (4) maintenance of historic return flows when a new treatment system, such as land application, is used, and (5) the capture and reuse by municipalities of the return flows from consumptive use transfers from rights bought from agricultural water users. If the State Legislature does not act to clarify these issues, they will be resolved on a piecemeal basis by the water courts.

9.1.5 Economic Evaluation of Water Reuse Alternatives

Cost-effectiveness analysis is the usual method used by municipalities for the economic evaluation of water supply and wastewater treatment alternatives. Due to rapidly rising incremental costs of supplying additional units of water, however, benefit-cost analysis is recommended for setting water supply project outputs. Cost-benefit analysis accounts for the decrease in water demand as the costs of supply rise. The economic methodology presented in Chapter 5 shows how to incorporate benefit-cost analysis into the development of water reuse alternatives.

Cost-effectiveness analysis should be used in the final comparison of water reuse alternatives with combinations of single purpose alternatives that accomplish the same objectives. The least cost alternative or combination of alternatives that fulfills project purposes is the best choice in economic efficiency terms.

9.1.6 Reuse Exchange Potential of the South Platte River Basin

The South Platte River Basin is ideally suited for water reuse exchange arrangemetns between municipalities and agriculture. The water supply originates above the municipalities and the municipalities are located adjacent to or above the irrigated agricultural lands. This arrangement means that agricultural water exchanges involve short transfer distances thereby minimizing water losses and that municipal wastewater return flows can be transported using existing canals and streams. Reuse exchange alternatives with these advantages can be low in cost compared to other water supply alternatives.

The reuse exchange potential evaluation made in Chapter 7 indicates that there is sufficient water in the South Platte River Basin to meet all but the very highest projections of municipal water demand out to the year 2020. The sequential reuse/foreign water form and the sequential reuse/native water form were used to demonstrate the exchange potential. An exchange ratio of 8.5 to 1 exists in SPRB meaning that eight units of agricultural water exist for each single unit of urban water demand. High exchange ratios indicate that water reuse plans are relatively easy to formulate while low ratios indicate the opposite.

9.1.7 Reuse Exchange Potential of the Cache la Poudre River Basin

The City of Fort Collins has excellent water reuse exchange opportunities. Although short on foreign water rights ownership, the reuse exchange possibilities with PRPA for Windy Gap water beyond the existing reuse exchange agreement are good. In addition, several other reuse exchange options are available to Fort Collins that involve both foreign water and native water exchanges. All of Fort Collins water demands could be met to the year 2020 with water reuse exchange options.

The water reuse exchange opportunities available to the City of Greeley are more limited due to its geographic location at the lower end of the CLPRB and lack of foreign water ownership. Both groundwater and surface water in the Poudre and South Platte rivers have very high

TDS levels making exchanges of treated wastewater effluent for local irrigation water undesirable. Greeley does own 8,000 acre-feet of Windy Gap water which, when it becomes available in 1984, will open up at least two reuse exchange opportunities.

9.2 Recommendations

Like any relatively new field of study, water reuse planning has many problem areas that need further study. The majority of these involve unanswered questions about water reuse exchange schemes between municipalities and irrigated agriculture. Areas where further study would be useful are:

1. Problem areas in applying the appropriative water law of Colorado to water reuse plans should be identified and legislative recommendations made in order to resolve major areas of uncertainty and conflict.
2. A standard water reuse vocabulary with carefully thought-out definitions should be adopted for use by water resource planners.
3. A biological standard needs to be set to protect public health when reusing municipal wastewater for non-potable purposes.
4. Case studies should be undertaken using benefit-cost analysis techniques for municipal water reuse planning and water supply planning. Benefit-cost analysis outcomes should be compared with cost-effectiveness outcomes.
5. Water reuse exchange projects commonly use canals instead of the natural streams for wastewater transportation. The long-term effects on minimum streamflows should be studied.

6. At present, each water use entity conducts its own water planning separately from the other water use entities. A new look at locally controlled basinwide water resource planning agencies is needed. Agencies of this type could serve as centers for information on water systems, demands and uses and for planning system projects that could serve the needs of more than one user.

The normal sources of raw water have been developed to an apex where increasingly large capital investments yield smaller and smaller quantities of water. Essentially, water reuse means more intensive use of the water resources that have already been developed. In a world of limited resources there is no other choice.

REFERENCES

American Water Works Association. 1979. Managing Water Rates and Finance. Published by the American Water Works Association, Denver, Colorado.

American Water Works Association. 1969. Water Treatment Plant Design. published by the American Water Works Association.

ARIX. 1979. "Appendices--Wastewater Facilities Plan for Greeley--Appendix B Water Rights."

Barkley, J.R. 1974. "Northern Colorado Water Conservancy District." Loveland, Colorado.

Barkley, P.W. and Seckler, D.W. 1972. Economic Growth and Environmental Decay, The Solution Becomes the Problem. Harcourt Brace Jovanovich, Inc., New York.

Bittinger, M.W. and Associates, Inc. 1974. "Analysis of Foreign Water Reuse Possibilities by the City of Fort Collins." Fort Collins, Colorado.

Blair, J.R. 1978. "An Input-Output Model Analysis of Effluent Disposal Alternatives for the City of Fort Collins." Master's Thesis, Colorado State University, Fort Collins, Colorado.

C.E. Maguire, Inc. 1978. "Final Plan--Wastewater Disposal and Reuse Plan--Segment II of the Wastewater Facilities Plan for the City of Sterling, Colorado." Denver, Colorado.

City of Fort Collins, Water Supply and Storage Co., and Platte River Power Authority. 1978. "Agreement for the Reuse of Water for Energy Generation." Fort Collins, Colorado.

City of Fort Collins. 1980a. "Water Supply Alternatives to Meet Future Demands--Preliminary." prepared by Denis Bode, Fort Collins, Colorado.

City of Fort Collins. 1980b. "Informational Report on Conservation and Metering in Fort Collins." Prepared by Denis Bode and Steven Olson, Fort Collins, Colorado.

City of Fort Collins. 1980c. TDS data from wastewater treatment staff. Fort Collins, Colorado.

City of Greeley. 1980. "1979 Annual Report." By the Water and Sewer Department, Greeley, Colorado.

City of Greeley. 1952. "General History of Water Supply." Greeley, Colorado.

Clark, J.W., W. Viessman, Jr. and M.J. Hammer. 1977. Water Supply and Pollution Control. Harper and Row, Third Edition.

Colorado Department of Health. 1979a. "Regulations for Effluent Limitations." Section 10.1.0-10.10.1.16, Amended March 5, 1979.

Colorado Department of Health. 1979b. "Regulations Establishing Basic Standards and an Antidegredation Standard and Establishing a System for Classifying State Waters for Assigning Standards and for Granting Temporary Modifications." Denver, Colorado.

Colorado Department of Health. 1979c. "State of Colorado Federal Construction Grant Priority Systems and Grant Administration Procedures." Denver, Colorado.

Colorado Department of Health. 1979d. "Statement of Basis and Purpose for the Regulations Entitled: Amendment to Regulations for Effluent Limitations." Denver, Colorado.

Colorado Department of Health. 1978. "Policy on Land Treatment for Municipal Wastewater." Denver, Colorado.

Culp-Wesner-Culp. 1979. "Water Reuse and Recycling: Vol. 1, Evaluation of Needs and Potential." Prepared for U.S. Dept. of Interior, Office of Water Research and Technology. OWRT No. RU-79/1.

Denver Post. 1979. "Metro Sewage District Seeks Citizen Opinions on Wastewater Treatment." Denver, Colorado. Vol. 87, September.

Denver Regional Council of Governments. 1977. "DRCOG Clean Water Plan--Technical Report." Denver, Colorado.

Denver Water Department. 1976. "The Denver Successive Use Program, Selected References." Denver, Colorado.

Denver Water Department. 1975. "Metropolitan Water Requirements and Resources, 1975-2010. Vol. 2" Prepared for the Colorado State Legislature.

Dille, J.M. 1958. "A Brief History of the Northern Colorado Water Conservancy District and the Colorado Big Thompson Project."

Duckstein, L and C.C. Kisiel. 1977. "Alternative Water Reuse Systems: A Cost-Effectiveness Approach." In Water Renovation and Reuse, edited by H.L. Shuval. Academic Press, New York.

Evans, R.G. 1971. "Hydrologic Budget of the Poudre Valley." Master's Thesis, Colorado State University, Fort Collins, Colorado.

Federal Register. 1978. "Municipal Wastewater Treatment Works Construction Grants Program. Appendix A - Cost-Effectiveness Analysis Guidelines." Vol. 43, No. 188, p. 44087.

Federal Register. 1973. "Principles and Standards for Planning Water and Related Land Resources." Water Resources Council. Vol. 38, No. 174, p. 24778. September 10, 1973.

Fonda, S. (Utilities Director of Englewood). phone conversation with Chuck Turner on September 21, 1979.

Fischer, W.H. 1977. "Reuse of Foreign Water by the City of Fort Collins Colorado." printed in Exhibits for Agreements for Reuse of Water for Energy Conservation.

Fischer, W.H. 1973. "Report on the Reuse of Foreign Water by the City of Fort Collins, Colorado." Continued in report entitled "Exhibits for Agreement for the Reuse of Water for Energy Generation," for the City of Fort Collins, Colorado.

Goolsby, W. 1975. "Optimal Pricing and Investment of Community Water Supply." J. American Water Works Association, Vol. 67, No. 4, p. 220.

Hanke, S.H. and R.K. Davis. 1971. "Demand Management through Responsive Pricing." J. American Water Works Association, Vol. 63, No. 9, p. 555.

Hendricks, D.W. 1977. "Water and Related Land Resources Management Study--Metropolitan Denver and South Platte River and Tributaries--Colorado, Wyoming and Nebraska." Vol. V, Appendix J, Vol. I - Main Report - Water Supply and Demand Analysis, prepared for the U.S. Army Corps of Engineers.

Hendricks, D.W. and J.M. Bagley. 1969. "Water Supply Augmentation by Reuse." Proceedings of the AWRA Symposium on Water Balance in North America. Edited by A.H. Lagcock, M. Francisco, T. Fisher. AWRA Proceeding Series No. 7. Urbana.

Hickey, W.K. 1965. "Foreign Water in Colorado--The City's Right to Recaptüre and Reuse its Transmountain Diversion." Denver Law Center Journal. Vol. KLII, p. 116-139.

Howe, C.W. and F.P. Linaweaver. 1967. "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure." Water Resources Research, Vol. 3, No. 1, pp. 13-32.

Houghteling, J.L. 1968. The Dynamics of Law. Harcourt, Brace, and World, Inc.

Hutchins, W. 1976. Selected Problems in the Law of Water Rights in the West. Miscellaneous Publication 418 (Washington: USDA, 1942), p. 361 from Radosevich, G., Evolution and Administration of Colorado Water Law: 1976-1976. Water Resources Publications, Fort Collins, Colorado.

James, D.L. and R.R. Lee. 1971. Economics of Water Resources Planning. McGraw-Hill Book Company, New York.

Jankowski, D.F. 1978. Correspondence with consultant contained in report "Wastewater Disposal and Reuse Plan Segment II of the Wastewater Facilities Plan for the City of Sterling, Colorado," by C.E. Maguire, Inc. for the City of Sterling, Colorado.

Klooz, D. 1981. "Water Reuse in Input-Output Modeling." Master's Thesis, Colorado State University, Fort Collins, Colorado.

Leonard Rice Consulting Water Engineers, Inc. 1978. "Water Rights Impacts of Clear Creek Facility Planning." Prepared for Metro Denver Sewage Disposal District No. 1.

Longest, III, H.L. 1980. "Draft PRM Regarding Procedures for Determining Grant Eligibility for Multiple-Purpose Projects." Office of Water and Waste Management, USEPA, Washington, D.C.

March, Jr., A.E. and W.H. Fischer. 1973. "Report of Investigations and Accomplishments Regarding Raw Water Supplies for the City of Fort Collins, Colorado." Fort Collins, Colorado.

McKinney, R. 1962. Microbiology for Sanitary Engineers. McGraw-Hill Book Company.

Metropolitan Denver Sewage Disposal District No. 1. 1979. "Central Plant Facility Plan, Phase 1 Report." Denver, Colorado.

Metropolitan Denver Sewage Disposal District No. 1. 1977. "Sand Creek Facility Plan." Denver, Colorado.

Metropolitan Water District of Southern California. 1978. "Orange and Los Angeles Counties Water Reuse Study." October 17, 1978.

Metcalf & Eddy, Inc. 1979. Wastewater Engineering: Treatment Disposal Reuse. McGraw-Hill Book Company, Second Edition.

Middleton, F.M. 1975. "Overview of Wastewater Reuse and EPA Research Strategy." In Research Needs for the Potable Reuse of Municipal Wastewater--Proceedings of a Workshop, EPA-600/9-75-007.

Milliken, J.G., L.C. Lohman, A.S. Trumbly, and L. Roll. 1979. "Overcoming Legal and Institutional Barriers to Planned Reuse of Water in the Colorado River Basin." Prepared for the Office of Water Research and Technology, OWRT No. RU-79/3.

National Water Commission. 1973. Water Policies for the Future. Washington, D.C.

Neutze, J. 1980. Personal Conversation, September, 1980.

Northern Colorado Water Conservancy District. 1938. "Contract for Colorado Big Thompson Project between the U.S. Bureau of Reclamation and the Northern Colorado Water Conservancy District."

Northern Colorado Water Conservancy District. 1980. "Delivery Schedule for 1980." Loveland, Colorado

Northern Colorado Water Conservancy District. 1977. "Municipal Subdistrict, Northern Colorado Water Conservancy District Official Statement Relating to $3,000,000 Water Revenue Bonds, Series A." Loveland, Colorado.

Northern Colorado Water Conservancy District. 1979. "Summary of Allotments Certified for Delivery through 10/31/80." Loveland, Colorado.

Pacific Reporter. 1977. "557 p 2d 1182, 1977" West Pub. Co., St. Paul, Minnesota.

Pacific Reporter. 1976a. "550 p 2d 1182, 1977" West Pub. Co., St. Paul, Minnesota.

Pacific Reporter. 1976b. "550 p 2d 297, 1976". West Pub. Co., St. Paul, Minnesota.

Pacific Reporter. 1973. "179 Col 47, 506 p 2d, 144, 1973" West Pub. Co., St. Paul, Minnesota.

Pacific Reporter. 1972. "179 Col. 36, 499 p 2d 1190, 1972". West Pub. Co., St. Paul, Minnesota.

Pacific Reporter. 1954. "120 Col 575, 272 p 2d 629, 1954". West Pub. Co., St. Paul, Minnesota.

Pacific Reporter. 1951. "124 Col. 366, 237 p 2d 116, 1951". West Pub. Co., St. Paul, Minnesota.

Pacific Reporter. 1948. "118 Col. 225, 194 p 2d 342, 1948". West Pub. Co., St. Paul, Minnesota.

Pacific Reporter. 1939. "13 Cal 2d 3431, 90 p 2d 58, 1939". West Pub. Co., St. Paul, Minnesota.

Pacific Reporter. 1922. "70 Col. 565, 203 p 681, 1922." West Pub. Co., St. Paul, Minnesota.

Peskin, H.M. and E.R. Seskin. 1975. "Basic Concepts Used in Cost-Benefit Analysis." In Cost-Benefit Analysis and Water Pollution Policy, edited by H.M. Peskin and E.R. Seskin. The Urban Institute, Washington, D.C.

Phipps, E. 1980. Personal interview. Northern Colorado Water Conservancy District, December 24, 1980. Loveland, Colorado.

PRC Toups Corporation. 1979. "208 Facilities Planning Alternatives for Douglas County." Prepared for the Denver Regional Council of Governments, Denver, Colorado.

PRC Toups Corporation. 1977. "Estes Park Sanitation District--201 Facilities Plan--Wastewater Treatment Plant Improvements." Loveland, Colorado.

Radosevich, G. 1977. "Colorado Water Laws." Dept. of Economics, Colorado State University, Fort Collins, Colorado.

Radosevich, G., K.C. Nobe, D. Allardice, and C. Kirkwood. 1976. Evolution and Administration of Colorado Water Law: 1876-1976. Water Resources Pub., Fort Collins, Colorado.

Radosevich, G., ed. 1975. Colorado Water Laws--A Compilation of Statutes, Regulations, Compacts and Selected Cases. Colorado State University, Fort Collins, Colorado.

Simpson, H. 1979. Personal Conversation during September, 1979. State Engineer's Office.

State of California Department of Health. 1975. "Wastewater Reclamation Criteria." California Administrative Code, Title 22, Division 44, Environmental Health.

State of Colorado. 1973. Colorado Water Quality Control Act, CRS(1973) 25-8-101.

Trelease, F.J. 1974. Water Law. West Publishing Company, St. Paul, Minnesota.

Turner, C.D. 1980. "Analysis of Agricultural Productivity as Used in the Final Northgleen EIS dated June 1980." Prepared for Dr. T. Sanders, Colorado State University, Fort Collins, Colorado.

U.S. Army Corps of Engineers, Omaha District. 1977. "Water and Related Land Resources Management Study--Metropolitan Denver and South Platte River and Tributaries Colorado, Wyoming, and Nebraska." Vol. V, Appendices D and J. App. J prepared by the Environmental Engineering Program at Colorado State University. Omaha, Nebraska.

U.S. Bureau of Reclamation. 1963. "Cache la Poudre Unit, Reconnaissance Report." USBR Region 7, Denver, Colorado.

U.S. Bureau of Reclamation. 1959. "Report on the South Platte River Basin, Colorado-Wyoming-Nebraska." USBR Region 7, Denver, Colorado.

U.S. Congress. 1977. The Federal Water Pollution Control Act (PL 92-500) as Amended by the Clean Water Act of 1977 (PL 95-217). Washington, D.C.

U.S. Department of Agriculture, Forest Service. 1980. "Draft Environmental Impact Statement--Cache la Poudre Wild & Scenic River Study Report." U.S. Forest Service #02-10-80-03. Fort Collins, Colorado.

U.S. District Court, District of Colorado. 1955. United States vs Northern Colorado Water Conservancy District. Civil Nos. 2782 (incorporating nos. 5016 and 5017). Final Consent Decree.

U.S. Geological Survey. 1977. "Water Resources Data for Colorado Water Year 1977. USGS Report No. CO-71-1.

U.S. Environmental Protection Agency. 1980a. Draft, Environmental Impact Statement--Northglenn Water Management Program, City of Northglenn, Colorado. EPA 908/5-79-002A.

U.S. Environmental Protection Agency. 1980b. Final, Environmental Impact Statement--Northglenn Water Management Program, City of Northglenn, Colorado. EPA 908/5-79-002B.

U.S. Environmental Protection Agency. 1980c. "Guidelines for Water Reuse." Prepared by Camp, Dresser & McKee, Inc. EPA-600/8-80-036.

U.S. Environmental Protection Agency. 1979. "Northglenn Water Management Plan--Panel Managing on August 30, 1979."

U.S. Environmental Protection Agency. 1979. Strategies for Funding of Multiple Purpose Projects. Office of Water and Waste Management.

U.S. Environmental Protection Agency. 1977. "Funding Policy for Design and Construction of Multiple Purpose Projects." PRM77-4.

U.S. Environmental Protection Agency. 1972. "Technical Appendix on Municipal Waste--Source Evaluations, Water Quality Investigations in the South Platte River Basin, Colorado." National Field Investigations Center, Denver and Region VIII, Denver, Colorado.

Work, S. and N. Hobbs. 1976. "Management Goals and Successive Water Uses." J. of American Water Works Association. Vol. 68, No. 2, pp. 86-92.