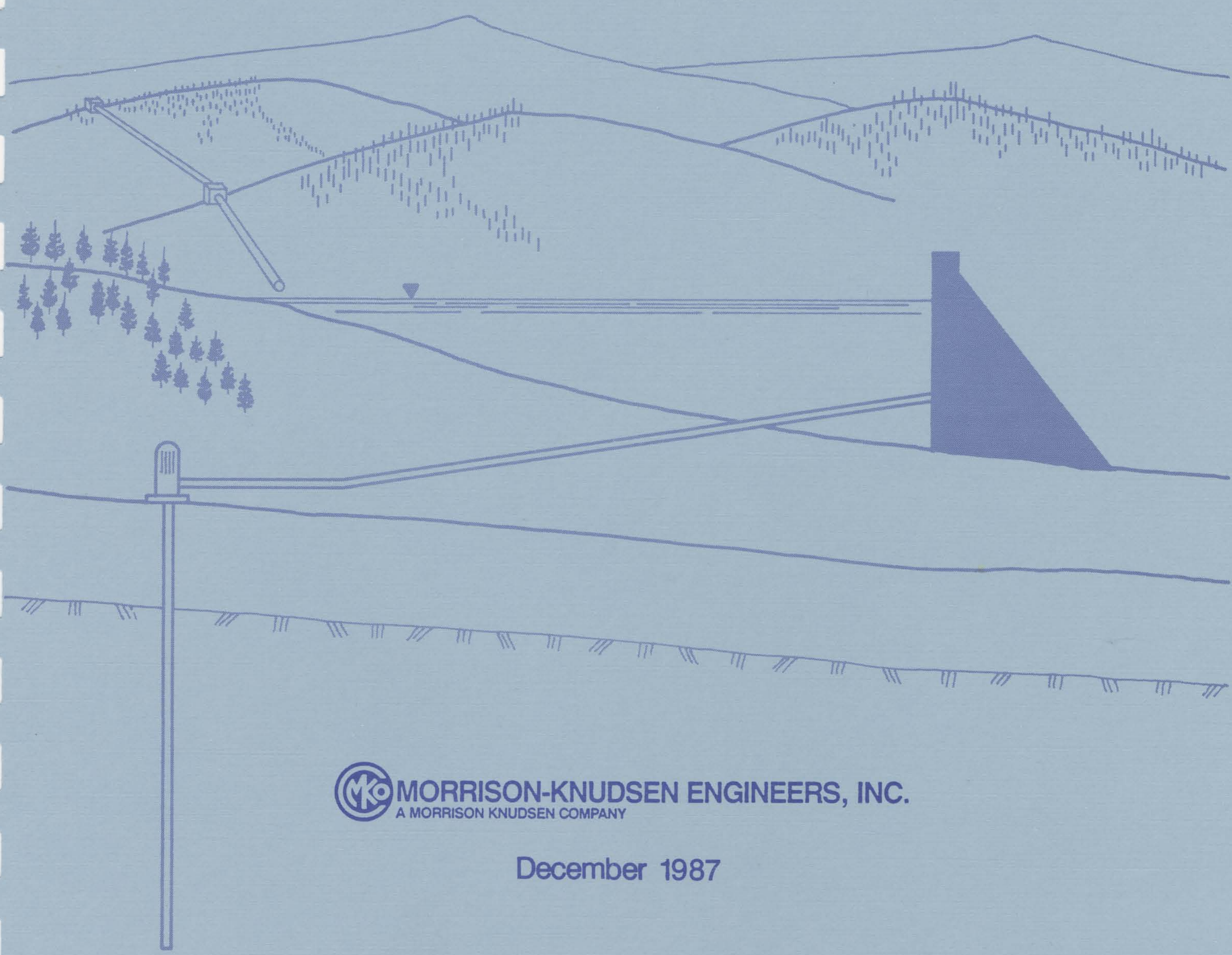
CHERRY CREEK WATER RESOURCES PROJECT PHASE I FEASIBILITY STUDY

FINAL REPORT

Prepared for the

Colorado Water Resources
and
Power Development Authority



MORRISON-KNUDSEN ENGINEERS, INC.
A MORRISON KNUDSEN COMPANY

December 1987

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December 1, 1987

Mr. Uli Kappus, P.E.
Executive Director
Colorado Water Resources and
Power Development Authority
1580 Logan Street, Suite 620
Denver, Colorado 80203

Reference: CHERRY CREEK WATER RESOURCES PROJECT
Final Report - Phase I Feasibility Study

Dear Uli:

Morrison-Knudsen Engineers, Inc. (MKE) is pleased to submit the Final Report for the Phase I feasibility investigation of the Cherry Creek Water Resources Project. One camera-ready original and 150 copies of the Final Report, along with 10 copies of the Appendixes, are transmitted herewith.

MKE and our subconsultant, John C. Halepaska and Associates, Inc. (JCHA), have enjoyed participating in this investigation with the Colorado Water Resources and Power Development Authority (Authority) and the Parker Water and Sanitation District (PWSD). The report identifies and evaluates several diverse water resources development alternatives which could meet the estimated future needs of the upper Cherry Creek Basin and reduce the region's dependence on deep ground-water supplies. Three of the alternatives were recommended for further study to allow a more thorough comparison of technical, legal, environmental, and socioeconomic issues associated with project development.

The investigation presented in this report points out the strong need for establishment of a regional water development entity to provide a vehicle for joint participation in project development. Continuation of the public information program initiated under this study is an essential element for future investigations, to bring together the water providers in the Cherry Creek Basin. This new regional entity should then become the local project sponsor, eventually responsible for project implementation.

Thank you for allowing MKE and JCHA to participate in this study with the Authority and the PWSD. Messrs. Ralph Kerr, Project Manager for the Authority, and Frank Jaeger, Manager of the PWSD, have been a pleasure to work with, and their ideas have contributed greatly to the study effort. We hope this investigation has provided additional insight into the water needs of the region and formed a foundation for the formulation of a specific water resources development project to serve this area.

Very truly yours,

William A. Price

William A. Price, P.E.
Project Manager

WAP:jc
Enclosures

CERTIFICATE OF ENGINEER

CHERRY CREEK WATER RESOURCES PROJECT
PHASE I FEASIBILITY STUDY

This report was prepared by Morrison-Knudsen Engineers, Inc. (MKE) and our subconsultant, John C. Halepaska and Associates, Inc. (JCHA). The technical material, data, and analyses contained in this report were prepared by the following professionals:

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The technical analyses, data, and documentation developed in this study were prepared under the supervision and direction of the undersigned Project Manager of MKE, whose seal as a professional engineer is affixed below.

William A. Price

WILLIAM A. PRICE
MKE Project Manager
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State of Colorado
No. 16044

CHERRY CREEK WATER RESOURCES PROJECT
PHASE I FEASIBILITY STUDY

EXECUTIVE SUMMARY

Prepared for the

Colorado Water Resources
and
Power Development Authority

MORRISON-KNUDSEN ENGINEERS, INC.
A MORRISON KNUDSEN COMPANY

John C. Halepaska & Associates

December 1987

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

1.0 INTRODUCTION

This preliminary evaluation of developing additional water supplies for the Cherry Creek Basin was initiated by the Colorado Water Resources and Power Development Authority (Authority) at the request of the Parker Water and Sanitation District (PWSD). The purpose of this Executive Summary is to present a concise overview of the study. The Final Report presents the findings of this study in greater detail.

The Authority was created by the legislature in 1981 as a political subdivision of the State. The nine member Board of Directors represents the eight major drainage basins in the State, and the City and County of Denver. The Authority's purpose is to provide the State with a mechanism to finance water and hydroelectric projects by issuing revenue bonds. Since its inception, the Authority has focused on the planning, design, and financing of water resource projects.

Much of the population growth of the metropolitan area has taken place south and east of Denver due to the topographic limitations with the foothills to the west. The area upstream of Cherry Creek Dam within the Cherry Creek Basin has shared in this growth, and 1985 projections by the Denver Regional Council of Governments (DRCOG) show a six-fold population increase in the next twenty- five years.

To date, the water supplies to satisfy municipal demands in the Cherry Creek Basin have been provided almost entirely from ground water in the alluvial and Denver Basin aquifers. The ground water in the aquifers of the Denver Basin has been classified as nontributary to the surface water system. This deep ground water is the most prominent supply source. Recent laws and regulations tie ownership of the nonrenewable resource to the overlying lands, and limit the annual rate of withdrawal of the nontributary ground water to one percent of the estimated underlying volume in storage. Most of the present deep ground-water withdrawals from the Denver Basin are from the Arapahoe and Dawson Formations, which are confined aquifers.

In 1985 the PWSD, which presently serves the largest population concentration in the area, conducted planning studies for future water supplies within its boundaries. They found that even with full utilization of the maximum allowed withdrawal of nontributary ground water, they could not provide enough water to serve the projected build-out within the PWSD boundaries. This analysis led the PWSD to the conclusion that they should become less dependent on the finite resources of the deep ground water through the development and use of renewable surface water supplies. PWSD also realized that the native surface water resources of the Cherry Creek Basin are very limited and extremely variable and that alternatives for importing water supplies require major storage and conveyance facilities.

In March 1986, the PWSD applied to the Authority for assistance in investigating regional water development alternatives. Regional participation in planning, design, financing, and construction of water supply facilities was sought to prolong the life of the deep ground water supplies and to achieve economies of scale in implementing a Cherry Creek Water Resources Project. The Authority initiated this study in October, 1986, under contract with Morrison-Knudsen Engineers, Inc. (MKE). John C. Halepaska and Associates (JCHA) was designated as a subconsultant to test the feasibility of artificially recharging the deep ground-water aquifers.

The primary objective of the study was to identify and evaluate a range of viable water resources development alternatives that could serve the needs of the upper Cherry Creek Basin and decrease this area's dependence on the deep ground-water supplies. A secondary objective was to assist the Authority and the sponsoring entity, PWSD, in seeking additional participation of water users in the region in a water development project. As a result, a public information program was established to provide up-to-date findings of the project through a combination of public meetings and interim reports. The four interim reports were provided for review and comment to some fifty entities in the region including municipalities; water purveyors; local, state, and federal agencies; plus additional parties expressing interest in water development in the region.

2.0 STUDY PROCESS

This Phase I study represents a reconnaissance level of evaluation. The study was conducted in sufficient detail to characterize the primary features and operations of alternative water development plans and provide a preliminary indication of the viability of the alternatives formulated. This study is the first step in a complex process leading to the construction of a water resources project. This process is illustrated in Figure E.1.

During the study, maximium use was made of data from previous investigations and studies. One of the key previous studies was the water quality investigations conducted by the Denver Regional Council of Governments (DRCOG) in 1985. The population and land use projections to the year 2010, presented in that study, were adopted and utilized as the planning horizon for this investigation. The population of the basin in year 2010 was projected to reach 301,800. The study area encompasses 385-square miles of the Cherry Creek drainage basin upstream from the existing Cherry Creek Lake, as shown on Figure E.2.

Future water demands were estimated by employing per capita use rates typical of the Denver metropolitan area. Water demand based on these use rates was then reduced to account for implementation of water conservation measures, and to eliminate areas served by Aurora and rural large lot developments that would not be utilizing municipal water supplies. As shown on Table E.1, projected water demand for the basin in the year 2010 is 35,300 acre-feet (af). Expansion of the study area may occur prior to future studies, leading to a larger water demand to be addressed by the project.

A variety of potential sources for new supplies were inventoried and evaluated, including: nontributary ground water, tributary ground water, surface water from Cherry Creek, imported supplies from the Arkansas River, and imported supplies from the lower South Platte River.

REPRESENTATIVE TIME AND COST SCHEDULE FOR A $100 MILLION WATER STORAGE PROJECT

COMPLETED PROJECT

YEARS		CUMULATIVE YEARS	APPROXIMATE COSTS $ (MILLIONS)
2 TO 6	CONSTRUCTION	9 TO 17	$ 105 [1]
2 TO 3	FINAL DESIGN	7 TO 11	6
2 TO 3	PRE-DESIGN STUDIES REGULATORY COMPLIANCE OBTAIN PERMITS, LICENSES, ETC.	5 TO 8	5
2 TO 3	PHASE II-FEASIBILITY STUDY AND ENVIRONMENTAL-IMPACT STATEMENT	3 TO 5	3
1 TO 2	PHASE I-FEASIBILITY STUDY CONCEPTUAL ANALYSES	1 TO 2	1
		TOTAL =	$ 120 [2]

Notes: [1] Includes 5% for construction management.

[2] Engineering and permitting costs may vary considerably between projects due to project complexity & environmental conditions.

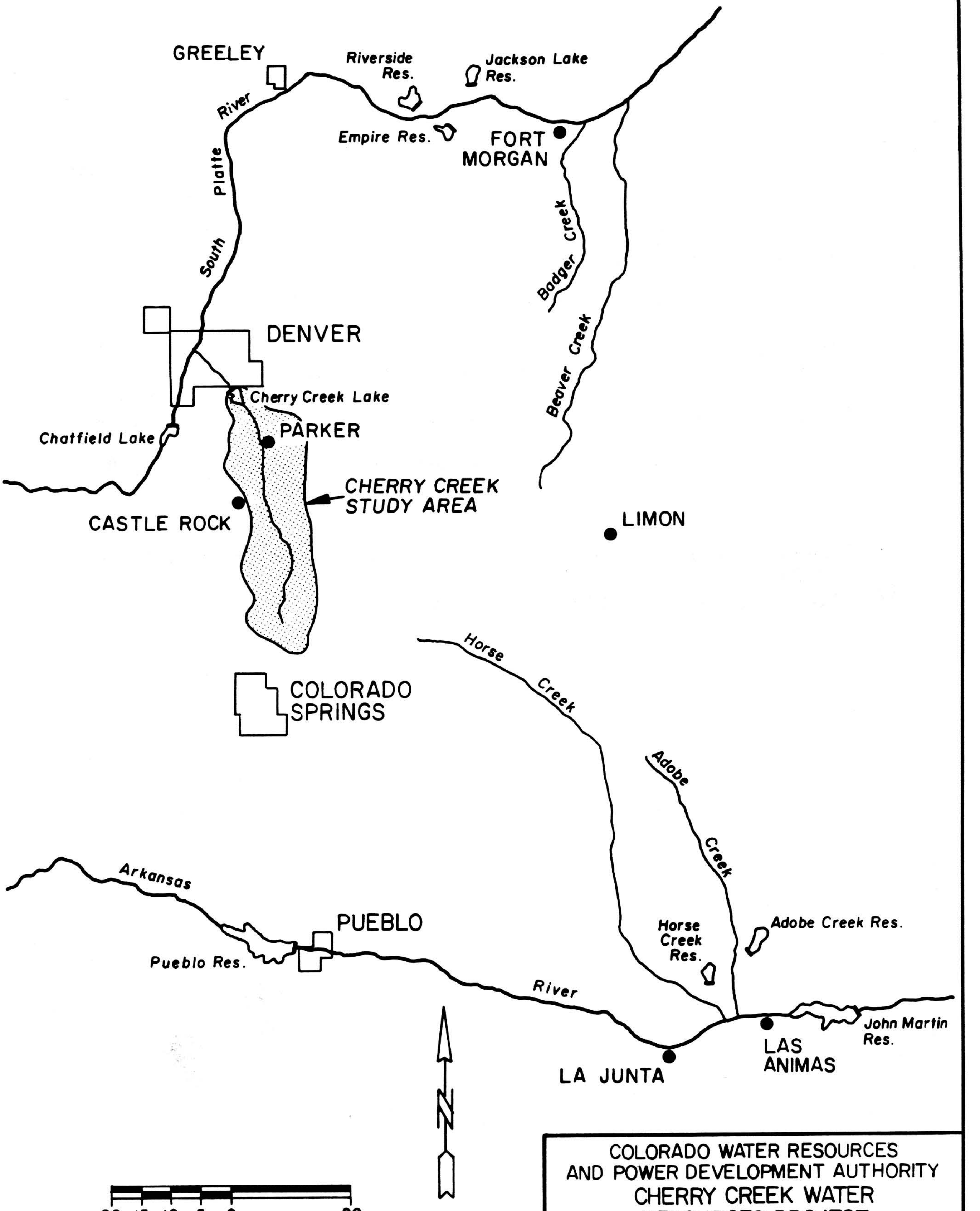
COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY

CHERRY CREEK WATER RESOURCES PROJECT

WATER RESOURCE PROJECT PLANNING & DESIGN PROCESS

MORRISON-KNUDSEN ENGINEERS, INC.

DATE OCT. 1987 FIGURE E.1



COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY
CHERRY CREEK WATER RESOURCES PROJECT

LOCATION MAP

MORRISON-KNUDSEN ENGINEERS, INC.
DATE JULY 1987 FIGURE E.2

TABLE E.1

Cherry Creek Basin Water Demand in Year 2010

	Water Demand (acre-feet)
Unconstrained Demand[1]	70,000
Water Conservation Reduction[2]	(11,900)
Total Water Demand	58,100
Existing Supplies	(11,200)
Future Supplies of Aurora and Other Project Water Purveyors	(9,600)
Sparsely Populated Areas Served by Wells	(2,000)
New Water Supply Needed	35,300

(1) Based on 207 gpd/capita from Denver EIS and population estimates from DRCOG

(2) Based on 17 percent reduction from Denver EIS

3.0 STORAGE

For any new water development along the Front Range, storage plays a major role. This study was oriented toward making preliminary evaluations of both surface storage and underground storage as a means of regulating the time-variable surface water supplies.

3.1 SURFACE STORAGE

The native stream flow of Cherry Creek represents a small resource, yet with surface storage on the main stem, some flows could be captured and utilized as a component of the overall supply system. Surface storage reservoirs may also serve multiple functions, and in the case of the Cherry Creek Basin, there are reservoir sites that could provide facilities for flat-water recreation and flood control.

During the study, four new dam and reservoir sites were identified and analyzed for suitability as components of a variety of water development options. Of these four sites, two were selected for further study because water storage costs were much lower than for the remaining sites. The selected sites are the Castlewood and Bridge Canyon sites. Both are located on the main stem of Cherry Creek. The one existing reservoir on Cherry Creek, the Cherry Creek Lake flood storage reservoir, was also analyzed and then selected for further study.

The Castlewood site is located in Castlewood State Park at the site of the former Castlewood Dam, which was built in 1890 and failed in 1933. A dam and reservoir is currently being considered by the U. S. Army Corps of Engineers (COE) at this location as a potential solution to the inadequate spillway capacity of Cherry Creek Dam. A reservoir with a 102,000 af capacity at the site has been investigated in this study. Only 11,000 af of storage would be utilized as a recreational pool and active storage to regulate Cherry Creek flows, resulting in an average yield of 3,500 af/yr from native surface water. The remaining 91,000 af of storage would be available to temporarily store flood flows. The appearance of this reservoir, as well as its recreational usage, would be very similar to the existing Cherry Creek Lake.

The conceptual design for a large Castlewood Dam includes a rockfill dam with a large unlined spillway channel excavated in the rock rim of the canyon around the left abutment. The dam has an estimated cost of construction of $70.6 million and a unit cost of storage of $700 per af. These costs do not include interest during construction and financing costs.

The Bridge Canyon site is located on Cherry Creek approximately two miles upstream of the Castlewood site. There would be only incidental flood control capability at this site due to the small storage potential of 11,600 af. Therefore, the dam would have to fully pass the probable maximum flood (PMF), estimated to be over 300,000 cubic feet per second (cfs). The site foundation and the large spillway requirements led to the selection of a roller compacted concrete (RCC) type dam for the conceptual design.

The Bridge Canyon Dam would provide a recreational pool of 4,000 af and active storage of 7,600 af. It could provide partial regulation of Cherry Creek streamflows or a terminal storage facility for imported supplies. This reservoir would have an average yield of 3,500 af/yr from native surface water. The dam has an estimated cost of construction of $7.8 million and a unit cost of storage of $670 per af.

A third surface storage option in the basin is to utilize some of the existing Cherry Creek Lake storage capacity. Its location at the lower end of the study basin is of great advantage in regulating the native streamflows of Cherry Creek, which are expected to increase significantly with basin development. About 2,500 af of storage at Cherry Creek Lake would provide efficient regulation of those native surface flows if used in conjunction with storage at either the Castlewood or Bridge Canyon Dam sites. A companion system of a pump station and pipeline would be required to deliver water supplies back to the project service area. The construction cost estimated for the storage and pump back system was estimated to be $12.5 million. This includes $2.0 million to modify and relocate recreational features within the new active storage component at the lake. The yield of this system would depend on the level of development within the basin. Runoff to Cherry Creek Lake is projected to increase by 23,000 af due to increased impervious area with new development. In 2010, this storage and pumping system is projected to yield an average of 8,700 af/yr.

3.2 DEEP AQUIFER STORAGE

Data from previous PWSD studies indicate that there might be components of water development alternatives in the Cherry Creek Basin where conjunctive use of surface water and ground water would be feasible. The need for storage, coupled with the vast underground storage reservoir of the deep bedrock aquifers of the Denver Basin, led to the consideration of injecting temporary surplus surface water supplies into the aquifers for later recovery. Artificial recharge could also be very beneficial in extending the aquifer life and in maintaining confined pressure conditions, thus postponing increased expenditures for energy and for the additional wells which would eventually be required.

Municipalities, that are drawing water from the Denver Basin aquifers for most of their supply, have the total well capacity to meet peak summer month demands. During the rest of the year, these facilities are operated at reduced rates or are taken out of service. If renewable surface water supplies could be developed, there would be opportunities to recharge the ground water aquifers when supplies exceed the demands. There would be no evaporation losses, and the stored water could be reclaimed during the peak summer demand period, or stored for longer periods until drought conditions necessitated its use.

While recharge and injection programs have been carried out in other regions of the country, a demonstration of injection into the Denver Basin aquifers was needed to test the physical feasibility of a regional recharge program. The initial data collected during this study are expected to be extremely valuable in addressing the various technical, institutional, and legal issues associated with recharge/recovery systems.

During the period between mid-February and the end of May 1987, eight injection/pumping cycles were run. The program consisted of injecting water from the PWSD's water supply system into the "Parker North Dawson" well. The location of this well is approximately one mile north of the center of the Town of Parker. The predominant source of the injection supply was the "KOA" Cherry Creek alluvial well, located about one mile south of the center of Parker.

The Parker North Dawson well is a production well of the PWSD system, which was first placed in operation in April 1980. The well is approximately 610 feet deep with the lower 280 feet screened and gravel packed. As the name implies, this well extends only into the Dawson Formation. The normal pumping capacity when the well is in full operation is approximately 200 gpm.

This well was retrofitted during this investigation to accommodate injection. The piping installed was designed to allow water to backflow from the PWSD distribution system down the pump column installed in the well. The driving pressure for injection was the direct operating pressure of the PWSD distribution system. Instrumentation was installed to monitor water flow and pressure. Water quality tests were conducted prior to injection and at numerous times during the tests.

A total of eight injection/pumping cycles were conducted during this investigation. Injection rates ranged from 56 gpm to 96 gpm, and the duration of the runs ranged from 4 to 17 days. Each injection run was followed by a short period of pumping lasting several hours. During the pumping cycle following injection, water was diverted to an external discharge outside the pumphouse where water quality was monitored. The total volume of water injected was 27 af. The sixth injection run was the most successful, lasting 17 days, at a rate of 91 gpm. The duration of the seventh injection run was shortened when biological growth in the well caused a substantial pressure increase over a short period of time (4 days). Following the removal of this growth from the well, pre-injection conditions were achieved prior to the eighth injection run.

This trial injection program demonstrated that injection of surface water supplies into the Denver Basin aquifers is physically viable utilizing existing production wells. Since the test program was only preliminary in nature, a more extensive data base is required before the long-term effects of a fully operational injection program can be evaluated.

Retrofitting an existing Arapahoe aquifer well for injection is expected to cost approximately $10/af for an injection program lasting six months each year. Additional operation and maintenance costs for that well are projected to average $40/af. Other injection costs depend on the raw water source and the associated conveyance and treatment needs. These additional injection costs will depend on the alternative selected for water supply development in the Cherry Creek area. Once water is injected, a typical cost to obtain water from the Arapahoe Aquifer is presently $200/af, including amortization of well construction, energy costs, and other operation and maintenance costs.

4.0 PLAN FORMULATION AND EVALUATION

Nine water development options covering a wide range of water sources were developed to meet the project demands. These varied from heavy reliance on deep ground water to importation of the entire new supply. These options were compared and screened based on estimated costs and potential development constraints. Four plans were then formulated and evaluated in greater detail. The alternatives selected are as follows:

Alternative 1 - High Ground-Water Use

For comparison purposes, one alternative was selected that continued to develop the deep ground water as the single water supply source. In this alternative the ground water supply was conserved as much as possible by means of an indirect reuse plan which would utilize the alluvial aquifer and advanced treatment of waste water.

Alternative 2 - Maximum Local Surface Supply

Surface storage at the Castlewood site and Cherry Creek Lake were key features of this alternative. The Bridge Canyon site was retained as an alternative to the Castlewood site. Reuse of reclaimed waste water would also be employed, and additional supply components would be obtained by purchase of tributary ground-water rights presently being used for agricultural purposes. The deep ground-water aquifers were used to supplement these supplies.

Alternative 3 - Arkansas Importation

Under this plan a large percentage of the total demand would be met by importing surface water supplies from the Arkansas River. Storage and direct flow water rights would be purchased and converted from existing agricultural use to municipal use. A 151-mile, 38-inch diameter pipeline with seven pumping stations is part of this plan to convey the surface supply from Horse Creek Reservoir into the Cherry Creek service area. Storage is provided by Horse Creek Reservoir to minimize pipeline size. The water would be treated using conventional methods prior to conveyance to the basin. During periods of excess supply, the surface water supply would receive advanced treatment for injection into the deep aquifers. In times of drought or during peak demand periods, the water would be withdrawn from the underground storage and used to meet the demands. Other components of this alternative include a reuse system plus use of tributary ground-water and deep ground-water supplies.

Alternative 4 - South Platte Importation

This plan is similar to Alternative 3, except the surface water supply is obtained from the South Platte River near Fort Morgan. This alternative is based on utilizing South Platte streamflows that are flowing out of the state in excess of compact requirements. The size of the importation pipeline is minimized by providing operational storage near the point of diversion in alluvial aquifers. These aquifers would be rapidly recharged during periods of excess South Platte River flow and would be used during dry years and dry seasons. The conveyance system would consist of a 67-mile pipeline, 22 inches in diameter, driven by four pumping stations. The entire supply would receive conventional water treatment prior to conveyance to the service area. There is also an injection system into the deep aquifers in the Cherry Creek Basin. Reuse, local tributary ground water, and some deep ground water would be utilized to meet the remaining demand.

Table E.2 summarizes the water sources and amounts for the four alternatives described above. In that table, water supply obtained through reuse is not shown as a "source" to be developed. Rather it is shown separately as a water conservation measure which allows a developed water source to be used to extinction.

Since each of the alternatives was formulated to provide the same firm yield, the total cost and the unit cost per acre-foot of yield for each alternative can be compared directly. Table E.3 presents a summary of the total investment cost, total annual cost, and unit cost per acre-foot of yield for the four alternatives. The table also presents, for comparative purposes, a cost for providing 35,300 af entirely from pumping nontributary ground water.

The estimates of total annual cost and total unit cost of firm yield in Table E.3 include the full cost of advanced waste water treatment for the reuse component of each alternative plan. Also included are all of the treatment and conveyance costs of delivering a potable municipal supply to the project service area. It was necessary to determine the cost of a delivered potable supply rather than a raw water supply because water quality from the alternative water sources was highly variable. Therefore, treatment costs play a major role in cost comparisons between alternatives.

The net unit cost of firm yield is also presented in Table E.3 as a means of comparison with other raw water supply systems proposed for the Denver metro area. This net unit cost excludes the unit cost of water treatment and secondary waste water treatment which is typically expended for any system along the Front Range.

TABLE E.2

Water Sources for the Water Development Alternatives

Source	Annual Supply (af) Alternative No. 1	Alternative No. 2	Alternative No. 3	Alternative No. 4
Nontributary Ground Water	21,400	9,700	8,500	8,500
Tributary Ground Water	-	800	800	800
Cherry Creek above Castlewood Dam	-	3,500	-	-
Cherry Creek above Cherry Creek Lake	-	8,700	-	-
Imported from Arkansas River	-	-	12,000	-
Imported from South Platte River	-	-	-	12,000
Subtotal	21,400	22,700	21,300	21,300
Reuse	13,900	12,600	14,000	14,000
Total Supply	35,300	35,300	35,300	35,300

Alternatives 3 and 4 require large financing packages to enable construction of the importation system. Staged construction of project features is possible for each of the four alternatives. However, the costs shown in Table E.3 do not reflect staged development because of the very large array of possible construction schedules. The effect of staging will be considered in future studies to present a more refined evaluation of annual costs and unit costs of firm yield.

Potential constraints to the development of each alternative are shown in Table E.4. Preliminary evaluation indicates none of these constraints would preclude implementation of any of the four alternatives.

A useful comparison made by this study is the relationship between the cost of the alternatives and the useful life expectancies of the deep aquifers. Figure E.3 is included in this summary to graphically illustrate that decreasing the dependency on the deep ground-water source will increase the cost of providing the basin's additional water supply. However, increasing the use of surface water resources will permit the aquifer systems to be available as a future insurance policy for very severe droughts and/or unexpectedly high growth rates. These critical conditions may require far more rapid response than is possible in constructing large surface water facilities. It should also be noted that the costs shown in Table E.3 and Figure E.3 are based on pumping water from the Denver Basin aquifers under confined conditions.

Based on present and projected pumping rates, the Denver Basin aquifers will gradually change from confined to unconfined conditions over the next several decades. This will eventually result in marked increases in costs over those shown in Table E.3 for the base condition, and to a lesser extent for Alternatives 1 through 4.

TABLE E.3

Cost Comparison of Cherry Creek
Water Development Alternatives[2]

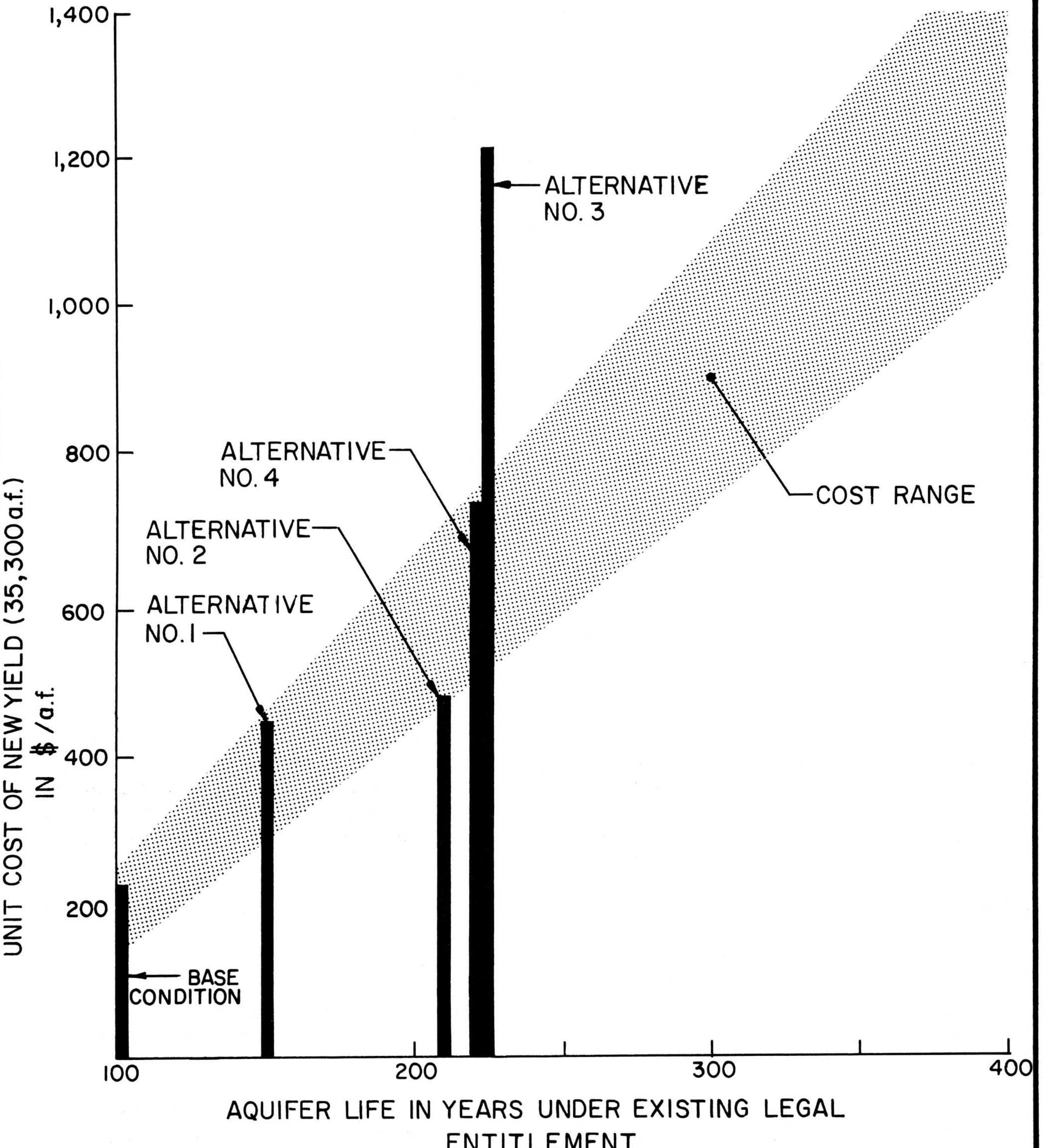
Alternative	Total Investment Cost[1]	Total Annual Cost[3]	Unit Cost of Firm Yield ($/af/yr) Total[3]	Net[4]
Base Condition - Entire Supply Nontributary Ground Water	$ 40,405,000	$ 8,238,000	233	200
Alternative 1 High Ground-Water Use	$ 32,573,000	$15,672,000	444	314
Alternative 2 Maximum Local Surface Supply	$ 40,822,000	$17,548,000	497	367
Alternative 3 Arkansas Importation	$207,002,000	$43,894,000	1,243	1,113
Alternative 4 South Platte Importation	$ 71,346,000	$26,459,000	750	620

(1) Investment costs include the following: estimated construction costs, engineering and administration costs, interest during construction, mitigation costs, debt service reserve fund, and financing expenses. Investment costs for advanced waste water treatment required for the reuse component of all four alternatives are not included here. These costs are shown as an operation cost in this study and are included as part of the "Total Annual Cost."

(2) These costs are based on pumping water from Denver Basin aquifers under confined conditions.

(3) "Total Annual Costs" and "Total Unit Costs" include those expenditures required to produce potable water for the given alternative. This includes the cost of full water supply treatment and of tertiary waste water treatment for the reuse component of each alternative.

(4) "Net Unit Cost" excludes those expenditures equivalent to the cost of chlorination for water treatment plus secondary waste water treatment. These expenditures are excluded here because they are standard costs which are incurred as a minimum for water treatment and waste water treatment.



COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
CHERRY CREEK WATER
RESOURCES PROJECT

**COST OF YIELD VERSUS
DENVER BASIN AQUIFER LIFE**

MORRISON-KNUDSEN ENGINEERS, INC.
DATE JULY 1987 FIGURE E-3

TABLE E.4

Potential Constraints for the Water Development Alternatives[1]

Constraints	Alternative 1: High Ground-Water Use	Alternative 2: Maximum Local Surface Supply	Alternative 3: Arkansas Importation	Alternative 4: South Platte Importation
Physical/Technical:				
Infiltration rates for recharge may decline with time. Extensive testing is needed.	L	L	H	H
Water quality of supplies is poor.	L	L	H	M
Future nontributary water level declines and limited ground-water supply.	H	M	M	M
Controlling Cherry Creek phosphorus levels will require extensive future waste water treatment.	H	H	H	H
Compatibility of injection water with aquifer materials and ground water may affect recharge activities.	L	L	H	M
Alluvial aquifer characteristics are needed.	M	M	M	M
Damsites must have adequate foundations.	NA	M	NA	NA
Future Cherry Creek streamflows need close examination.	NA	M	NA	NA
Construction materials must be fully tested.	NA	M	L	L
Legal/Institutional:				
Joint development of nontributary ground water may not be allowed.	M	L	L	L
Conversion of agricultural water rights to municipal use is needed; point of diversion must also be changed.	NA	L	M	L
Cherry Creek Lake recreation facilities need relocation.	NA	M	NA	NA
Cherry Creek Lake flood control space needs reallocation to conservation storage.	NA	M	NA	NA
Interstate compact litigation between Colorado and Kansas may impact water transfers.	NA	NA	L	NA
Dominion and control issues related to recharge water need resolution.	L	L	M	M
Water rights are needed for project implementation.	L	M	L	M
Federal, state, and local permits need to be obtained.	L	H	M	H
State will administer South Platte calls on Cherry Creek.	L	M	L	L
Socioeconomic:				
Local agricultural economies will decline with conversion of agricultural water rights to municipal use.	NA	L	H	L
Water reuse needs public acceptance.	H	H	H	H
Small water imports limit opportunities for economies of scale.	NA	NA	M	M
Land or easements are needed from many owners.	NA	L	H	H
Large up-front capital expenditures are required.	L	M	H	H
Future operating costs are dependent on energy prices.	M	L	H	H
Environmental:				
Potential adverse effect on threatened and endangered species.	NA	M	NA	H
Mitigation needed for local effects from construction of facilities.	L	H	L	M

(1) H - High degree of severity anticipated.
M - Medium degree of severity anticipated.
L - Low degree of severity anticipated.
NA - Not applicable to this alternative.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

During the process of screening options, formulating alternatives, conducting operations studies, preparing cost estimates, and making comparisons, a number of conclusions were reached regarding water resources development for the Cherry Creek Basin. These conclusions are presented in four categories: (1) project costs, (2) water demands, (3) technical issues, and (4) institutional issues. These conclusions should be given consideration in determining the future direction of water resources development for the Cherry Creek Basin.

5.1.1 Project Costs

- Non-tributary ground water, a component of each alternative, supplies approximately 60 percent of the water for Alternative 1 and 25 percent for Alternatives 2, 3, and 4. The costs for non-tributary ground water are based on pumping from the Denver Basin aquifers under confined conditions. As the Denver Basin aquifers gradually change from confined to unconfined conditions, unit costs of producing water will gradually increase over those shown in this report.

- Each alternative has been formulated with the potential to be expanded to serve a larger population, either in areas adjacent to the Cherry Creek Basin and/or in years beyond the 2010 planning horizon used in this initial study. Increased participation by other areas may reduce costs per acre foot of delivered water.

- Staging of construction activities, resulting in potential lower costs, is possible for each of the four alternatives, but is not reflected in the costs shown in this report. The effect of staging on the unit costs of producing water will need to be evaluated in future studies.

- Treatment of imported supplies at the point of diversion may provide opportunities for participation by other water users along the pipeline route, and should reduce the pipeline and pumping system cost per acre foot of water delivered.

- Advanced waste water treatment, combined with reuse operations, allows maximum conservation of the water supply in all of the proposed alternatives. Future technology and large volume treatment plants may lower the unit costs significantly.

- Project costs for Alternative 2 will be affected to some extent by the proposed Cherry Creek Dam and Reservoir modifications eventually selected by the Corps of Engineers.

5.1.2 Water Demands

- Based on a projected population of 301,800 within the Cherry Creek Basin in the year 2010, with a total unconstrained water demand projected to be 70,000 af/yr, there is a need for a new water development project to supply half of this demand. The remaining demand would be met by water conservation, existing supplies, and planned future water development by others.

- Of the projected unconstrained water demand within the Cherry Creek Basin in the year 2010, it is anticipated that 35 percent will be supplied through conservation measures, which include water reuse.

5.1.3 Technical Issues

- Future residential, commercial, and industrial development will become restricted if the basin's only source of additional water supply is deep ground water. For some districts, the allowable nontributary ground-water supplies are not capable of supporting the projected growth levels for the basin for the year 2010.

- Surface water storage, located downstream of areas projected for urban development, can significantly increase the yield from local water sources. The water supply for Alternative 2 is partially dependent on the additional runoff which will occur from newly created impervious areas (roofs, parking lots, etc.) in the basin upstream from Cherry Creek Lake.

- Upper basin active storage of 7,000 to 10,000 af, at either the Castlewood or Bridge Canyon Dam sites, in combination with a smaller volume of storage at Cherry Creek Lake, provides the flexibility necessary to regulate, control, and maximize the use of in-basin surface water resources.

- Future Cherry Creek Basin water quality problems and solutions are very much dependent on the water supply plan adopted for the basin. Close coordination of water resources development plans with the water quality activities of the Cherry Creek Basin Authority is extremely important.

- The water quality of potential imported water sources identified in the Arkansas River Basin and the lower South Platte River Basin is poor and would require treatment at the source for municipal use.

- The technical feasibility of injection of surface water into the deep ground-water aquifers has been partially demonstrated in this study. Plans that depend upon injection need additional field testing with actual water sources to demonstrate acceptable levels of performance and required levels of treatment.

- A successful deep ground-water recharge system should have an established procedure approved by the State Engineer for administering the operations of the recharge/recovery system.

- Deep ground-water recharge systems are viable plan components only when the water available from imports and reuse exceeds total basin demands. This condition usually occurs for two to four months during those years with at least average runoff.

- A deep ground-water injection system requires a minimum imported supply of 10,000 af/yr.

- o Implementation of the reuse component for each of the four alternatives may depend on approval of this technology by one or more state and/or federal agencies and may also entail a pilot program prior to full implementation.

- o Importing water from the South Platte River presents opportunities for leasing agricultural water during dry years, thereby reducing carryover storage requirements.

5.1.4 Institutional Issues

- o A regional water supply development organization is needed to implement any of the alternatives and allow population densities to increase to those projected for the year 2010. Even implementation of Alternative 1, involving only deep ground- water use and water reuse, would need an umbrella entity with rights to withdraw nontributary ground water underlying a large surface area.

- o Opportunities may exist for joint participation with water users adjacent to the Cherry Creek Basin; this may reduce unit costs and increase project feasibility by taking advantage of economies of scale.

- o Continuing contacts are necessary with potential participants in this water supply project; contacts must also be maintained with the three major water purveyors in the region: Denver, Aurora, and Colorado Springs.

- o Developing a regional water supply system which balances water supply components from many sources, will reduce the risk of not meeting future municipal water demands.

- o Many other entities are currently studying flood control needs, water quality issues, recreational needs, water rights, ground- water aquifers, and water development plans. A continuous interchange of ideas and information is necessary to assure that current information is used in subsequent investigations.

- o Importation of water from the lower South Platte will require agreements with owners of the ditches and other property, which is required for the diversion and artificial recharge scheme in Alternative 4. These agreements would need to provide incentives to the agricultural community in that area.

- o The potential technical, institutional, environmental, and socioeconomic constraints are minimal for Alternatives 1 and 2. Potential constraints for Alternatives 3 and 4 include technical problems, related to water quality and ground-water injection, and socioeconomic constraints involving right-of-way acquisition for the importation pipelines. Several known endangered species in Nebraska may be impacted by Alternatives 2 and 4.

5.2 RECOMMENDATIONS

The results and conclusions of this study provide the basis for the following recommendations:

1. The water supply components of Alternatives 1, 2, and 4 should be further evaluated in sufficient detail to select which of these components are preferable based on a comparison of technical, legal, environmental, and economic issues.

2. Alternative 3 should not be considered any further due to the relatively high cost compared to the other three alternatives.

3. A regional water development entity should be formed. This new regional entity would become the local project sponsor, eventually responsible for project implementation. The entity should consist of the water providers in the Cherry Creek Basin, as well as providers in adjacent basins with interest in pursuing joint water resources development.

4. Discussions should continue with other entities studying water-related problems in the Cherry Creek Basin, in particular, the U.S. Army Corps of Engineers, Cherry Creek Basin Authority, Colorado State Engineer's Office, U.S. Geological Survey, and the Colorado Division of Parks and Outdoor Recreation. These discussions should

lead to cooperative efforts to jointly resolve the water supply, water quality, flood control, and water- based recreation issues on Cherry Creek.

5. The public information program initiated under this study should be continued with the specific objective of providing detailed information to those water purveyors in the region with a potential interest in this water supply project.

6. Contact should be maintained with the major water purveyors adjacent to this region, namely, Denver, Aurora, and Colorado Springs. The potential for cooperative efforts should be explored with these entities.

7. A detailed scope of work for the next level of investigations should address the following subjects:

   - Physical and legal availability of water supplies in the Cherry Creek Basin and for diversion from the lower South Platte River.

   - Ground water studies to include artificial recharge, storage, and recovery of water from the Denver Basin aquifers, Cherry Creek alluvial aquifers, and lower South Platte alluvial aquifers.

   - Water supply storage, water quality, flood control, and recreational issues related to the existing Cherry Creek Lake.

   - Studies for water storage at the Castlewood and Bridge Canyon Dam sites to include geotechnical investigations, water quality issues, and preliminary environmental and recreational assessments.

   - Technical and institutional investigations related to water reuse.

   - Formation of a regional water development entity through cooperative discussions with water purveyors.

It should be re-emphasized that a regional water development entity is necessary to provide for long-term water development needs. The plan formulation and yield analysis for the water development alternatives structured in this investigation have assumed that regional interest in joint development will be established, and have led to the stated recommendations. Upon formation of the regional entity, water demands and development plans will need to be further refined to allow development of construction implementation schedules and more detailed project cost estimates.

CHERRY CREEK WATER RESOURCES PROJECT
PHASE I FEASIBILITY STUDY

FINAL REPORT

Prepared for the

Colorado Water Resources
and
Power Development Authority

MORRISON-KNUDSEN ENGINEERS, INC.
A MORRISON KNUDSEN COMPANY

John C. Halepaska & Associates

December 1987

FINAL REPORT

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ACRONYMS AND ABBREVIATIONS

af	Acre-feet
af/yr	Acre-feet per year
Authority	Colorado Water Resources and Power Development Authority
cfs	Cubic feet per second
COE	United States Army Corps of Engineers
CWCB	Colorado Water Conservation Board
Denver EIS	Metro Denver Water Supply Environmental Impact Statement
DOPR	Division of Outdoor Parks and Recreation
DRCOG	Denver Regional Council of Governments
DWD	Denver Water Department
EPA	Environmental Protection Agency
^{o}F	Degree Fahrenheit
ft	Feet
ft/yr	Feet per year
gpd	Gallons per day
gpm	Gallons per minute
JCHA	John C. Halepaska and Associates, Inc.
kW	Kilowatts
kWh	Kilowatt-hour
MCL	Maximum contaminant level
mgd	Million gallons per day
mg/L	Milligrams per liter
mi	Mile
MKE	Morrison-Knudsen Engineers, Inc.
mo	Month
MSL	Mean sea level
MWS	Maximum water surface
NWS	Normal water surface
OM&R	Operations, maintenance and replacement
PMF	Probable maximum flood
POS	Plan of study
ppm	Parts per million
PWSD	Parker Water and Sanitation District
RCC	Roller compacted concrete
ug/L	Micrograms per liter
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
yr	Year

FINAL REPORT

1.0 INTRODUCTION

1.1 BACKGROUND AND PERSPECTIVE

The upper Cherry Creek Basin, located above Cherry Creek Lake (sometimes called Cherry Creek Reservoir) in Colorado, has experienced rapid population growth in the past decade. Water supplies to satisfy its municipal demands have been provided almost entirely from the alluvial aquifer along Cherry Creek and from the deep ground-water aquifers of the Denver Basin. The deep ground-water aquifers are non-renewable, and classified as nontributary to surface water sources. In 1985, the Colorado Department of Natural Resources developed rules and regulations to limit the withdrawal of ground water from the Denver Basin Aquifers, which are comprised of the Dawson, Denver, Arapahoe, and Laramie-Fox Hills Formations. These recent regulations limit the rate of withdrawal of the deep ground water based upon overlying land ownership. The allowable rate of removal is that which would deplete the underlying volume uniformly over a 100-year period.

Another water supply for the basin is derived from renewable surface water sources. Surface water supplies for municipalities in the Rocky Mountain region require significant storage to capture and regulate high spring flows for use when needed. The storage is required to adjust for seasonal differences in the supply and demand patterns, as well as to provide long-term carry over for drought protection. As ground water is pumped from the deep aquifers located prominently under the Cherry Creek Basin, the aquifers gain additional potential to provide some of the needed water storage capacity. This storage can be utilized by injecting the surface water into the aquifers by means of wells, and repumping it to the surface upon demand. A new regulating reservoir, coupled with deep aquifer injection and storage, may allow economical development of surface water, as well as make the most efficient use of surface water supplies transported into the Cherry Creek Basin.

In 1985, the Parker Water and Sanitation District (PWSD) conducted planning studies for future water supplies within their boundaries. They found that, even at the maximum allowable withdrawal of nontributary ground water, they could not provide enough water to serve the projected full build-out within the PWSD. This projected water supply shortage becomes even larger when taking into account the PWSD desire to become less dependent on the finite resources of the nontributary ground-water aquifers, and to extend the life of the deep ground-water supply through the use of renewable surface water.

The PWSD realized that most of the available alternatives for developing surface water supplies require major storage and conveyance facilities which are beyond the financial capability of small entities to plan, design, finance, and construct. They also believed that other water purveyors in the Cherry Creek Basin would, in the future, face similar problems, and that a larger scale regional water supply plan might be of benefit to many in the area. Therefore, in March 1986, the PWSD submitted an application to the Colorado Water Resources and Power Development Authority (Authority) requesting the performance of a water supply study for the Cherry Creek Basin.

1.2 STUDY AUTHORIZATION

The Authority, which was created by the Colorado General Assembly in 1981 as a political subdivision of the State, has the responsibility to finance water and hydroelectric projects through the issuance of revenue bonds. In addition to financing, the Authority is authorized to assist regional or local entities in the planning, design, and construction of water and power projects.

The Board of Directors of the Authority approved the application and loan agreement with the PWSD in August, 1986. The agreement authorized a Phase I- level study to be performed for water resources development for the Cherry Creek Basin. In early October 1986, the Authority contracted with Morrison-Knudsen Engineers, Inc. (MKE) to conduct the Phase I feasibility study of the Cherry Creek Water Resources Project. John C. Halepaska and Associates, Inc. (JCHA) was designated as a subconsultant to MKE.

1.3 STUDY OBJECTIVE

The primary study objective is to identify and evaluate a range of viable water resources development alternatives that could serve the needs of the upper Cherry Creek Basin and decrease the dependence on the deep ground-water supplies. A secondary objective of the study is to assist the Authority and PWSD in seeking the joint participation of water users in or near the Cherry Creek Basin in a regional water development project.

This Phase I study represents a reconnaissance-level evaluation. It was conducted in sufficient detail to characterize the primary features and operations of alternative plans and to provide a preliminary indication of the viability of various alternatives.

1.4 STUDY PROCEDURES

1.4.1 Structure of the Study

The study procedures were defined in a "Plan of Study" (POS) prepared jointly by the Authority, MKE, and the project sponsor, PWSD. The POS identified the study tasks and outlined general sub-objectives and methods of approach. The seven study tasks are listed in Table 1.1. The findings of study Tasks 1 through 5 were documented in four interim reports, or Task Memorandums, prepared and issued during the course of the study and are included as Appendixes to this Final Report. This Final Report further documents the findings and results of the study.

1.4.2 Performance of the Study

This study has attempted to maximize the use of data and information from previous studies and investigations. The list of references provided in Section 10.0 of this report indicates the wide range of information sources utilized. With the exception of measurements and observations obtained from the deep well injection program, no original data were collected specifically for this study.

A number of assumptions were necessary to handle the large amounts of data, and to complete the study within the time and resources available. These assumptions have been noted in the report and appendixes, and were maintained as consistent and comparable as possible among components of alternative plans.

Frequent contact and communications were maintained with the Authority and the project sponsor during the course of the study. The tasks were performed in general chronological order, with activities documented in monthly progress reports to the Authority. The work was performed by MKE and JCHA staff based in Denver.

TABLE 1.1

Cherry Creek Water Resources Project
Phase I Study Tasks

Task	Title
1	Evaluation of Water Development Options
2	Safe Yield of New Water Supplies
3	Dam and Reservoir
4	Deep Well Injection
5	Project Formulation and Evaluation
6	Involvement of Cherry Creek Water Users
7	Preparation of Phase I Reports

1.5 WATER USERS AND PUBLIC INVOLVEMENT

During the conduct of the study, three meetings were held to: outline the interim study results of Task 1; identify users interested in participating in the project; and seek input from local water suppliers and the public. One meeting emphasized the water demand-supply relationships in the basin and sought public input as to acceptable water development options. The second highlighted the alternative solutions developed by the study team and sought input from water user organizations in the vicinity of the Cherry Creek Basin and also from the Cherry Creek Basin Authority, which was created to handle water quality issues. Study results, conclusions, and recommendations were presented at the final meeting.

In addition, interviews and telephone conversations were held with representatives of numerous public and private entities. These entities include the U.S. Army Corps of Engineers; State Engineer's Office; Cities of Denver, Colorado Springs, and Aurora; Colorado Division of Wildlife; Colorado Division of Outdoor Parks and Recreation; Douglas County; Colorado Interstate Gas Company; and FORT-CO, which is a company formed by a group of individuals who own shares in a ditch company taking water from the Arkansas River.

2.0 STUDY AREA DESCRIPTION

2.1 LOCATION AND PHYSIOGRAPHY

The upper Cherry Creek Basin is defined for the purposes of this study as the geographical area within the Cherry Creek drainage basin upstream of the existing Cherry Creek Dam. The basin encompasses a surface area of 385 square miles and includes land within Douglas, Arapahoe, El Paso, and Elbert Counties. The major municipalities located within the basin include portions of the Cities of Aurora and Greenwood Village, and the Town of Parker. Figure 2.1 shows the location of the basin with respect to Denver, Colorado Springs, and the South Platte and Arkansas Rivers. Figure 2.2 presents a more detailed view of the basin, and shows the locations of the potential dam sites evaluated as a part of this investigation.

Cherry Creek flows northward toward its confluence with the South Platte River at Denver. The elevation of the basin ranges from 5550 ft at Cherry Creek Lake to 7650 ft at its headwaters in the Black Forest. The watershed has a total length of 43 miles and an average width of 9 miles. The average basin slope is about 50 ft/mi. Drainage patterns are generally well defined, and the predominant watershed cover is range land.

The mild, sunny, and semi-arid climate is typical of the Great Plains. The moderate climate results largely from the basin's location east of the Rocky Mountains in the belt of the prevailing westerlies. Situated a long distance from any moisture source, and separated from the Pacific Ocean by the Rocky Mountains, the basin enjoys a low relative humidity and considerable sunshine, but receives a low average annual amount of precipitation.

Spring is the wettest, cloudiest, and windiest season. Much of the precipitation that occurs in spring falls as snow during the colder periods of the season. In the summer, precipitation usually results from scattered local thunderstorms during the afternoon and evening. Mornings are usually clear and sunny. Annual precipitation over the basin ranges from 7.8 to 25.0 inches, and averages 14.5 inches (National Climatic Data Center, 1986). Extreme temperatures range from -40°F to 110°F. The hottest month is usually July, and the coldest, January.

2.2 POPULATION, LAND USE, AND ECONOMY

In 1983, the basin population was estimated at 43,300, and total employment was about 20,200 (DRCOG, 1985). Nearly one-quarter of this population was located within the municipal boundaries of Aurora. The areas surrounding Centennial Airport are the largest present centers of employment. About 80 percent of the jobs in the Cherry Creek Basin occur in these areas, which include the Inverness and Meridian office parks.

Land use in the basin primarily consists of open space and large lot residential development. Agriculture and range lands in the southern region comprise most of the open space areas. Some commercial and industrial land has been developed around the airport and Cherry Creek Lake. This development is largely for office, retail, and light industrial uses.

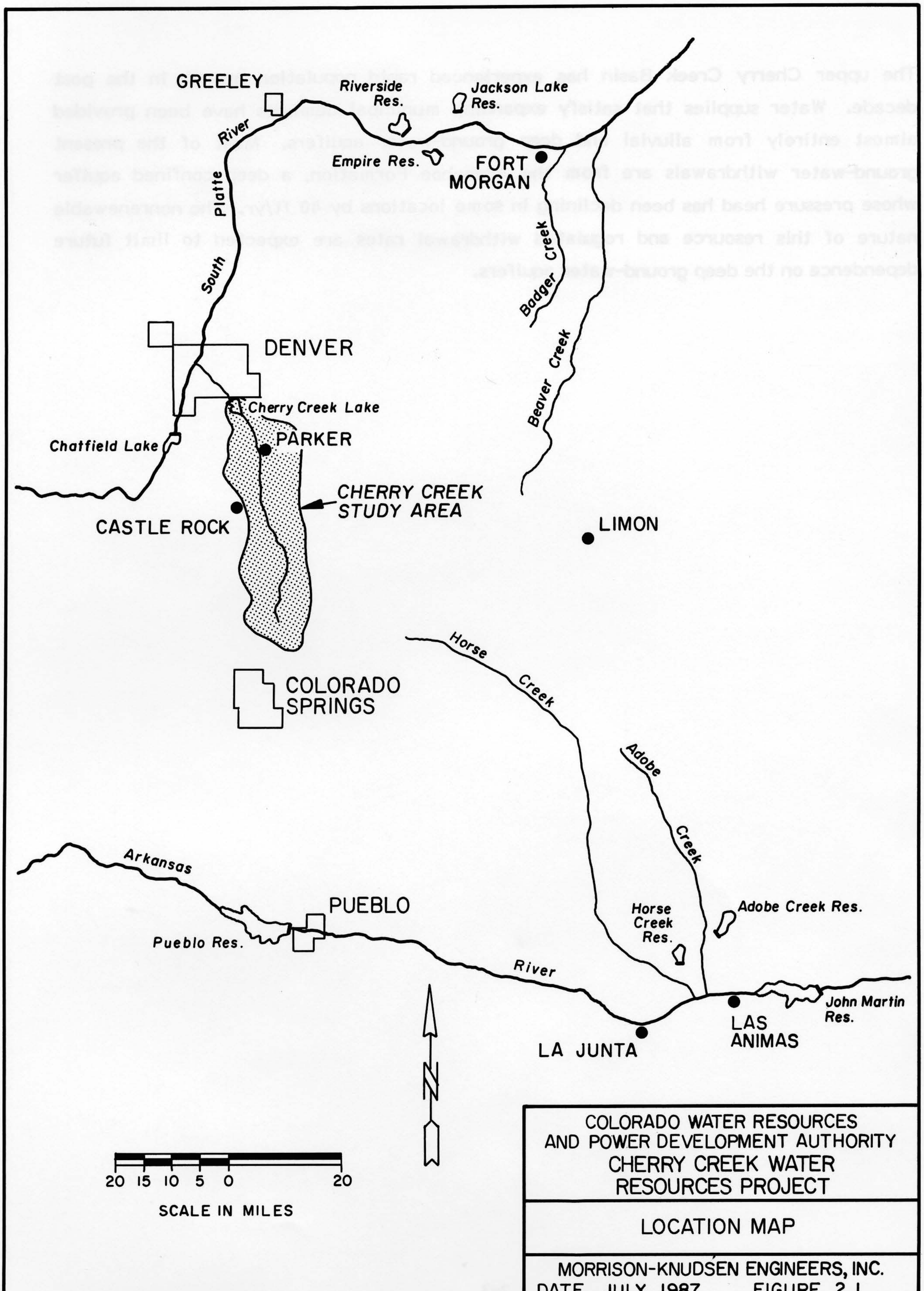
The regional economy is healthy and expanding quickly. The development of the large office parks and improved transportation facilities are encouraging rapid growth in the northern portion of the basin. Centennial Airport is the busiest airport in the metropolitan area for small commercial and private aircraft, and is expected to expand considerably in coming years. Agriculture is generally on the decline in the basin, with farm land being steadily converted to residential and commercial use.

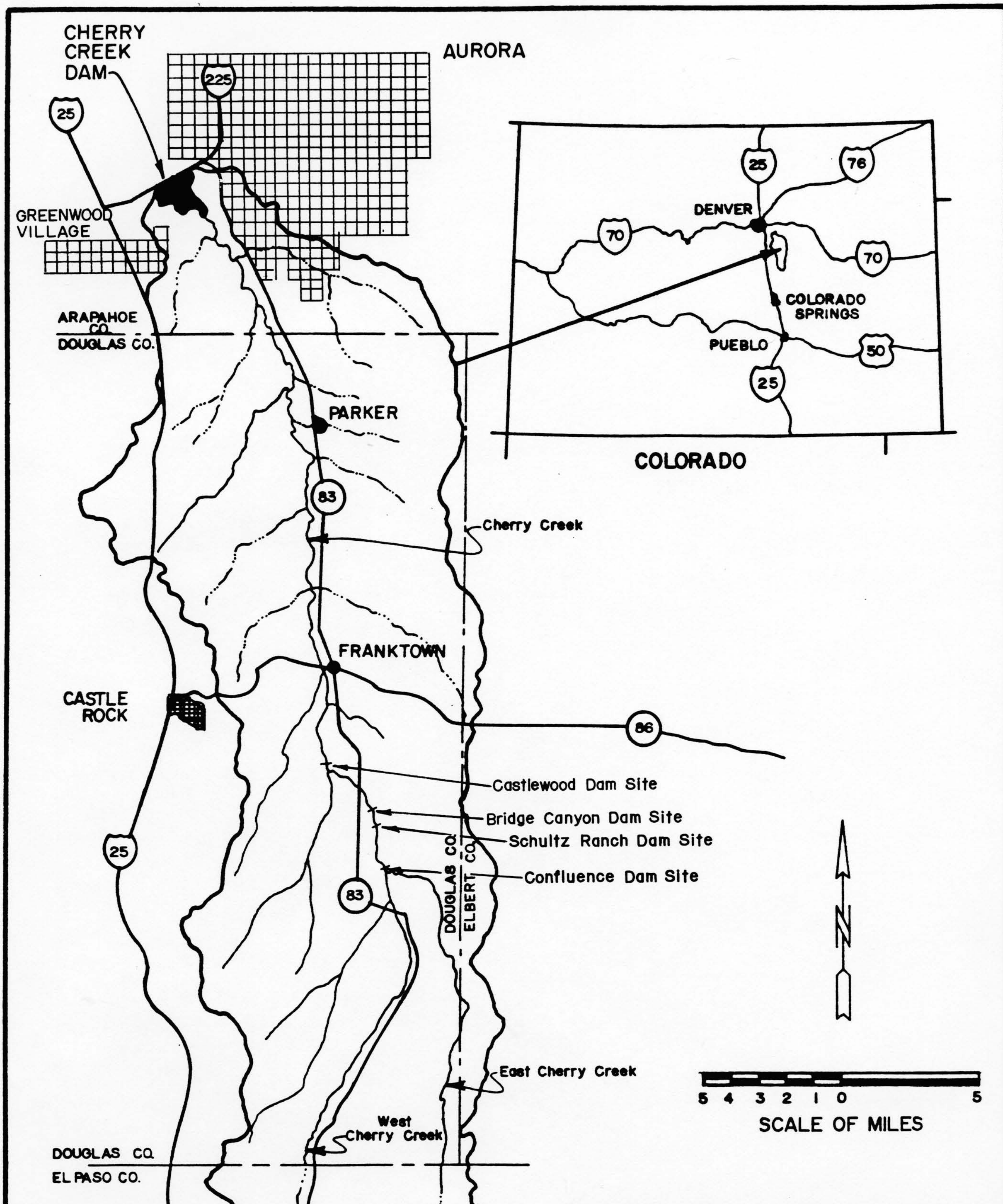
2.3 HISTORIC WATER DEVELOPMENT

Castlewood Dam is the only major dam which has historically existed upstream of Cherry Creek Lake. It was constructed in 1890, just upstream from Franktown, but failed in 1933. At the time of failure, the reservoir contained 3400 af of water and was primarily used for irrigation and flood control. The dam was constructed by the Denver Water Storage Company and irrigated 16,000 acres of cherry orchards at the Clark Colony, about 15 miles downstream on Cherry Creek (Colorado Division of Outdoor Parks and Recreation, 1981). Remnants of the original 600-foot-long, 75-foot- high structure still exist.

Cherry Creek Dam was completed by the U.S. Army Corps of Engineers (COE) in June 1950, and storage began in May, 1957. The reservoir capacity is 92,800 af at the crest of the spillway. At elevation 5550, about 15,100 af of storage is maintained for recreation. The remaining storage is allocated for flood control.

The upper Cherry Creek Basin has experienced rapid population growth in the past decade. Water supplies that satisfy expanding municipal demands have been provided almost entirely from alluvial and deep ground-water aquifers. Most of the present ground-water withdrawals are from the Arapahoe Formation, a deep confined aquifer whose pressure head has been declining in some locations by 40 ft/yr. The nonrenewable nature of this resource and regulated withdrawal rates are expected to limit future dependence on the deep ground-water aquifers.


GREELEY
Riverside Res.
Jackson Lake Res.
Empire Res.
FORT MORGAN
South Platte River
Badger Creek
Beaver Creek
DENVER
Cherry Creek Lake
PARKER
Chatfield Lake
CHERRY CREEK STUDY AREA
CASTLE ROCK
LIMON
Horse Creek
COLORADO SPRINGS
Adobe Creek
Arkansas River
PUEBLO
Pueblo Res.
Horse Creek Res.
Adobe Creek Res.
John Martin Res.
LAS ANIMAS
LA JUNTA
N
20 15 10 5 0 20
SCALE IN MILES
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
CHERRY CREEK WATER
RESOURCES PROJECT
LOCATION MAP
MORRISON-KNUDSEN ENGINEERS, INC.
DATE JULY 1987 FIGURE 2.1



COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY

CHERRY CREEK WATER RESOURCES PROJECT

BASIN MAP

MORRISON-KNUDSEN ENGINEERS, INC.

DATE: JULY 1987 FIGURE 2.2

3.0 WATER DEMANDS AND SUPPLIES

3.1. GENERAL

The water demands and water supplies form the foundation for plan formulation activities. The Cherry Creek Basin overlies large ground-water resources, but contains very limited surface water supplies. For this reason, adjacent areas in the Arkansas and South Platte River watersheds were inventoried for potential supplies which could be imported to the basin. After evaluating the quantity and location of potential water supplies, facilities were planned which could regulate and convey the water supplies to the project service area.

The project service area includes the entire Cherry Creek Basin, but virtually all water demand is from the portion of the Cherry Creek Basin located between Cherry Creek Lake and Franktown. Although the area upstream of Franktown is a part of the study area, providing water service to that area does not appear feasible because land use is expected to consist of large lot residences and open space. Large areas north of Franktown, along the eastern portion of the basin, are also expected to contain large lot residences, with less than one dwelling per acre, and are not planned to be served by the project. Water supplies in these areas would come from individual domestic wells. The boundaries of the project service area (i.e. the Cherry Creek Basin) have been established as a starting point in this initial planning study. Adjacent areas can be added to the project service area during future phases of this study to accommodate the water supply needs of the entire region in and adjacent to the Cherry Creek Basin.

The planning horizon for estimating future water needs was selected to be the year 2010. This is the same year used for a number of other recent development plans for the Front Range and within the basin. Selection of a common point in time allows some of the data and population projections from other studies to be used directly in this investigation. Water demand will continue to increase within the service area far beyond the 2010 planning horizon of this study. Therefore, the water supply alternatives considered in this report recognize that the 2010 water demand is not considered "full build-out", but rather will continue to expand much further into the future.

3.2 WATER DEMANDS

The areas to the east and southeast of Denver have experienced rapid growth in the last decade. This growth is expected to continue because the natural topography limits Denver metropolitan growth to the west. Past development, within the upper Cherry Creek Basin, has consisted of a wide variety of land uses and a gradual increase in urbanization. The residential development pattern has contained a high percentage of large lot, single-family dwellings. Some light commercial and industrial development has also taken place.

The general approach used in this study for determining water demands was to review other investigations and select population projections, per capita use rates, and probable water conservation measures deamed applicable for the region. First, an unconstrained water demand was calculated from the estimated population and per capita use rates. Demands were estimated for each decade from 1990 through 2010. The existing supply and estimated supply contribution from implementing water conservation measures were then deducted to provide a projection of the basin's need for new water by the year 2010.

At the present time, it is assumed that a regional water development agency will be formed which encompasses the demand area, and that this agency would be the entity to implement the Cherry Creek Water Resources Project to provide the needed additional water supplies. There will be portions of the demand for new water that will be supplied by individual well owners and by other municipalities, such as Aurora, who have portions of their systems extending into the basin. These sources further reduce the total amount of water to be supplied by the Cherry Creek Water Resources Project.

3.2.1 Population and Land Use Projections

The most comprehensive population projection made for the upper Cherry Creek Basin was conducted by the Denver Regional Council of Governments (DRCOG) in 1985 to support requirements for water quality control measures. These population estimates were assembled based upon DRCOG's knowledge and experience in the entire metropolitan area, combined with land use information provided by local governments. The geographic area of the DRCOG study is identical to the study area for this investigation.

DRCOG estimated the 1983 population of the upper Cherry Creek Basin as 43,300 and projected a 2010 population of 301,800 people. The land use data supporting this projection reflects the level of development indicated by zoning, platting, and planning as of June, 1984.

Figure 3.1 displays DRCOG's anticipated land use patterns for the year 2010. The information is tabulated and summarized on Table 3.1. Open space is expected to continue to be the primary land use for the total basin. Parks, flood plains, and agricultural uses define the open space areas which are predominant in the southern portion of the basin.

North of Franktown, the development pattern of the basin is expected to become mostly urban. Agricultural land is currently being converted to large lot residential development and future plans suggest that large lot areas will occupy the eastern ridge and portions of the western ridge of the basin. Urban residential, commercial, and industrial development is expected to occur more prominently in the valley areas.

The airport and the commercial and industrial areas are concentrated at the extreme north end of the basin and are only partially developed at the present time. Residential areas generally extend from just south of the Arapahoe/ Douglas County line to Castle Rock, except that a non-residential buffer has been established around Centennial Airport.

Nearly one-half of the basin's current population is located within the municipal boundaries of Aurora and Greenwood Village, near Cherry Creek Lake. These areas are nearing full development, so future growth is expected to concentrate in the area between the Arapahoe/Douglas County line and Franktown. DRCOG projects the basinwide population to double between 1983 and 1990, and double again by year 2000. The population is estimated to grow at an average rate of 7.5 percent per year. Table 3.2 contains DRCOG's forecasts of total population and employment for 1990, 2000, and 2010.

As indicated in Table 3.2, the area is projected to become a major business center with employment increasing substantially in relationship to resident population. The area around Centennial Airport currently supplies 80 percent of all jobs in the basin, and this area is still expected to produce the majority of the jobs in the year 2010. The Inverness and Meridian office parks are located in this part of the basin, and future plans indicate

TABLE 3.1

Distribution of Land Use in the Cherry Creek Basin Projected for Year 2010

Land Use	Acreage
Large Lot Residential(1)	68,107
Residential(2)	37,709
Multi-Family Residential(3)	1,074
Commercial	2,662
Industrial	9,694
Open Space	101,966
Airport Property	1,921
TOTAL ACRES(4)	223,133

(1) Less than or equal to 1 dwelling unit/acre
(2) More than 1 dwelling unit/acre
(3) More than 11 dwelling units/acre
(4) A total of 245,537 acres exist in the basin. The difference, or 22,404 acres, lies within the unincorporated area of El Paso County.

Source: Cherry Creek Basin Water Quality Management Master Plan; Denver Regional Council of Governments; September, 1985.

TABLE 3.2

Population and Employment Projections for the Cherry Creek Basin(1)

Year	Population	Employment
1983	43,300	20,200
1990	90,400	59,300
2000	187,600	162,800
2010	301,800	300,000

(1) Cherry Creek Basin Water Quality Management Master Plan; Denver Regional Council of Governments; September, 1985.

that present vacant lands will be developed into commercial, office, and industrial property.

3.2.2 Water Use Rates

Previous investigations were reviewed and evaluated to determine estimates of present and future water use rates. The selected per capita water use rate was taken from the water demand forecast model utilized in the Metropolitan Denver Water Supply Environmental Impact Statement (Denver EIS). The product of the selected unconstrained per capita use rate and the projected population was computed to determine a total unconstrained water demand.

The Denver EIS (COE, 1986) established water demand forecasts for 55 existing water purveyors for the years 1990, 2000, 2010, and 2035. Per capita use rates developed for the purveyors located within the Cherry Creek Basin were selected for use in this study. The resulting per capita use rates in gallons per day (gpd) were 207 for 1990, 208 for 2000, and 207 for 2010.

3.2.3 Water Conservation

Water conservation can be considered in a number of different ways in a regional planning investigation. It can be outlined as the central component of non-structural alternatives; treated as a separate water supply source; or considered as a factor in reducing the water demand. For this study, water conservation has been considered to be a combination of activities and actions that will be implemented during the next twenty-five years to reduce the unconstrained water demand. The following is a summary of evaluations made in the Denver EIS (COE, 1986) and the assumptions made for reducing the water demand in the metropolitan area.

A high level of water conservation, based on generally voluntary programs, was selected as being representative of an attainable program suitable for this study area. Such a water conservation program would consist of metering, mandatory implementation of low water use landscaping for new construction, a voluntary evapotranspiration program, a voluntary retrofit of commercial and industrial sectors with low-flow toilets, and a leak detection program. It was assumed that current conservation practices would continue. Current policies within some of the project area include a plumbing code which requires: (1) low-flow toilets, shower heads, and faucets for new homes; (2) natural retrofit of existing homes, as replacement plumbing fixtures become necessary; and (3) use of low-flow appliances. Table 3.3 presents the percent demand reduction expected with implemention of this conservation program.

3.2.4 Project Water Requirements

Utilizing the values for population, per capita use, and water conservation defined in the preceeding sections, water demand estimates were prepared for the upper Cherry Creek Basin. Table 3.4 presents a summary of the computations and the resulting annual demands for years 1990, 2000, and 2010.

The total water demand estimate summarized in Table 3.4 does not consider existing supplies or the portion of future development that will be supplied by other entities. These two components have been quantified and subtracted from the total water demands to determine the annual volume of new water that is required to be supplied by the Cherry Creek Water Resources Project.

Table 3.5 presents the demand reductions to account for the City of Aurora estimates of future water supplies in the basin and the estimated water supply by other non-project users. Existing basin water supplies include 11,200 af/yr distributed by local purveyors. Future water supplies were projected to include 2000 af/yr pumped by large lot residences, and 9600 af/yr provided by Aurora and other purveyors. The water development alternatives to meet year 2010 demands were formulated to satisfy the shortage of 35,300 af of water annually. Figures 3.2 and 3.3 show the annual demand build-up and monthly demand pattern, respectively.

3.3 WATER SUPPLIES

A wide range of water sources were evaluated for their potential to provide water to satisfy upper Cherry Creek Basin needs. Surface water supplies in Cherry Creek are very limited; therefore, imported water and deep ground water become the prominent supply sources. The water resources with development potential include: (1) nontributary ground water originating in the Denver Basin aquifers; (2) tributary ground water in the Cherry Creek alluvial aquifer; (3) Cherry Creek streamflows; and (4) surface water imported from the Arkansas and South Platte Rivers. The development of local supplies are more economical than the imported ones, but have the drawback of either being very limited in extent or being finite and non-renewable.

TABLE 3.3

Effects of Water Conservation on Project Demands(1)

Year	Percent Demand Reduction
1990	7
2000	14
2010	17

(1) Metropolitan Denver Water Supply Environmental Impact Statement; COE, 1986.

TABLE 3.4

Summary of Upper Cherry Creek Basin Water Demands

	Year		
	1990	2000	2010
Population	90,400	187,600	301,800
Per Capita Use Rate (gpd)	207	208	207
Unconstrained Demand (af)	21,000	43,700	70,000
Water Conservation Reduction (percent)	7	14	17
Water Conservation Reduction (af)	1,500	6,100	11,900
Total Water Demand (af)	19,500	37,600	58,100

TABLE 3.5

Summary of Upper Cherry Creek Basin
Water Development Demand - Year 2010
(in af)

Total Water Demand	58,100
Existing Supplies	(11,200)
Future Supplies of Aurora and Other Project Water Purveyors	(9,600)
Sparsely Populated Areas Served by Wells	(2,000)
New Water Supply Needed	35,300

The remainder of Section 3.3 will characterize the various water sources which were employed in formulating water development alternatives. The use of these supplies will vary among alternatives, even though some of the supply sources are common to more than one plan.

3.3.1 Nontributary Ground Water

The nontributary ground-water aquifers, which comprise the Denver Basin, are the primary source of existing supply for the project service area. Because natural recharge is much less than current pumping rates, pumping heads have been declining in these confined bedrock aquifers. As a source of municipal water supply, the Denver Basin is characterized by its finite quantity and nonrenewable water supply. For these reasons, concerns are being raised regarding how to extend the useful life of these aquifers. The degree of reliance on nontributary ground water from the Denver Basin aquifers varies in each of the alternative plans.

The Denver Basin underlies a 6700 square mile area extending from the Front Range of the Rocky Mountains east to Limon, and from Greeley south to Colorado Springs. The maximum depth of the Denver Basin is about 2500 feet, underlying an area in northeastern Douglas County. The ground water found in the bedrock aquifers is predominantly nontributary, which means it is not hydraulically connected to the surface water system. The estimated total water in storage in the Denver Basin aquifers is approximately 470 million acre-feet (USGS, 1984). Current pumpage estimates are unavailable; however, pumpage from the Denver Basin aquifers was estimated as 41 cfs in 1978, nearly triple the estimated pumpage twenty years earlier (USGS, 1984). In the Cherry Creek project service area, pumpage is currently about 18 cfs.

The Denver Basin includes the Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers, and portions of each aquifer underlie the Cherry Creek Basin. Estimates of the actual amount of recoverable water vary among technical investigators; however, the U.S. Geological Survey has estimated 260 million acre-feet of recoverable water in storage in the four bedrock aquifers. Approximately 0.1 percent of this water is stored under confined conditions.

The volume of water in confined storage is estimated to be only about 300,000 af. This is the amount of water that would be released from storage as water levels in confined areas decline until water table conditions develop in each aquifer. Water level declines of as much as 40 ft/yr have been recently experienced in parts of the Cherry Creek Basin. Parts of the basin can be expected to go unconfined within the next 10 to 20 years at the present rate of ground-water withdrawal.

3.3.1.1 Water Law

Based upon Colorado Senate Bill 5, passed in 1985, the Colorado Department of Natural Resources, Division of Water Resources, developed rules and regulations applying exclusively to the withdrawal of ground water from the Denver Basin. The rules define the limits of availability of nontributary ground water and the extent of its development. The purpose of the rules is to permit the withdrawal of ground water, without materially affecting vested water rights.

Nontributary ground water is, by definition, not hydraulically connected to the surface water system. The legal definition in Colorado states that ground water which, when withdrawn, causes a stream depletion less than one-tenth of one percent of the annual rate of withdrawal at 100 years, is nontributary. Nontributary ground water is allocated to the overlying landowner and is not administered under the doctrine of prior appropriation.

The allowable annual withdrawal, for permitting purposes, is based on a 100-year aquifer life. Even though the lower Dawson, Denver, Arapahoe, and Laramie-Fox Hills aquifers are presently confined, water allocations assume the aquifers are unconfined.

In determining the allowed average annual amount of withdrawal, the specific yield and saturated thickness for each aquifer were used for evaluating the total volume of water under the project service area. The average annual withdrawal is limited to one percent of this volume. In order to assure that surface water rights are not materially affected by withdrawals of nontributary ground water from the Denver Basin aquifers, the regulations allow consumption of no more than 98 percent of the annual withdrawal.

The original legislation (Senate Bill 5) contains a key provision for developing the nontributary ground-water supplies beneath a municipality or water district. As long as water service is reasonably available to lands within the municipal or district boundaries, a special ordinance or resolution can be adopted, which implies consent to develop nontributary ground water beneath its service boundaries. In essence, when areas decide to accept water service from a water purveyor, their nontributary ground-water rights belong to the purveyor.

Table 3.6 summarizes the maximum withdrawal rate that would be allowed according to state laws for each aquifer in the Denver Basin. The rate is based on uniform withdrawal of the water in the aquifers over a 100-year period. After the volume is theoretically exhausted, substantial quantities of water may still physically reside beneath the project service area due to nonuse by surrounding landowners.

3.3.1.2 Water Quality

Water in the Dawson aquifer is generally of excellent chemical quality. Due to the preponderance of dissolved calcium and bicarbonate ions, the water is classified as a calcium bicarbonate-type water. The water is considered moderately hard, but meets drinking water standards for public supplies in most of the area.

The Denver and Arapahoe aquifers produce good quality water and generally meet standards for public supplies in most areas. Water is predominantly a calcium bicarbonate-type in the Denver aquifer, and a sodium bicarbonate-type in the Arapahoe aquifer. Generally in the outcrop areas, along the margins of the aquifers, dissolved solids and dissolved sulfates increase to concentrations which may locally exceed drinking water standards.

TABLE 3.6

Legal Entitlements to Nontributary Ground Water Beneath the Project Service Area

Aquifer	Allocated Nontributary Ground Water (af)	Maximum Annual Withdrawal (af)
Laramie-Fox Hills	1,481,700	14,800
Denver	853,100	8,500
Upper Dawson	56,700	600
Lower Dawson	660,500	6,600
Upper Arapahoe	2,149,000	21,500
Lower Arapahoe	109,200	1,100
	5,310,200	53,100

The Laramie-Fox Hills aquifer generally yields water which is classified as a sodium bicarbonate-type. Dissolved solids and dissolved sulfates increase toward the margins of the aquifer. In areas of this aquifer with strong reducing conditions, sulfate minerals and organic materials reduce to form hydrogen sulfide and methane gases. When these gases are present in high concentrations, water pumped from the aquifer effervesces, smells, and is of marginal value for most uses.

3.3.2 Tributary Ground Water

Ground water originating in the Cherry Creek alluvial aquifer can contribute only a relatively minor amount of water toward meeting project needs. Its importance as a supply source is derived from the opportunity to exchange reclaimed waste water for tributary ground water. The extent of the supply and aquifer characteristics are not as thoroughly documented as for the Denver Basin aquifers. Therefore, the information presented in this section of the report will not quantify the water in storage, but will identify the expected yield from historical water use information.

Approximately 60 wells are located in the alluvial aquifer between Franktown and Cherry Creek Lake. Most of these wells were constructed during the 1950's to serve agricultural lands along the Cherry Creek flood plain. Since that time, some of the wells have been purchased by municipal water supply entities, and their use has been converted from agricultural to municipal purposes.

The Cherry Creek alluvial aquifer is predominantly composed of coarse grained sand with intermittent layers of silt and clay. The aquifer is essentially nonexistent upstream of Franktown, but gradually increases in thickness toward Cherry Creek Lake. The alluvium averages 50 to 70 ft thick, and the average depth to water is approximately 10 ft. The hydraulic characteristics of the aquifer result in well production rates between 500 and 2000 gpm.

3.3.2.1 Water Law and Rights

Alluvial ground water is considered tributary to Cherry Creek and is administered in priority along with surface water rights. The laws which apply to the withdrawal of alluvial water are much the same as those for the appropriation of streamflows. The use of surface and tributary ground water is administered by the State under the Appropriation Doctrine. The State protects the right of water users to appropriate water according to a "first in time, first in right" doctrine, limited only by the physical availability of water to those able to put it to beneficial use.

The Water Rights Determination and Administration Act of 1969 established a tool for facilitating development of reliable water supplies for municipal or industrial use, called an augmentation plan. Some of the features important to augmentation plans and the Cherry Creek Water Resources Project are the provisions which allow the establishment of alternate points of diversion, conversion of agricultural rights to municipal use, reuse of reclaimed waste water, and credit for project return flows. The emphasis on establishing an augmentation plan is to keep senior appropriators free from injury, while allowing complex water supply systems and operations.

Although tributary ground water does not represent any major new supply potential, it is extremely important to the basin's total water supply plan. The size and location of the shallow aquifers will allow exchange of municipal return flows for tributary water, which can be used in the project distribution system.

Most of the water currently appropriated in the basin is for agricultural use, with the predominant irrigated crops being alfalfa and turf. The annual historical use of tributary water rights averages 10,800 af within the basin above Cherry Creek Lake (In-situ, 1985). Most of these rights utilize a very small portion of their adjudicated right. Of the 10,800 af, 10,300 af is derived from pumping wells in the alluvial aquifer, while the remainder is direct diversions of streamflow from Cherry Creek.

In this study, the historical water use information has been used to analyze the frequency that rights with common priority dates were entitled to divert water. The analysis indicated that, assuming intrabasin administration, a water right would need a 1930's priority, or earlier, to have a water supply virtually all of the time. A 1940's right would usually have a sufficient supply, but may not be allowed to divert in some of the dry years. The majority of the Cherry Creek Basin water rights have priority dates in the 1950's. These rights would only be in priority about one-third of the time.

The situation changes considerably if the basin is administered from the South Platte River, as appears likely in the near future. A water right in Cherry Creek would need an 1880's priority date or earlier to assure a reliable municipal supply under the condition of administered South Platte calls. Only 800 af of annual historical use has occurred upstream of Cherry Creek Lake from these senior rights. About 300 af originates from the alluvial aquifer, and 500 af are diverted from Cherry Creek.

3.3.2.2 Water Quality

Water in the Cherry Creek alluvium is of good chemical quality and generally meets drinking water standards for public supplies. When used for municipal supplies, the only water treatment prior to distribution is chlorination. The water can be generally classified as a calcium bicarbonate-type and very hard. Water quality gradually worsens in the downstream direction.

3.3.3 Cherry Creek

Cherry Creek originates in El Paso County near the town of Black Forest and flows through Denver to the South Platte River. The only storage within the basin is Cherry Creek Lake, which is owned and operated by the COE for flood control and recreation purposes. At the normal water surface elevation of 5550 ft, about 15,100 af of storage is available for recreation.

Two U.S. Geological Survey stream gaging stations have historically operated in the Cherry Creek Basin. The station near Franktown is currently active and located on Cherry Creek in Castlewood Canyon, just downstream from the breached Castlewood Dam. The other station, which stopped operating in 1969, was located near Melvin, about 5.5 miles upstream from Cherry Creek Dam and six miles northwest of Parker.

The Franktown gaging station started operations in November, 1939 and measures streamflow of a 169 square mile contributing drainage area. The average annual discharge at the gage is 6,540 af. Extremes for the period of record range from a minimum discharge of 0.2 cfs to a maximum of 9,170 cfs. The average annual volume ranged from 2,090 af in 1954 to 21,370 af in 1983.

The gage near Melvin, downstream of Parker, operated from October, 1939 to September, 1969. The contributing drainage area is 336 square miles, and the average discharge for the 30-year period of record is 8,500 af/yr. About 5000 acres (In-situ, 1985) have been historically irrigated above the station. Extremes in flow vary from zero flow for prolonged periods, to the maximum discharge of 39,900 cfs which occurred June 16, 1965. The 1965 maximum discharge was the largest since at least 1858. The flood of August 3, 1933 was 34,000 cfs; however, it was caused by the failure of Castlewood Dam.

Most of the flow in Cherry Creek occurs in the late winter and early spring seasons. The seasonal flow distribution indicates more than 50 percent of the annual runoff occurs from March through May. Figure 3.3 shows the historic monthly flow distribution as a percentage of the average annual flow for Cherry Creek at the Franktown gage. For comparison purposes, the average monthly demand pattern is also included on the figure.

A comparison between the monthly distributions of water supply and water demand indicates the months with the largest water supplies occur about 4 months earlier than the greatest demands. The largest water needs occur from June through September. To bring the raw water supplies into phase with water needs on a seasonal and annual basis requires storage, either in reservoirs or aquifers.

3.3.3.1 Water Law and Rights

As with all surface water and tributary ground water in the state, the Prior Appropriation Doctrine is used to administer Cherry Creek. Historically water rights on Cherry Creek have not been regulated under the priority system of administration. The State Engineer's Office has indicated a change in this policy this year. Starting April 1988, water right owners will be precluded from diverting water if the call is on the South Platte River downstream from its confluence with Cherry Creek.

The most viable approach toward developing a dependable supply from Cherry Creek surface water sources requires a storage right and reservoir. Free river conditions are generally expected to exist on the South Platte River and Cherry Creek between October and March, but flow conditions are extremely variable.

DRCOG (1985b) projected runoff into Cherry Creek Lake to increase by about 23,000 af/yr for land use conditions expected in the year 2010. Only a portion of the runoff increase would become available as a supply source for a Cherry Creek Water Resources Project, because much of the water would belong to senior water right owners. Allowing for expected South Platte River calls to be enforced on Cherry Creek reduces the storable increase in runoff by an estimated 50 percent.

3.3.3.2 Water Quality

Very little water quality information is published for the upper Cherry Creek Basin. Temperature and specific conductance data are collected at the stream gage near Franktown. Additional water quality information is collected and analyzed for Cherry Creek Lake on a periodic basis.

Examination of the specific conductance information for the Franktown gage indicates relatively low concentrations of dissolved solids for most of the year. For the water years from 1980 through 1983, the specific conductance ranged from 80 to 480 micromhos. Generally, the lowest values were obtained during the fall and winter when flows were low. The highest specific conductance values occurred from March through May when flows were the highest.

Governmental entities in the Cherry Creek Basin recently completed a water quality management master plan for the basin (DRCOG, 1985b). The objective of the cooperative effort was to protect Cherry Creek Lake from accelerated eutrophication. In August, 1984 the Water Quality Control Commission established a 0.035 mg/L total phosphorus standard for the reservoir. The plan allocated future phosphorus loadings to point, nonpoint, and industrial sources, as well as septic systems. Management schemes were developed to control total phosphorus loads from each source.

Water quality data for Cherry Creek Lake were obtained for the 1980 and 1981 water years. The water was very hard, and in the spring, turbid. Total phosphorus concentrations ranged from a low of 0.04 mg/L to a high of 0.18 mg/L, always exceeding the 1984 standard. A program to monitor phosphorus concentrations in the Lake and at various locations upstream has recently been undertaken by the Cherry Creek Basin Authority. This Basin Authority is responsible for meeting the phosphorus standards for the reservoir.

3.3.4 Arkansas River

Cherry Creek originates at the Monument Divide which separates the Arkansas and Cherry Creek Basins. The geographic proximity to Cherry Creek makes the Arkansas River a potential source of supply. Water could be pumped to Cherry Creek directly to the point of use, or conveyed by the streambed to a regulating reservoir for later diversion.

The Arkansas River is fully appropriated, providing water to agricultural, municipal, and industrial users within the basin. Due to a deteriorating regional agricultural economy, many irrigation canal companies have sold portions of their water rights to municipalities. The change in type of use requires a water court action to assure that other existing in-basin appropriators are not harmed or are adequately compensated. The consumptive use portion of the agricultural right is the only amount that can be transferred.

The imported supply used for this investigation results from a hypothetical purchase of water from shareholders of the Fort Lyon Canal Company. The company provides water for irrigation of approximately 93,000 acres of land between La Junta and Lamar and has almost 94,000 shares of stock outstanding. The system consists of the Fort Lyon Canal; Fort Lyon Storage Canal; and Horse Creek, Adobe Creek, and Thurston Reservoirs. The Fort Lyon Canal was selected as the supply source because:

1. An abundant quantity of water is currently being marketed by a group representing approximately 65 percent of the total shares;
2. Water rights for upstream ditches have already been purchased by other municipalities;
3. Sufficient storage exists to regulate the supply; and
4. Water quality in the Arkansas River deteriorates in the downstream direction.

3.3.4.1 Water Rights

The Fort Lyon Canal Company owns numerous water rights which total 933 cfs, and have priority dates ranging from 1884 to 1893 (Tipton and Kalmbach, Inc., 1987). The storage rights for Horse Creek and Adobe Creek Reservoirs are for 28,000 and 87,000 af, respectively. The priorities for the original storage rights and subsequent enlargements range from 1900 to 1910. Additionally, the canal company owns a portion of Queen Reservoir, which is part of the Great Plains Reservoir System, for the first 5,483 af available under its storage rights.

During the 1951 through 1985 water years, an average of 240,800 af was diverted into the Fort Lyon Canal. Of this amount, an average of 43,700 af was delivered to the Kicking Bird Canal, and 6,800 af was delivered to another perpetual water right. In addition, the canal company received about 3,900 af from its interest in Queen Reservoir.

The reservoir system of the Fort Lyon Canal Company stored an average of 37,200 af annually in Horse Creek and Adobe Creek Reservoirs. Most of this water, 33,400 af, was diverted from the Arkansas River, while the remainder, or 3,800 af, came from native flows of Horse and Adobe Creeks.

About 42 percent of the Arkansas River storage water is diverted during November through March. In recent years, diversions have increased considerably during this period, due to the Pueblo Reservoir winter storage program. Most of the storable inflows resulting from Horse and Adobe Creeks occur from March through September.

When water rights are converted from agricultural to municipal use and conveyed out of the basin of origin, only the historic consumptive use can be transferred, which represents the water consumed or depleted from the stream system as a result of the historical usage of the water rights. Historical consumptive use determinations are the basis for evaluating the quantity, distribution, and price of the water supply.

During the water years 1951 through 1985, the estimated consumptive use for both the Fort Lyon Canal and its storage system averaged 158,300 af annually, and ranged from 69,100 af in 1954 to 290,800 af in 1985. Of this total, 129,700 af was attributable to the canal water rights and 28,600 af to the storage system. These consumptive use figures include evapotranspiration from crops, and evaporation from reservoirs, canals, and laterals.

3.3.4.2 Water Quality

The U.S. Environmental Protection Agency (EPA) developed interim primary drinking water standards which became effective in 1977. The purpose of these standards was to establish maximum contaminant levels (MCL) for specific drinking water parameters essential to protecting human health. A group of secondary drinking water standards were also developed, which relate to aesthetic considerations for potable water supplies, rather than public health. The primary standards are enforced by the Colorado Department of Health.

Average concentrations of several water quality parameters, in the Arkansas River at the headgate of the Fort Lyon Storage Canal, appear to exceed the drinking water criteria. Water quality generally worsens in the downstream direction, and varies with the time of year. Usually, quality is substantially better during the summer than winter. Parameters which exceed the standards are total dissolved solids, hardness, sodium, sulfate, iron, and manganese. The gross alpha concentration also exceeded the criteria, but is only regulated if Radium-226 and 228 exceed their respective criteria.

Another parameter of concern is uranium. Although not currently regulated, an "Advanced Notice of Proposed Rulemaking" was issued by EPA in 1986 for comments on new standards for radionuclides. The anticipated MCL for uranium is about 15 ug/L. A maximum level of 14 ug/L has been detected at Catlin Dam, just a few miles upstream from the Fort Lyon Storage Canal headgate.

Treatment required for Arkansas River water as a municipal source would depend on the diversion location, time of year, and operating plan. Diversions from the headgate of the Fort Lyon Storage Canal taken during the summer would require less treatment than year-round diversions. Similarly, if the water is blended with better quality water from another source, treatment requirements might be less. The treatment processes needed to deliver potable supplies to the Cherry Creek Basin without blending include coagulation, flocculation, sedimentation, filtration, disinfection, softening, and possibly ion exchange.

3.3.5 South Platte River

The South Platte River is the principal source of water along the Front Range of Colorado. It supplies numerous municipalities and irrigates most of the land in northeastern Colorado. Historically, the river flowed intermittently, but now it gains throughout most of its course due to the vast system of canals and reservoirs adjacent to the river.

Streamflow is quite variable on a seasonal, annual, and spacial basis. Typically, flows are high from May through July as a result of snowmelt. The basin is also susceptible to deluge-type rainstorms which may produce large floods and widespread damage. The large flows usually last only a few days.

Since a long-term average of 350,000 af of water flows out of Colorado each year, the South Platte River was examined for its potential to contribute to the water supply for the Cherry Creek Basin. Numerous opportunities for development have been studied in the past. Most of the major tributaries along the Front Range have been studied for the potential to develop large dams and reservoirs. Some projects have also been considered along the main stem of the South Platte. A thorough inventory of the development potentials in the South Platte Basin was beyond the scope of this study; therefore, the Authority requested use of either the Badger-Beaver Artificial Recharge Project, or the Beebe Draw Diversion and Augmentation Program to represent a typical diversion from the South Platte River to Cherry Creek. Since the Badger-Beaver Artificial Recharge Project has a better water supply and no current sponsor, it was selected for use as a water supply component in this investigation. In addition, the Narrows Reservoir Project was evaluated as a representative surface storage facility for developing South Platte River water.

For the past decade, the U.S. Bureau of Reclamation (USBR), water users in the lower South Platte Basin, and the State of Colorado, have formulated project plans and sought Federal funding for the Narrows Project. This project was conceived to primarily provide supplemental agricultural water supplies. The multi-purpose dam and reservoir, located near Fort Morgan, was also planned to provide municipal water within the local region and flood control downstream.

For the purposes of this evaluation, the data employed in the reservoir operating model by the USBR were used in estimating the project yield. Using the reservoir's 393,000 af of active storage capacity resulted in 62,000 af of yield for municipal use. Only a portion of the yield is needed in the Cherry Creek Basin. The project would develop new supplies from the undeveloped excess native flows in the South Platte River.

The Badger-Beaver Artificial Recharge Project would divert water through the Bijou Canal; the canal headgate is located about halfway between Kersey and Sublette. The point of diversion is downstream of all the major Front Range tributaries and can capture return flows resulting from upstream users. Regulating storage can be obtained by recharging the alluvial aquifers associated with Badger and Beaver Creeks near Fort Morgan.

The average annual flow decreases in the downstream direction between Kersey and Balzac, even though the South Platte River gains throughout its length. The many large diversions throughout this reach account for the decline in streamflow. The average annual flow of the South Platte River at Kersey from 1927 through 1955 was 625 cfs, and from 1952 through 1976 the flow was 847 cfs (USGS, 1980).

3.3.5.1 Water Rights

The South Platte River is not a fully appropriated basin. Numerous conditional water rights for water storage projects exist along the Front Range tributaries and main stem, which will eventually reduce the state line flows; however, economic considerations and small present water needs in the northeast portion of the state have resulted in very little water development in recent years.

Water supplies in the basin can be developed by either acquiring a junior storage right, purchasing water, or filing for a new storage right. Acquisition of water from the Narrows Reservoir would result in a very reliable supply, because the water right is senior to most of the proposed upstream developments. The Narrows Project has two conditional storage decrees, with the most senior having a 1970 adjudication date and a 1957 priority date for 718,147 af.

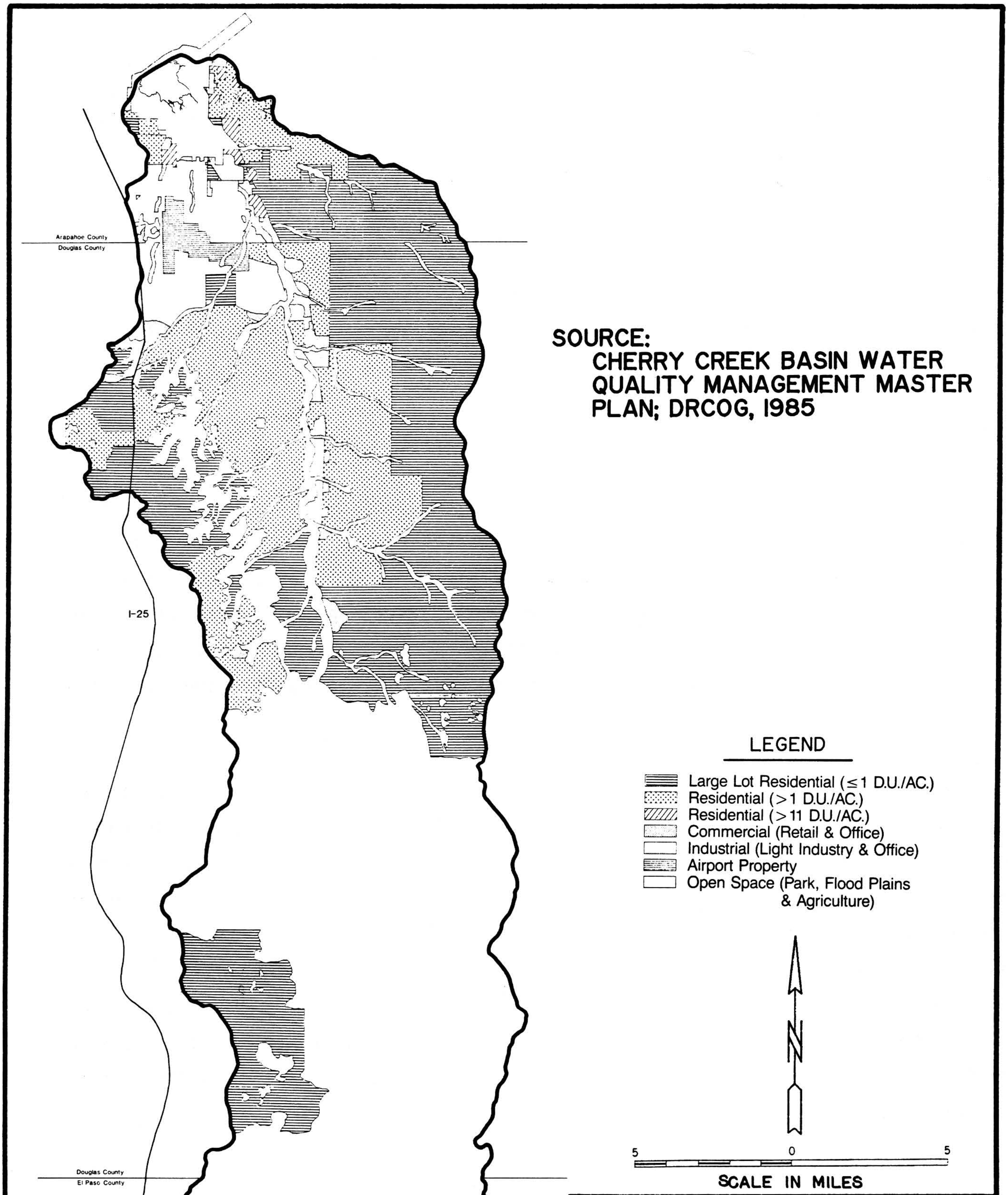
In 1976, the Badger and Beaver Water Conservancy District was formed to promote artificial ground-water recharge in the alluvial aquifers of Badger and Beaver Creeks. The District filed for a water right for 240,000 af annually in the hopes of diverting 90,000 af/yr into the canal system to raise the water table to historical levels, and return lands to irrigated conditions. Since that time, diligence has not been maintained, and the right has been disapproved by Water Division No. I District Court. A new water right would be needed to recharge and store diversions from the South Platte River for use in the Cherry Creek Project.

Acquiring a new water right by filing at the present time would make this project the most junior on the river. Many upstream conditional storage rights could be developed which would impact the available water supply for this project. Almost all of the major tributaries along the Front Range contain potential water resource developments senior to this one. In addition, major main stem projects, such as Narrows, Hardin, or South Platte-Frenchman could potentially deplete the river by more than 200,000 af. In essence, the water right situation on the South Platte River makes an artifical recharge project on Badger and Beaver Creeks very risky. Thus, more reliable water rights would have to be obtained.

3.3.5.2 Water Quality

Water quality data for the South Platte River near Weldona was reviewed and compared to potable drinking water standards. Several water quality parameters exceed the standards including total dissolved solids and sulfate. The water is also very hard and needs softening for a municipal supply. The concentrations of these parameters vary considerably with flow and time of year. Generally, salinity concentrations are highest in late summer and autumn when flows are low, and lowest during high flow periods in the spring and early summer.

For South Platte water conveyed directly to the Cherry Creek Basin, some treatment would be necessary, even if the water was blended with higher quality supplies. When the water has been artifically recharged into the Badger and/or Beaver Creek alluvial aquifers, sufficient dilution may lower the concentrations of some constituents to acceptable levels. Water quality data from either the Beaver or Badger Creek alluvial aquifers has not been located, so potential impacts from recharging South Platte River water into these aquifers have not been addressed. Alluvial water in these areas may already need treatment for potable supplies due to the historical agricultural development in the area. The parameter which would most likely need treatment is the nitrate concentration.



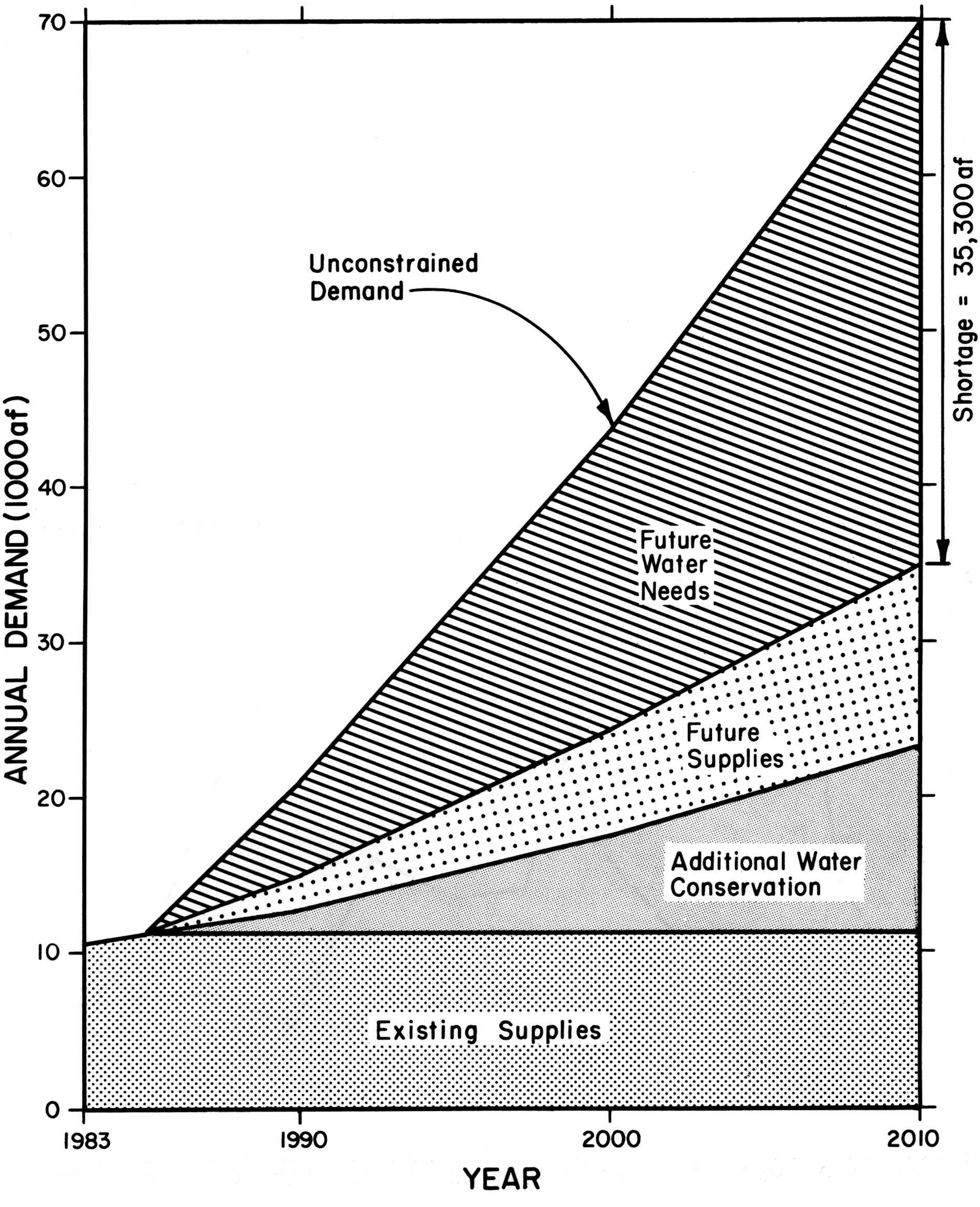
COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY

CHERRY CREEK WATER RESOURCES PROJECT

CHERRY CREEK BASIN LAND USE AT THE 2010 LEVEL OF DEVELOPMENT

MORRISON-KNUDSEN ENGINEERS, INC.

DATE: JULY 1987 FIGURE 3.1



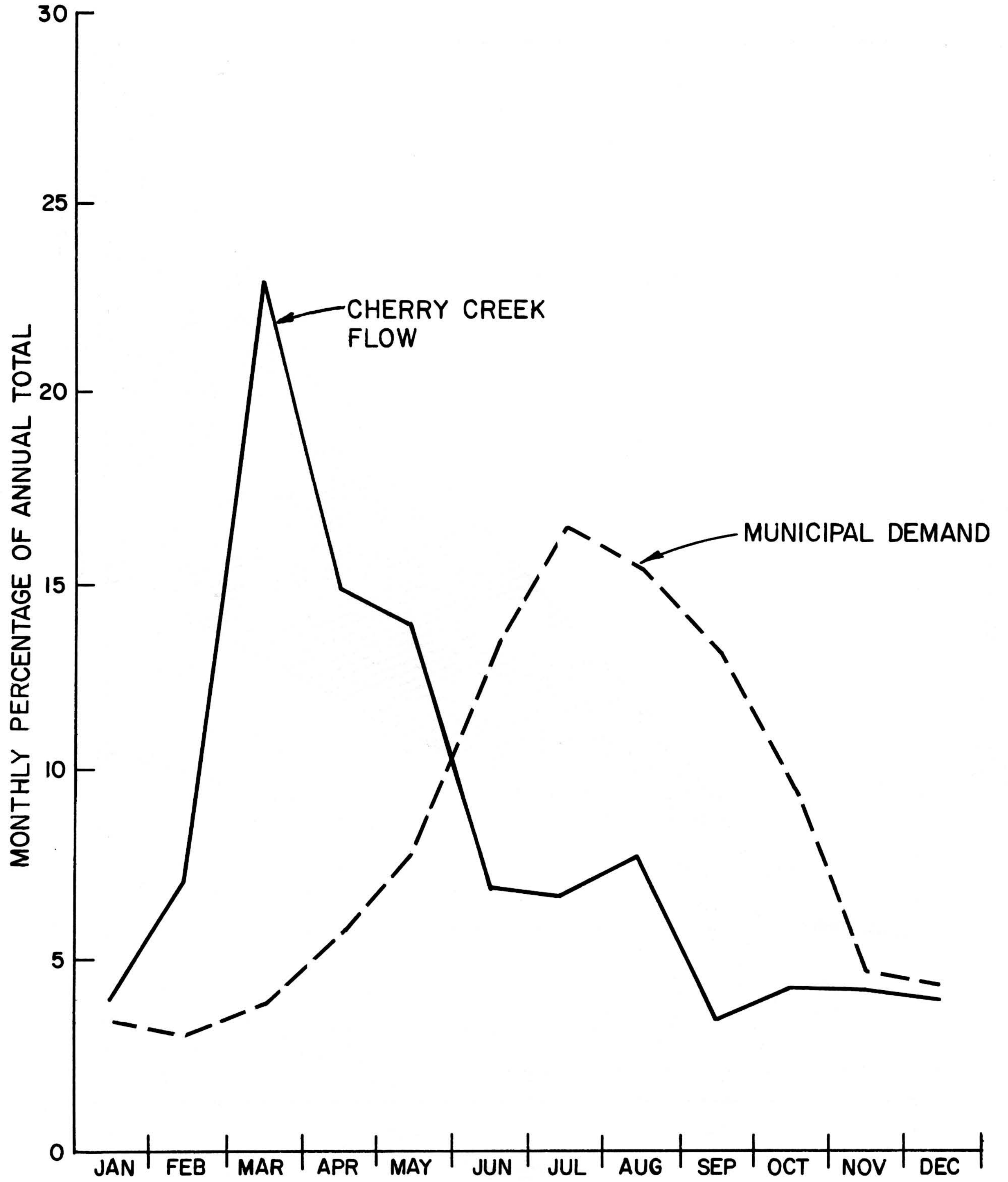
COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY

CHERRY CREEK WATER RESOURCES PROJECT

PROJECTED FUTURE DEMANDS

MORRISON-KNUDSEN ENGINEERS, INC.

DATE JULY 1987 FIGURE 3.2



COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
CHERRY CREEK WATER
RESOURCES PROJECT

CHERRY CREEK FLOW AND MUNICIPAL DEMAND DISTRIBUTION

MORRISON-KNUDSEN ENGINEERS, INC.
DATE JULY 1987 FIGURE 3.3

4.0 IN BASIN SURFACE STORAGE

For any new water development project along the front range, storage plays a major role. While potential utilization of underground storage was recognized to be a good possibility in the basin, it was also evident that surface storage could become a vital component of one or more of the alternative plans.

The native streamflow of Cherry Creek represents a small resource, yet with surface storage on the main stem, off-season flows and small floods can be captured and utilized as a water supply component. Surface storage reservoirs also have the ability to serve multiple functions, and in the case of the Cherry Creek Basin, the opportunities for flat water recreation and flood control, in addition to water supply, are strong possibilities.

This chapter summarizes the investigations, screening, layout, sizing, and cost evaluations that were made for dams and reservoirs within the Cherry Creek Basin. More detailed information is contained in Appendixes A and B.

4.1 SCREENING OF SURFACE STORAGE SITES

4.1.1 Storage Requirements

The only major dam and reservoir ever constructed in the Upper Cherry Creek Basin was the Castlewood Dam built in the 1890's to store surface water for agricultural irrigation. The dam initially impounded a maximum of 5250 af of water, but failed in 1933, sending a flood of 33,000 cfs into the City of Denver.

In 1950, Cherry Creek Dam was completed by the COE as a flood control facility to protect the urbanized area along the lower reaches of Cherry Creek through Denver. Cherry Creek Dam can impound about 90,000 af of water prior to initiating spillway flows. The reservoir storage would reach approximately 270,000 af with the water level at the dam crest.

There are some other small flood detention dams on various tributaries within the basin, but none that are used to regulate surface water supplies for consumptive uses.

The potential utilization of a dam and reservoir within the upper basin has been considered by numerous entities since the 1933 failure of Castlewood Dam. One of the most recent was the 1985 study by JCHA for the PWSD in search of alternatives to eliminate a projected 3000 af of annual water shortage for Parker. In that study, three dam and reservoir sites on Cherry Creek were examined to evaluate their capability to develop a water supply from native Cherry Creek flows. These three potential sites, and two additional, were selected for examination under this study. The objective was to screen the sites for dams and reservoirs that present the highest potential for use as components of the water development options.

The size and location of a reservoir site is very dependent on its overall function within a water supply plan. A dam and reservoir on the main stem of Cherry Creek could provide one or more of the following functions:

1. Terminal storage for regulating imported surface supplies;
2. Conservation storage for developing the Cherry Creek native supply;
3. Flood control storage;
4. Recreational storage (fishing, camping, boating, and water sports); and
5. Environmental enhancement.

The approximate ranges of storage used in the screening evaluations are presented below. These values were re-evaluated in later stages of this study. In the case of the conservation storage, requirements changed considerably from these initially used values.

<u>Terminal Storage</u> - This storage function is to provide a collecting point for imported surface water which has been released into the creek upstream or delivered by pipeline. It would be desirable to have at least a 30-day supply of water in case there was damage to the delivery system. Approximately 5000 to 8000 af of storage would serve this purpose.

<u>Conservation Storage</u> - The amount of yield that can be developed from native Cherry Creek flows for this project by an on-stream reservoir is dependent upon the volume of seasonal high flows, or flood flows, which can be economically stored. Operation simulations to accurately define the yield to storage relationships were not performed during the screening process. For this screening, it was assumed that

24,500 af of reservoir capacity would be required to develop 3000 af of yield from Cherry Creek based upon general estimates made by JCHA in 1985.

Flood Control Storage - There have been recent modifications in the policies and procedures for determining the magnitude of rare flood events. The COE has recomputed the probable maximum flood (PMF) for the Cherry Creek Basin and found that Cherry Creek Dam and Reservoir cannot fully regulate the newly estimated flood without causing extensive damage to the structure and to properties downstream of the spillway.

In the fall of 1986, the COE initiated studies to examine ways to alleviate the problem. One possibility is to provide large flood storage space in a new dam located upstream of the existing Cherry Creek Reservoir. For such a solution, it was estimated that an additional flood storage reserve of 75,000 to 100,000 af would be required. A large dam could be designed to include space for terminal storage, conservation storage, and a recreational pool, in addition to flood control storage.

Recreational Storage - Recreational uses can normally be met by designing for a minimum operating pool, which leaves adequate surface area and shore line to provide a variety of "flat water" recreational uses. The conditions vary for each site, but the needed storage would be in the range of 5000 af. A part of such storage could still be made available for consumptive use during emergency situations, but at the expense of the recreation function. Generally, terminal storage and recreational storage could be compatible and would utilize the same storage space.

Environmental Enhancement - No specific volume requirement has been developed to provide opportunities for enhancement of the environment. Any regulated reservoir could provide habitat for waterfowl, fish, and wildlife. A minimum pool equivalent to that desired for recreation should provide environmental enhancement potentials. There is presently no fishery in the upper Cherry Creek Basin, yet a new reservoir could provide an environment to support establishing fish habitat in the reservoir and possibly in the downstream reaches of the creek.

The four sites examined in the initial screening are shown on Figure 2.2 and have been called: Castlewood; Bridge Canyon; Shultz Ranch; and Confluence. There are size limitations at each site which become constraints in regard to serving the various functions. The capacity characteristics, dam types, spillway requirements, sedimentation reserve, site geology, and reconnaissance level cost estimates have been compared.

4.1.2 Flood Hydrology

The dams located on the main stem of Cherry Creek must be able to safely pass the PMF without causing the dam to fail. The probable maximum precipitation events were developed by applying the criteria presented in Hydrometeoro- logical Report No. 55, published by the National Oceanic and Atmospheric Administration. The PMF's for the region have been approximated at 2200 cfs per square mile of drainage area (JCHA, 1985). The drainage areas are in the range of 150 square miles, thus giving a computed PMF with a peak discharge of over 300,000 cfs.

PMF volumes at each site are over 150,000 af and none of the proposed sites are large enough to store the PMF. The structures must, therefore, be designed to safely pass the peak discharge.

4.1.3 Screening Results

Visual inspections were made at each of the dam sites. USGS topographic maps were used to determine storage capacity versus dam height and to delineate the valley cross section for volume computations. Table 4.1 summarizes the key features and comparisons of the dams and reservoirs screened.

The Bridge Canyon and Castlewood Dams and Reservoirs were selected as the most suitable sites. The Castlewood Dam could be a large multi-purpose facility, with flood control being one of the primary purposes. The project users would only pay a prorated amount for the use of an active storage component at the lower levels.

The Bridge Canyon RCC Dam would have an overflow spillway in its center section, as opposed to a separate spillway around the abutment. The RCC-type dam at this site is quite suitable for providing a small, economical, reservoir.

Additional design layouts, geologic evaluations, and cost estimates were prepared for the Bridge Canyon and Castlewood Dams for use in components of the final alternatives. These supplemental evaluations are described in the following sections, and in greater detail in Appendix B.

TABLE 4.1

Key Features and Comparison of
Upper Cherry Creek Dams and Reservoirs

Site	Dam Type	Dam Height (ft)	Total Storage (af)	Construction Cost of Storage ($ million)	Unit Cost of Storage ($/af)
Confluence	Rockfill	100	10,000	38.6	$3,900
Confluence	RCC(1)	75	7,500	20.0	2,700
Shultz Ranch	Earthfill	100	27,000	94.0	3,500
Bridge Canyon	RCC(1)	72	7,500	7.3	1,000
Castlewood	Rockfill	230	102,000	107.8	1,100

(1) Roller Compacted Concrete

4.2 CASTLEWOOD DAM

4.2.1 General

The Castlewood site was considered as an alternative to the existing Cherry Creek Lake by the COE in the early 1940's (U.S. Engineer's Office, 1944). More recent COE studies in the 1970's reconsidered flood control storage at this site, and in late 1986, additional investigations were initiated to evaluate possible ways to accommodate flood control deficiencies of the Cherry Creek Dam and Reservoir system (COE, 1970).

One of the alternative water development plans of this study centers around methods to maximize native in-basin supplies. It has been estimated that 10,000 to 20,000 af of active storage, located at the Castlewood and/or Cherry Creek Reservoirs, would provide control of the Cherry Creek native surface water supply.

A multi-purpose dam and reservoir at Castlewood, that could include major flood control capability, has been evaluated in this study. The maximum storage below the crest of the spillway would be approximately 102,000 af.

The lower portion of the reservoir could be utilized as active storage to assist in regulating Cherry Creek flows for the project water supply. A minimum reservoir pool of about 4000 af would result in a surface area of approximately 200 acres. The normal maximum storage is expected to be about 11,000 af, which would provide nearly 350 acres of surface area.

The large multi-purpose dam could be a joint project between the upper basin water users and the COE. Normal flood control operations for this type of dam would be to store the flood volumes only as long as needed to avoid additional downstream damage. Therefore, very little, if any storage of extremely large floods could be salvaged for long-term water supply use. If the maximum flood control storage was reached, the reservoir area would cover over 1600 acres and extend approximately 3.5 miles upstream. The Castlewood site is the only storage site above the existing Cherry Creek Dam large enough to make a significant reduction in the peak discharge of the PMF for the downstream Cherry Creek Lake.

The maximum active storage level of 11,000 af and the maximum reservoir line for 102,000 af of storage are shown on Figure 4.1.

The new dam is proposed to be located very near the axis of the former Castlewood Dam. The spillway would be located around the left abutment, with the excavated rock material from the spillway channel used to form the outer shells of the dam's rock fill section. The maximum height of the dam above the original streambed would be approximately 267 ft.

Figure 4.2 shows the profiles of the Castlewood Dam and spillway, as well as a cross section of the maximum plan section. The dam would contain over 2.5 million cubic yards of material.

4.2.2 Geology and Construction Materials

The Castlewood site is a "V"-shaped valley where Cherry Creek has cut a notch through about 100 feet of sound Castle Rock Conglomerate, and approximately 150 feet into the top of the weaker Dawson Formation. The conglomerate crops out high on both abutments and forms nearly vertical cliffs. From the top of the cliffs, the conglomerate outcrops extend in a very gentle slope up each abutment. The Dawson Formation slopes are about 2 ft horizontal to 1 ft vertical to the center of the valley. There Cherry Creek has eroded a channel, about 30 feet deep and 50 feet wide, with near vertical walls into the sandstone bedrock adjacent to what remains of the original rubble masonry dam. Much of the Dawson Formation's surficial exposure is masked by colluvial debris fed by the more resistant cliffs above.

The outcrops of the Castle Rock Conglomerate are sound and massive, and nearly continuous at the higher abutment elevations. Stress relief jointing is more pronounced near the edges of the rim rock, probably due to the undermining of the weaker Dawson sandstone below. These joints have allowed large blocks of sound conglomerate to separate from the rock mass and slide or roll into the valley below.

The Dawson Formation exposed at the site is composed of massive cross bedded light gray to yellowish-gray sandstone. The sand particles that make up the rock are generally uniformly graded and weakly cemented. Dark brown to gray lenses of claystone and shale, and spherical iron concretions are distributed throughout the unit parallel to the erratic bedding. The sandstone is soft and friable at the surface and can be easily excavated with a knife blade. The depth of weathering of the Dawson is not clear from the surface exposures in the channel at the Castlewood site, but a clear soil profile of several feet can be observed. No joints can be observed in the Dawson Formation, and no faults have been mapped in the vicinity.

No record of subsurface geotechnical work has been located, but several preliminary conclusions can be reached based on surficial observations. The foundation is adequate for an earth or rockfill embankment dam up to the maximum height contemplated for the site. The foundation may be suitable for a concrete gravity dam, but this cannot be confirmed without subsurface investigation to determine the strength and deformation characteristics of the sandstone. A substantial amount of excavation and shaping would probably be necessary with either type of dam. A grout curtain would probably not be required due to the unjointed nature of the bedrock, although permeability tests would be necessary to determine if chemical grouting of the sandstone matrix would be beneficial. The Dawson Formation is highly erodible and would have to be carefully protected against flows at the downstream toe, regardless of the type of dam constructed.

Construction materials for either a concrete gravity or zoned earth embankment are available within easy access of the dam site. Impervious core material for an earth embankment could be obtained from the dark, low plasticity clay that blankets the reservoir area to a thickness of 5 to 10 feet. The clay is underlain by a variable thickness of poorly graded sand and gravel that might be used after processing as a filter and drain material, or concrete aggregate. Suitable rock for the shell zone of a rockfill dam could be derived from the Castle Rock Conglomerate on either abutment, as required excavation for a spillway. The conglomerate could also be quarried and crushed for concrete aggregate. Aggregate and filter drain material could alternatively be furnished from commercial gravel pits in Castle Rock and sand pits near Franktown.

4.2.3 Design Features

The crest of the rockfill dam would be approximately 4050 ft in length. The internal zoning and side slopes proposed are illustrated on Figure 4.2. In the higher fill sections, the central impervious core would be founded on sound bedrock, with a double row grout curtain to control seepage. The depth of excavation can only be a rough estimate until detailed site geotechnical exploration has been performed. For this study, 30 feet of excavation was assumed to be required in the valley floor and five feet along each abutment.

The COE utilized a PMF having a peak discharge of 450,000 cfs in their analysis of the Castlewood Dam. During this study it was estimated that the reservoir routing effects would reduce the peak of the PMF to an outflow of about 268,000 cfs.

The spillway was proposed to be unlined and would dump the Cherry Creek flow back into Castlewood Canyon about a half-mile downstream of the dam. A gated and valved outlet works, capable of regulating normal flows and draining the full reservoir, would be provided. A ten-foot diameter conduit was used in the cost estimates for this study which would allow the draining of the maximum flood storage (91,000 af) within 60 days.

An access road would be provided to the dam crest from State Highway 83, and the existing Castlewood Canyon road would be improved downstream of the dam to allow access to the downstream toe. Relocations would be needed for transmission lines in the vicinity, and the State Highway 83 bridge crossing Cherry Creek would require replacement.

The construction period for a dam and related facilities of this size would be two to three years.

4.2.4 Recreation Potential

The present day popularity of the Chatfield Lake and Cherry Creek Lake indicates a strong and continuing demand for water-related recreation in the Denver metropolitan area. It is envisioned that a reservoir at the Castlewood site would be more visually attractive than those at Chatfield or Cherry Creek Dams. While the proposed minimum pool area at Castlewood Dam is not as large as the two existing COE facilities, there would be potentials for developing boating, lake fishing, camping, picnic areas, scenic overlooks and exhibit areas.

Castlewood Canyon was selected as a State Park because of the canyon's native beauty, and to preserve and protect a small part of the Black Forest, portions of the Cherry Creek floodplain, and the unique vegetative communities and wildlife habitats. A new dam near the old Castlewood Dam site would create a new type of recreational use in and around the reservoir area, which is not fully compatible with the present State Park management plan. The Division of Outdoor Parks and Recreation (DOPR) has expressed a willingness to re-examine park management schemes, should a dam be selected at this site.

4.2.5 Estimated Cost

The total construction cost for the Castlewood Dam is very sensitive to the unit price for excavation of the rock from the spillway section. Unit prices, initially estimated during the screening processes, and contingencies were revised, which resulted in a cost estimate for construction of $70.6 million. This does not include any costs for interest during construction or financing charges. For a total maximum storage of 102,000 af, the unit construction cost of storage would be approximately $700 per af.

4.3 BRIDGE CANYON DAM

4.3.1 General

The narrow Cherry Creek Canyon, approximately two miles upstream of the Castlewood Dam site, is the location of an alternative reservoir at the Bridge Canyon Dam site. The proposed dam axis is along the southern boundary of Section 25, Township 8 South, Range 66 West. A practical maximum reservoir of about 11,600 af can be provided at this site.

The Bridge Canyon Dam would make an excellent terminal reservoir for any system of importing untreated water supplies from other basins. There could also be 4000 to 6000 af of active storage assigned in this reservoir to partially regulate Cherry Creek streamflows. This amount of storage would be adequate to develop some limited new yield from native Cherry Creek flows.

For the purposes of this study, the Bridge Canyon Dam and Reservoir is considered an alternative to the large Castlewood Dam and Reservoir. The storage is very economical for a small reservoir and could be readily financed by local entities. Figure 4.3 shows the location of the reservoir and the surface area covered under minimum and maximum water levels.

4.3.2 Geology and Construction Materials

The Bridge Canyon site is located in a relatively narrow "U" shaped valley, where Cherry Creek has incised a channel about 50 feet deep and 200 feet wide into the Castle Rock Conglomerate. The conglomerate crops out on both abutments and forms nearly vertical cliffs above the floodplain. From the top of the cliffs the conglomerate continues to crop out over the length of the gently sloping abutments. The valley bottom is composed of medium to coarse, recent alluvial sand and gravel. Although the depth of the alluvium is unknown, it is estimated to be less than 10 feet and is assumed to be underlain by sound conglomerate.

The outcrops of Castle Rock Conglomerate are massive and sound; weathering is evidenced only at the cliffs. The coarse grains within the conglomerate are composed primarily of granitic rocks, with fragments of chert and tuff also present. Large pink to gray clasts of Wall Mountain Tuff, up to three feet in diameter, are common in the conglomerate.

The rock mass is virtually joint free, with only a few minor stress relief cracks present near the top of the cliffs. No horizontal separation along bedding planes was observed in the cliffs. No geologic faults have been mapped in the vicinity.

Although the land owner reports that drilling has been performed, no record of subsurface geotechnical work at the site was located. Even without subsurface investigation, several conclusions can be made based on surficial inspection. The foundation conditions at the site are excellent for a concrete gravity or earth embankment dam. Excavation would be limited to removal of the alluvial sand and gravel from the floodplain and trimming and shaping of the vertical cliffs. Foundation treatment would be minimal, probably consisting of minor amounts of dental concrete. A grout curtain would probably not be required, but should be included in preliminary designs until subsurface information is available.

A variety of construction materials occur in the vicinity. Aggregate for a concrete gravity dam, and filter and drain material for an embankment dam could possibly be obtained by processing river sands and gravel. However, based on the heterogeneous nature of the alluvium, it is more likely the coarse aggregate for the concrete would be obtained by crushing locally available bedrock or transporting aggregate from commercial aggregate pits near Castle Rock, a distance of approximately 12 miles. Blend sand or filter sand is available in commercial pits near Franktown, four miles downstream. Sound outcrops of either Wall Mountain Tuff or Castle Rock Conglomerate may be suitable, after crushing, for use as aggregate. A source of impervious fill material has not been identified, but it is very probable that a suitable deposit does exist within the reservoir area. Shell material for a zoned embankment dam could be provided by excavating streambed alluvium or by utilizing rockfill derived from required excavation.

4.3.3 Design

The RCC dam proposed for the Bridge Canyon site would have a crest width of 16 feet and have a crest length of approximately 1550 feet. The center 500 feet would be at an elevation 7.0 feet lower than the maximum dam height to form an overflow spillway section. The maximum dam height would be approximately 90 feet. The key features of the dam are shown on the profiles and sections in Figure 4.4.

The foundation appears to be extremely well suited for an RCC dam, yet field and laboratory geotechnical exploration will be required before feasibility level designs can be performed. It has been assumed that sound rock would occur at a depth of ten feet along the valley floor and five feet along the bedrock abutments. Preparation of the foundation would include diversion of the creek through a conduit that would later serve as the outlet works. In addition, the alluvial deposits and weathered overburden would be removed. The foundation would be cleaned with air and water to sound rock and irregularities smoothed with dental concrete. After placement of the RCC, a grout curtain would be installed near the upstream toe to inhibit seepage and reduce uplift pressures.

The selection of the RCC-type dam at this site was very much influenced by spillway requirements. The center notch with stepped downstream face and stilling basin was incorporated in the design to pass approximately ten percent of the PMF. Floods of greater magnitude would overtop the entire RCC dam sections including the smaller "wing" sections on either abutment. These concrete gravity sections can readily be designed to tolerate this type of overflow without endangering the dam. The rock abutments appear to be massive and durable enough to tolerate the short duration of overflow turbulance associated with overtopping. The reservoir storage during the passage of the PMF is not of sufficient quantity to materially reduce the peak discharge of the PMF which was estimated at 300,000 cfs.

The outlet works and a service spillway for small floods would be incorporated into a double chamber intake tower on the vertical upstream face of the dam. The conduit under the dam, which has been designed to serve as a diversion system during the RCC placement, would be connected to the intake tower to complete the outlet works. The intake would be gated to allow withdrawals from the reservoir and the end of the outlet conduit would terminate in a stilling basin structure.

Other than the building associated with the Shultz Ranch property and the dirt road connecting this property to State Highway 83, there would be no known relocations. Access to the dam could be provided by a 0.6 mile light duty road from State Highway 83, to the left abutment of the dam.

The construction time required for an RCC dam can be much shorter than for other types of dams. The actual placement of the RCC section would require approximately six weeks. The preparation of foundation, diversion of water, preparing aggregates, and installing control works would necessitate at least six months of work. The total dam and reservoir could, therefore be completed in an eight to ten month period.

4.3.4 Recreation Potential

The Bridge Canyon Dam and Reservoir would be physically separated from the State's

Castlewood Canyon Park by State Highway 83. The State owns 520 acres in the area south and east of the park. The dam axis is located near this property and could be integrated into an overall management plan that encompasses the State Park and recreational features of a new reservoir.

The minimum pool level of 4,000 af would provide a reservoir surface area of only 250 acres. This is only about one-fourth the area of the existing Cherry Creek Lake and thus might limit boating to small fishing craft only. There is not as much forested area immediately adjacent to the Bridge Canyon Reservoir compared to that around the Castlewood Reservoir site, yet the canyons below the dam and near the confluence of the east and west branches of Cherry Creek, just upstream, offer excellent opportunities for nature trails, hiking, and picnicing grounds. It is projected that some level of fishery could be established in the reservoir. The fishery would most likely be on a put and take basis because of pressure that would come from heavy public use.

4.3.5 Estimated Cost

The construction cost of Bridge Canyon Dam and Reservoir was estimated by determining the primary quantities and multiplying them by unit prices of recently constructed RCC dams. The total volume of RCC in the dam would be approximately 65,000 cubic yards. The estimated total construction cost including right-of-way, relocations, access roads, engineering, permitting, and construction management is estimated to be $7,800,000. This does not include any costs for interest during construction or financing charges. For a total storage capacity of 11,600 af, the unit construction cost of storage is computed as $670 per af.

4.4 ACTIVE STORAGE AT CHERRY CREEK LAKE

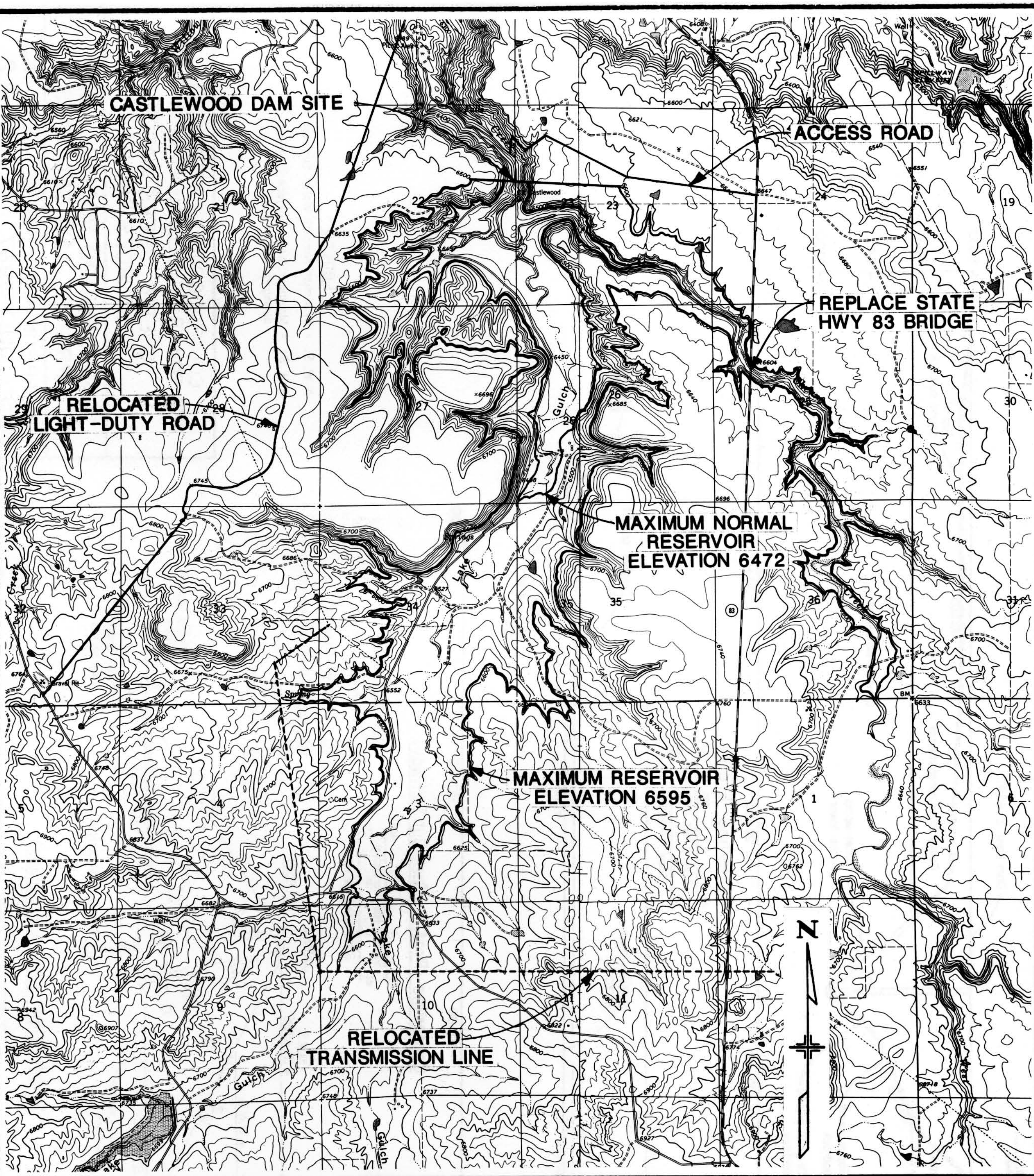
The location of Cherry Creek Lake at the lower end of the basin is advantageous for collecting additional surface flows, or return flows that will occur as a result of upstream land development. Active conservation of storage at this location could assist immensely in implementing reuse plans or exchanges with South Platte senior water rights holders.

The COE is evaluating the potential modification of Cherry Creek Dam to upgrade its flood control capability. Preliminary discussions with COE representatives indicate that it would be possible to add active conservation storage at the same time. If the solution to the flood control problem is construction of an upstream reservoir, then the Cherry Creek Water Resources Project might obtain an allocation for active storage in Cherry Creek Lake, without physically making major modifications to Cherry Creek Dam.

In any case, the addition of active conservation storage in Cherry Creek Lake would require modification of existing recreational facilities around the lake to accommodate higher operating water levels. The surface area of the minimum pool is approximately 1,200 acres, and thus every 1000 af of new storage requires a water level increase of nearly one foot. Operations studies indicate that increases of 2000 to 5000 af on Cherry Creek Lake would be of great assistance in maximizing the yield from in-basin resources.

There are plans being prepared by DOPR to rehabilitate and upgrade Cherry Creek Lake recreation facilities. It would be appropriate for such improvements to be conducted in concert with the potential assignment of additional active storage. The Colorado Water Conservation Board (CWCB) is the designated state agency to coordinate and determine policy of allocation of active storage available from COE reservoirs in the State.

For the purposes of this study, a cost of $2.0 million was estimated to be sufficient to make the needed modification of existing recreation facilities to allow 2500 af of active storage to be used.



RESERVOIR CAPACITY = 102,000 ACRE FEET
AT SPILLWAY CREST ELEVATION 6580
RESERVOIR SURFACE AREA = 1600 ACRES

RESERVOIR CAPACITY = 11,000 ACRE FEET
AT MAXIMUM NORMAL RESERVOIR ELEVATION 6472
RESERVOIR SURFACE AREA = 350 ACRES

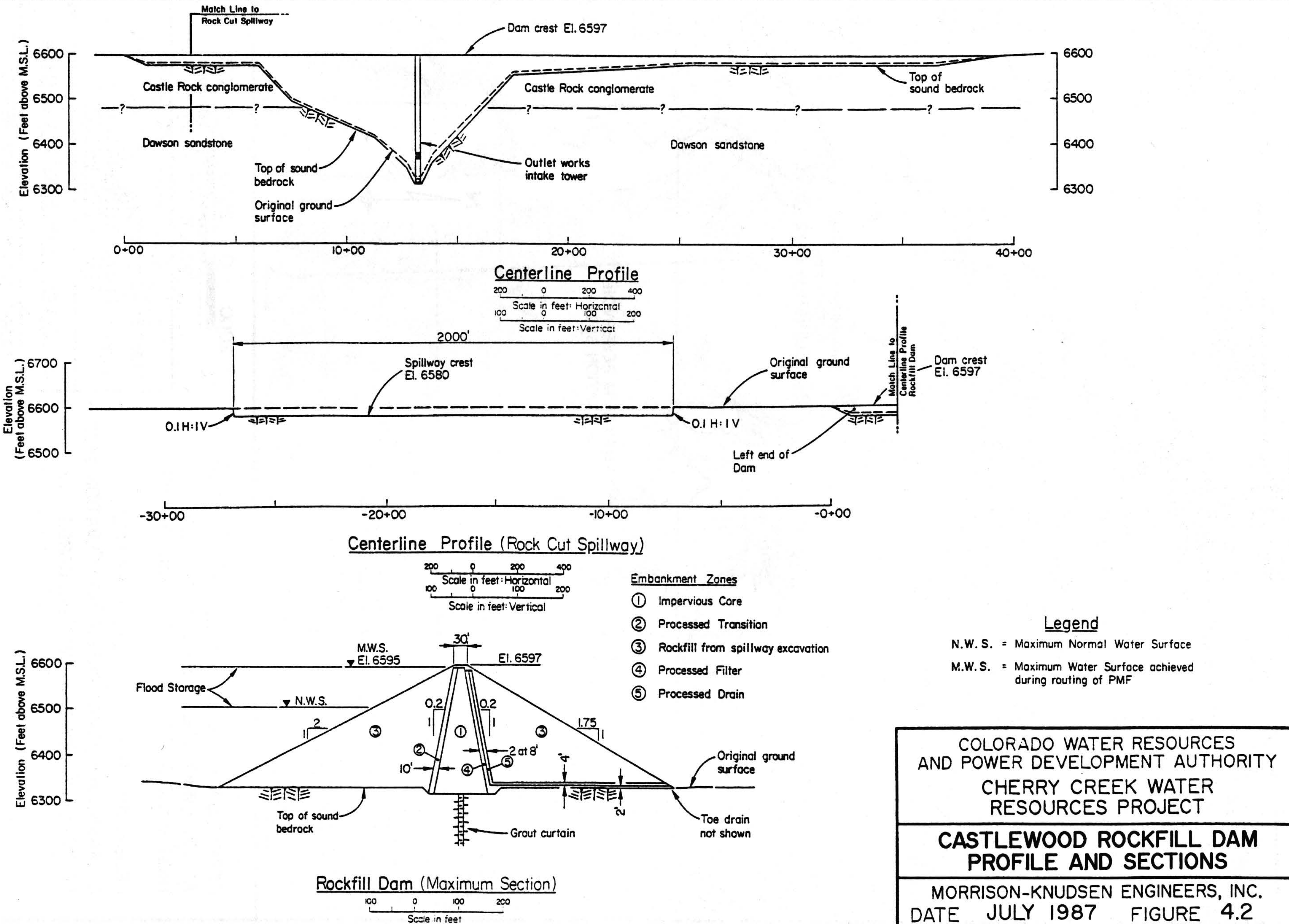
2000 0 2000 4000 6000

SCALE OF FEET

COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
CHERRY CREEK WATER
RESOURCES PROJECT

CASTLEWOOD DAM SITE

MORRISON-KNUDSEN ENGINEERS, INC.
DATE JULY 1987 FIGURE 4.1



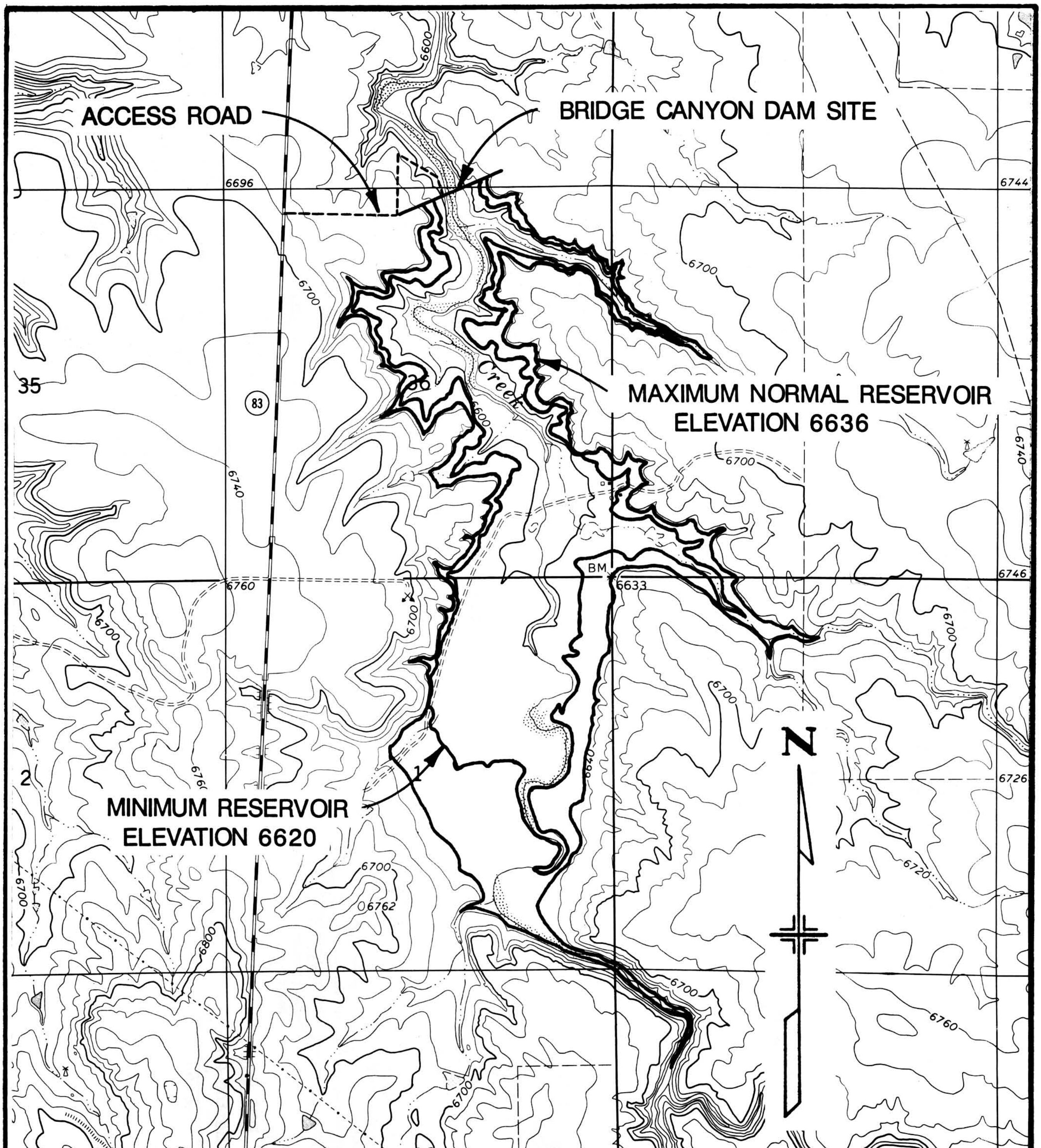
COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY

CHERRY CREEK WATER RESOURCES PROJECT

CASTLEWOOD ROCKFILL DAM PROFILE AND SECTIONS

MORRISON-KNUDSEN ENGINEERS, INC.

DATE JULY 1987 FIGURE 4.2



1000 0 1000 2000 3000

SCALE OF FEET

RESERVOIR CAPACITY = 11,600 ACRE FEET
AT MAXIMUM NORMAL RESERVOIR ELEVATION 6636
RESERVOIR SURFACE AREA = 507 ACRES

RESERVOIR CAPACITY = 5200 ACRE FEET
AT MINIMUM RESERVOIR ELEVATION 6620
RESERVOIR SURFACE AREA = 300 ACRES

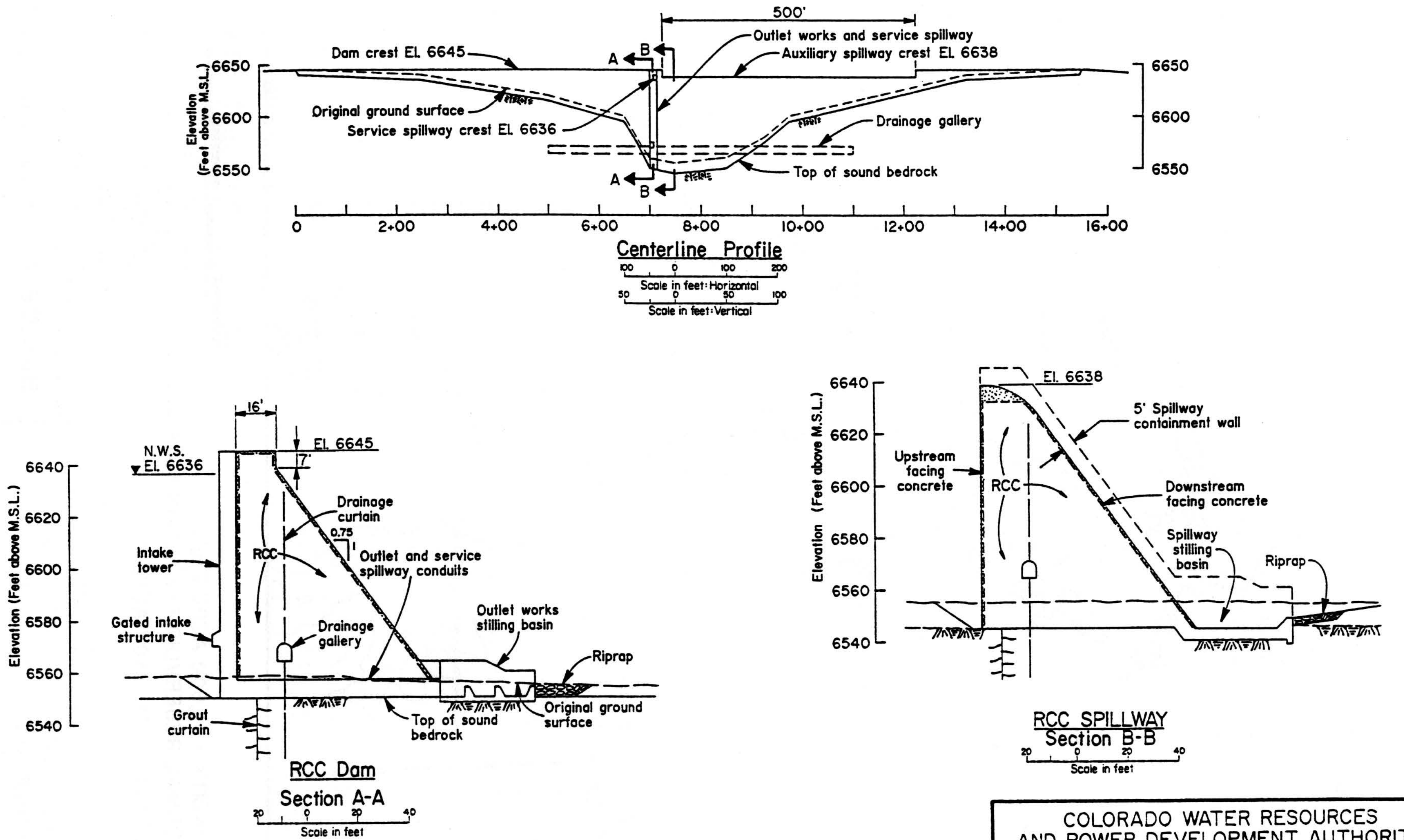
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY

CHERRY CREEK WATER
RESOURCES PROJECT

BRIDGE CANYON DAM SITE

MORRISON-KNUDSEN ENGINEERS, INC.

DATE JULY 1987 FIGURE 4.3



Legend

N.W.S. = Maximum Normal Water Surface

COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY

CHERRY CREEK WATER RESOURCES PROJECT

BRIDGE CANYON DAM PROFILE AND SECTIONS

MORRISON-KNUDSEN ENGINEERS, INC.

DATE JULY 1987 FIGURE 44

5.0 DEEP WELL INJECTION EVALUATION

5.1 GENERAL

Previous studies conducted for the PWSD indicated that there might be components of water development alternatives in the Cherry Creek Basin where conjunctive use of surface water and ground water would be feasible (JCHA, 1985). The obvious need for storage, coupled with the vast underground storage reservoir of the deep bedrock aquifers of the Denver Basin, gave rise to the possibility of injecting temporary surplus surface water supplies into the aquifers for later recovery. Artificially recharging the deep aquifers could be very beneficial in extending aquifer life and in maintaining confined aquifer.

Municipalities that are drawing from the Denver Basin Aquifers for most of their supply have the total well capacity to meet the peak summer month demands. During the rest of the year, these facilities are operated at reduced rates or are taken out of service. If renewable surface supplies could be developed to be available when user demands are low, then there would be opportunities to inject them into the ground-water aquifers. There would be no evaporation losses, and under confined conditions, dominion and control problems appear manageable. This stored water could then be reclaimed during the peak summertime demand period, or stored for longer periods until drought conditions necessitated its use.

While active recharge and injection programs have been carried out in other regions of the country, it was decided that a demonstration of injection into the Denver Basin aquifers would initiate the process of demonstrating and testing the physical feasibility of a regional recharge program. The initial data collected during this study are expected to be valuable in addressing the various technical, institutional, and legal issues associated with injection and recharge.

There are many questions to be answered in regard to chemical, physical, and biological compatibility of the surface water used for ground-water injection. Obviously, the small pilot demonstration program conducted as a part of this study cannot answer all these questions, but it could provide some initial indicators that are important to the region's water resources planning process. Detailed descriptions of the tests and results of the injection tests are contained in Appendix C. The remainder of this chapter summarizes the procedures used for the demonstration and the results of the injection tests.

5.2 INJECTION TEST PROGRAM AND RESULTS

During the period between mid-February and the end of May, eight injection/ pumping cycles were run. The program consisted of injecting water from the PWSD's water supply system into the "Parker North Dawson" well, located in Section 15, Township 6 South, Range 66 West. This location is approximately one mile north of the center of the Town of Parker. The predominant source of the PWSD supply during this testing period was the Cherry Creek alluvial well, the "KOA" well, located about one mile south of the center of Parker.

The existing Parker North Dawson well is a production well in the PWSD system, which was first placed in operation in April 1980. The well is approximately 610 feet deep with the lower 280 feet screened and gravel packed. As the name implies, and based on the well permit and decree, this well extends into the Dawson Formation. The normal pumping capacity when the well is in full operation is approximately 200 gpm.

This well was retrofitted during this investigation to accommodate the injection as shown in Figure 5.1. The piping installed was designed to allow water to backflow from the PWSD distribution system down the pump column installed in the well. A bleed-back control valve, set just above the pump in the pump column, served as the downhole flow control valve. Back pressure on this bleed-back valve was controlled at the surface by yet another valve. During the pumping cycle following injection, water was diverted to an external discharge outside the pumphouse, where water quality could be monitored. Under conditions which provided the needed positive pressure in the injection system, injection flow rates could vary from approximately 50 to 95 gpm at the installation. The driving pressure for injection was the direct operating pressure of the PWSD distribution system.

Instrumentation was installed to continuously monitor and record water pressure levels with time, and flow measurement equipment was included to measure injection and/or pumping flows.

Pre-injection tests were made on the water quality of both the well water and the supply water. These two water samples matched closely in regard to primary chemical content. A pre-injection pump test was also made over a five-hour period to provide data on the aquifer hydraulic characteristics of transmissivity, hydraulic conductivity, and the well specific capacity. A pumping rate of 148 gpm was utilized and results are shown on Figure 5.2.

In addition to the monitoring of head build up during the injection cycle, field measurements of selected water quality parameters were monitored on an approximate bi-daily basis. These parameters included pH, specific conductance, temperature, and chlorine residual. These parameters were monitored as an indicator of water quality shifts in the source water during the injection runs. Through the monitoring of these water quality parameters, it was anticipated that any major shifts in water quality could be detected, and the injection run would be halted.

Water quality samples were also collected and sent to an analytical laboratory for analysis at the beginning of each injection run and during the pumping portion of the injection cycle. These data were utilized to assess the continuing compatibility of the source water with the aquifer water.

After the initial injection run, subsequent injection/pumping cycles changed only one variable per run so that an assessment could be made of the sensitivity of that variable to the injection process. For example, the initial injection run was operated at an injection rate of approximately 60 gpm for a period of 7 days, followed by the second injection run, which also injected approximately 60 gpm, but with the period of time extended to 12 days.

A total of eight injection/pumping cycles were conducted during this investigation. Table 5.1 presents the data relating to the time, rates, and volumes injected.

During the course of each injection run, the head build up in the well was continuously monitored by the pressure transducer and recorded by the hydrologic monitoring unit. Then plots of these head build up data were made for each run. Figure 5.3 presents a typical plot of Cycle Number Three. As shown in this figure, during the initial portion of the injection run, the data basically simulated a theoretical response. However, as injection continued, the actual head build up response began to deviate from the

TABLE 5.1

Deep Ground Water Injection Data

Injection Number and Date	Elapsed Injection Time (Days)	Injection Rate (gpm)	Net Injected Volume (af)
1 (2/10-2/17/87)	7.0	60.0	1.8
2 (2/19-3/03/87)	12.1	56.5	3.0
3 (3/06-3/13/87)	7.0	78.5	2.4
4 (3/16-3/27/87)	11.1	86.1	4.1
5 (3/30-4/13/87)	13.9	88.3	5.4
6 (4/15-5/02/87)	17.1	91.1	6.8
7 (5/04-5/08/87)	3.9	96.1	1.5
8 (5/13-5/20/87)	7.0	64.5	1.8
		TOTAL	26.8

theoretical response. The deviation typically occurred quite early in the injection run, with the majority of the injected water creating above-normal head build ups compared to the theoretical.

Even with the use of high quality potable water supplies as the source water for injection, a film or skin will begin to form on the inside of the screen in the well, thus producing flow resistance and high head build ups within the well. This clogging effect is most probably attributable to a combination of effects; namely, accumulation of suspended solids, bacterial growth, and chemical oxidation and precipitation reactions.

The results of these combined flow resistant effects during injection is that an appreciable portion of the head build up in the well is attributable to well losses due to clogging, rather than the theoretical head build up that would be expected based on predicted aquifer response. Table 5.2 shows a comparison of the theoretical head build up to the actual head build up observed during each of the injection cycles.

Generally, actual head build up was relatively steady at an amount of approximately 40 to

TABLE 5.2

Comparison of Theoretical Head Build-Up to Actual Head Build-Up

Injection Cycle	Theoretical Head Build-Up (ft)	Actual Head Build-Up (ft)
1	36	55
2	37	53
3	51	75
4	55	84
5	60	101
6	61	111
7	56	123
8	41	83

50 percent greater than the theoretical for the first four runs. For the fifth injection run, the actual head build up was approximately 70 percent greater than the theoretical response. During the latter part of the sixth injection run, the head build up increased dramatically over the theoretical response. Based on data obtained subsequent to this injection run, regarding source water quality, it was concluded that more than normal clogging material was introduced during the latter part of injection Cycle 6. This caused high head build ups during that run, and continued through injection Cycle 7.

Head build up responses greater than theoretical are typical of the injection process. The clogging that causes these higher head build ups are the reason that injection wells have to be periodically cycled with interim pumping periods. Pumping the injection well creates a reversal in flow direction, thus removing some of the clogging particles, whether they be suspended sediment, chemical precipitates, or biological growth.

Because of the anomalies noted in Cycle 6 and 7, the injection during Cycle 7 was shut down after only 5655 minutes (3.9 days) to assess what was causing the high head build up. Upon pumping water after the completion of injection Cycle 7, the discharged water contained several small masses of what appeared to be biological growth.

The biological activity observed in this well appeared to only affect the injection process and not the pumping process. Pumping cycles that were conducted subsequent to the initial identification of problems in the injection process did not show any deterioration in pumping efficiency. However, when the flow was reversed for injection, the effects on head build up were profound. It is believed that some biological material, and possibly some inorganic material, was introduced to the injection well during the latter part of the sixth injection cycle, causing the clogging problems observed during that cycle.

Subsequent to the identification of biological activity in the well, the well was dosed with chlorine, which was allowed to stand overnight. The well was then pumped at the maximum discharge several times in order to remove as much of the clogging material as possible. The effectiveness of this chlorination and pumping process on the hydraulic characteristics of the injection process were observed during injection Cycle 8.

The final injection Cycle 8, was run at a pumping rate and duration similar to those of the first injection cycle, to provide a basis for determining whether or not prominent physical changes had occured to the well during the injection study. The head build up response of the last injection cycle closely matched the head build up response of the first cycle, which indicated that chlorinating and pumping the well were successful in controlling the biological activity and removing a significant portion of the clogging material. Head build up in the last injection cycle was somewhat higher than the first cycle because the injection rate was greater.

Between each injection run, a short pumping test was performed in order to restore the aquifer to pre-injection aquifer characteristics. Restoration of the well to pre-injection characteristics seems to be relatively insensitive to the rate of injection or the duration of the injection cycle. During the pumping cycle, it typically required approximately 10 to 15 minutes to produce clear discharge water, with the exception of the seventh pumping cycle, which needed 25 minutes to clear up. Thereafter, the aquifer response during most pump cycles matched the hydraulic characteristics measured during the pre-injection pump test. This was true for both the early injection runs and the latter injection runs, despite the greater degree of clogging and higher head build up that occurred during the latter runs.

A comparison of the aquifer hydraulic characteristics from the pre-injection pump test to those pump tests conducted after each injection cycle shows that the hydraulic characteristics of the aquifer have not been significantly changed by the injection process. Table 5.3 presents the comparison of these data.

TABLE 5.3

Comparison of Pre-Injection Aquifer/Well Characteristics to Post-Injection Characteristics

Pump Cycle	Transmissivity (gpd/ft)	Specific Capacity (gpm/ft)(1): Based on Original Water Level	Specific Capacity (gpm/ft)(1): Based on Subsequent Injection Run Water Level
Pre-Injection	2,442	2.2	2.2
1	2,221	3.1	2.5
2	1,853	2.2	1.8
3	1,925	2.2	1.9
4	1,941	2.2	1.6
5	1,643	2.2	1.6
6	3,000	2.0	1.5
7	2,700	2.2	1.6
8	2,859	2.3	1.6

(1) Projected to 1 day.

A secondary benefit of this recharge program was the supporting of the potentiometric surface in the Dawson Aquifer. Figure 5.4 shows the observed changes in the potentiometric surface during the course of the injection program. Based on the relatively small total volume of water injected, it is judged that the increase in the potential surface measured is much higher than the longer-term, steady-state condition. Once the aquifer pressure system equalizes, it is expected that the actual effects of the injection on the potentiometric surface to be somewhat less than shown in Figure 5.4.

There are continually fluctuating potentiometric surfaces in all of the Denver Basin bedrock aquifers, which makes it difficult to determine what portion of potentiometric surface changes in the Dawson Aquifer are directly attributable to the recharge activities. It is reasonable to assume, however, that this project did show a positive net effect on the Dawson Aquifer potentiometric surface.

Water quality samples were taken and monitored during the course of the injection program. Generally, the water quality in the source and aquifer water are very similar in nature. Initially, both waters were predominantly sodium-bicarbonate types. The principal difference noted in water quality between the source water and the aquifer water was the temperature. Typically, there were temperature differentials of from approximately 2^{o} Farenheit (F) to 12^{o}F, based on the source of water at any particular time. The temperature differentials were the greatest during early runs, when the source water was primarily Cherry Creek alluvial water, while the temperature differentials were minor when some water supply was being input from other District bedrock aquifer wells.

A review of the dynamic viscosities of the source water and the aquifer water, which are temperature-dependent, indicates that with thermal gradients as great as $12^{o}F$, intrinsic permeability can change by approximately 30 to 35 percent. These thermal gradients between the aquifer water and the source water could therefore contribute to the build up of head in the well, above that expected from a theoretical response. Given that the actual head build up typically was 40 to 70 percent greater than the theoretical response, and viscosity changes could account for approximately 30 to 35 percent in changes in permeability, it is apparent that thermal gradients could be a significant factor in the high head build up observed. However, during injection runs where the source water and the aquifer water temperatures were very similar (less than 2^{o}-$3^{o}F$), a marked decrease was not observed in the head build up above the theoretical response. It is our opinion, therefore, that thermal gradients do create some effect on the head build up, but these effects are relatively minor.

The field-monitored water quality parameters for the source water and aquifer water, respectively, showed very minor shifts in the aquifer water quality. However, some large changes in specific conductance, temperature, and chlorine residual were noted during the sixth injection run. This is most probably attributable to the change in source water from predominantly Cherry Creek alluvial water to more bedrock water supplies.

Of particular note in the field-monitored water quality parameters, is the residual chlorine in the source water. The Colorado Department of Health requires a chlorine residual in extremities of potable distribution lines of 0.20 mg/L (Personal Communication with Keith Raschke 5/18/87). This value was not met on a few occasions during this study, most notably during injection Cycle 7, when injection problems were noted due to biological growth. The data generated indicate that much closer attention needs to be paid to chlorine residual values in the source water in order to minimize the potential for introducing biological growth to the well and the aquifer.

Tabulations of the water quality measurements and a more detailed description of the results of each injection/pump cycle are contained in Appendix C.

5.3 EVALUATION OF DEEP WELL INJECTION

While the variety of tests, time duration, and diversity of source water during this investigation was limited, some of the conditions encountered and the test results should contribute to the continuing evaluation of the feasibility of recharge injection into the Denver Basin aquifers.

The changes in the rate of head build up due to increased flow resistance during injection could be a prominent factor in full scale and longer-term injection programs. The sudden changes observed due to biological activity in this investigation points to the need for carefully monitoring key physical and chemical conditions in test programs. This experience indicates that pre-injection filtering at the well-head may become a requirement for successful long-term injection.

Not all of the potential future injection water sources will be as compatible with the aquifer water chemistry as was the Cherry Creek Aquifer water used in these tests. Some of the potential imported supplies would require extensive treatment to reach potable water levels. Significant advanced treatment might be needed before such sources could be successfully injected in large volumes over a long time frame. The need to provide close compatibility may make some imported sources infeasible.

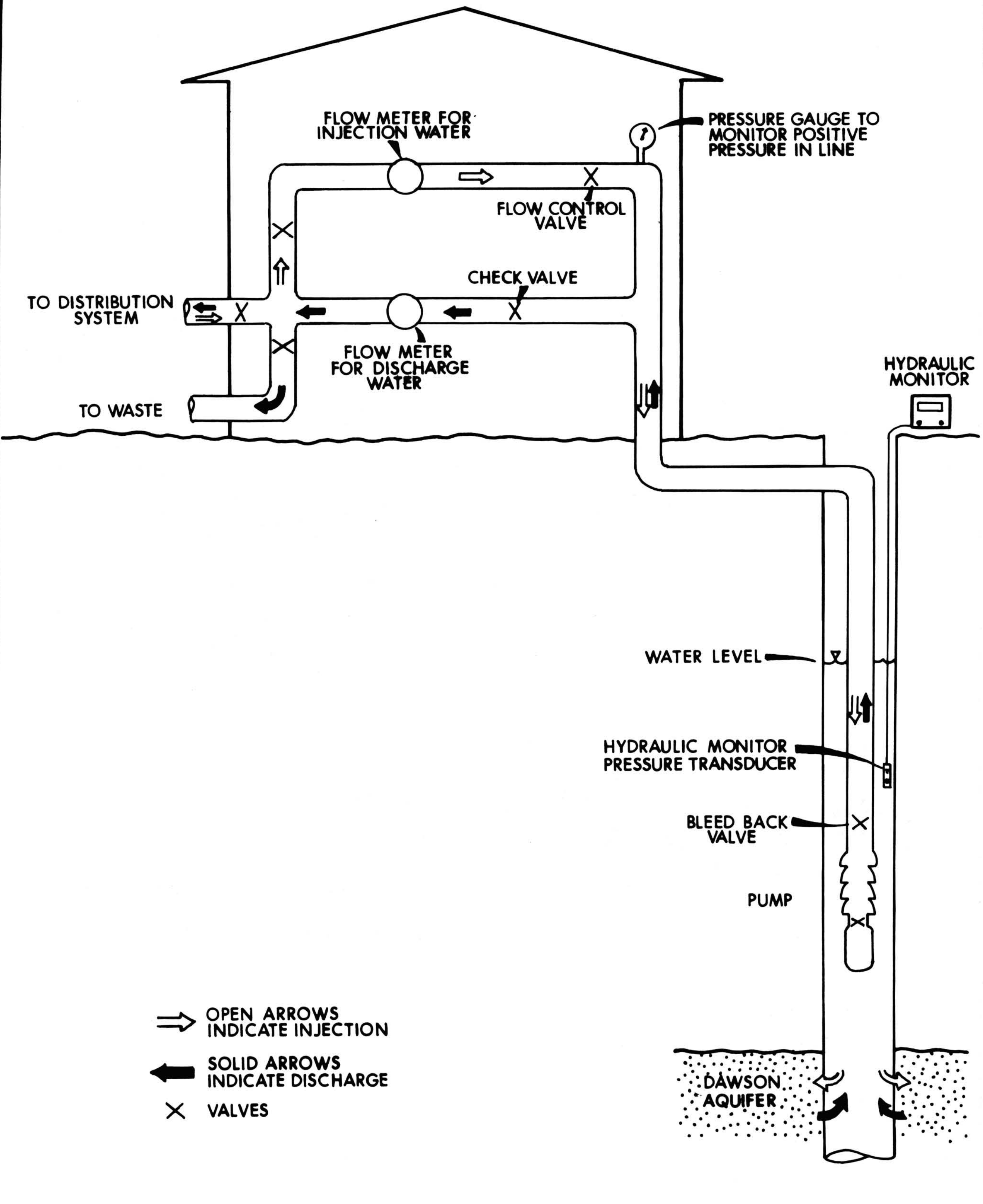
The well used for this injection test was in the Dawson Formation. Future tests should try to be set up in the Arapahoe Formation, which is the more prominently utilized aquifer in the region. The retrofit mechanics of this test can be significantly improved by having a separate piping system for injection inflow, as opposed to using the pump column. This would allow more flexibility in varying injection rates.

This trial injection program did demonstrate that injection of the Denver Basin aquifers is physically possible utilizing existing production wells. This program alone has stored over 28 acre-feet. In a small measure, this volume will contribute to the longevity of the deep aquifer and extend the conditions of confining pressures at the test well.

A more extensive data base is required before fully operational recharge programs can be initiated and several institutional, as well as legal issues, need to be resolved. Long-term testing of the physical characteristics and technical elements is also required.

An excess surface water supply is needed before it can be justified to initiate a major recharge program. If there is only enough surface water to meet a portion of the demand at any time, then the surface supply should be used directly and replace pumping. The only time when this may not be the case is where the confined aquifers could be employed as a conveyance facility. Water injected in one location could physically be withdrawn in another well, located some distance removed, without a net change in aquifer storage. However, after the Denver Basin system becomes unconfined, such conveyance would probably not be allowed from a legal standpoint due to potential injury to other ground water users.

Ground water recharge has been utilized in Alternative Plans 3 and 4 of this study. Both of those alternatives involve importation of large quantities of surface water supplies that allow effective injection schemes to be employed. The description, sizing, and costs of the recharge components are presented in Chapters 6 and 7.



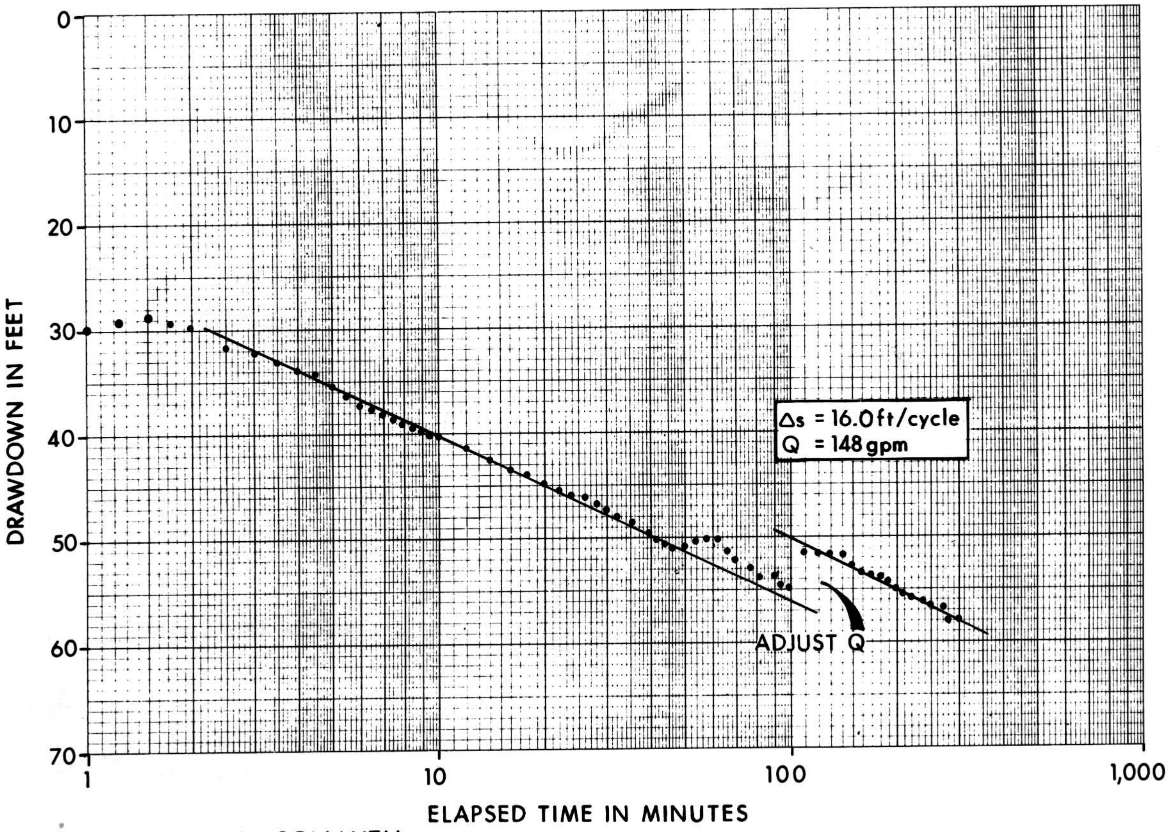
COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY

CHERRY CREEK WATER RESOURCES PROJECT

SCHEMATIC OF INJECTION WELL PIPING

MORRISON-KNUDSEN ENGINEERS, INC.
JOHN C. HALEPASKA & ASSOCIATES, INC.

DATE: MAY 1987 FIGURE: 5.1



PARKER NORTH DAWSON WELL CONSTANT DISCHARGE SOLUTION

TRANSMISSIVITY

$$T = \frac{264(Q)}{\Delta s}$$

$$T = \frac{264(148)}{16.0}$$

T = 2,442 gpd/ft

HYDRAULIC CONDUCTIVITY

$$K = \frac{T}{b}$$

$$K = \frac{2,442}{115}$$

K = 21.2 gpd/ft^2

K = 2.8 ft/day

WELL SPECIFIC CAPACITY

$$Sc = \frac{Q}{s}$$

$$Sc = \frac{148}{58}$$

Sc = 2.6 gpm/ft. at 5 hrs

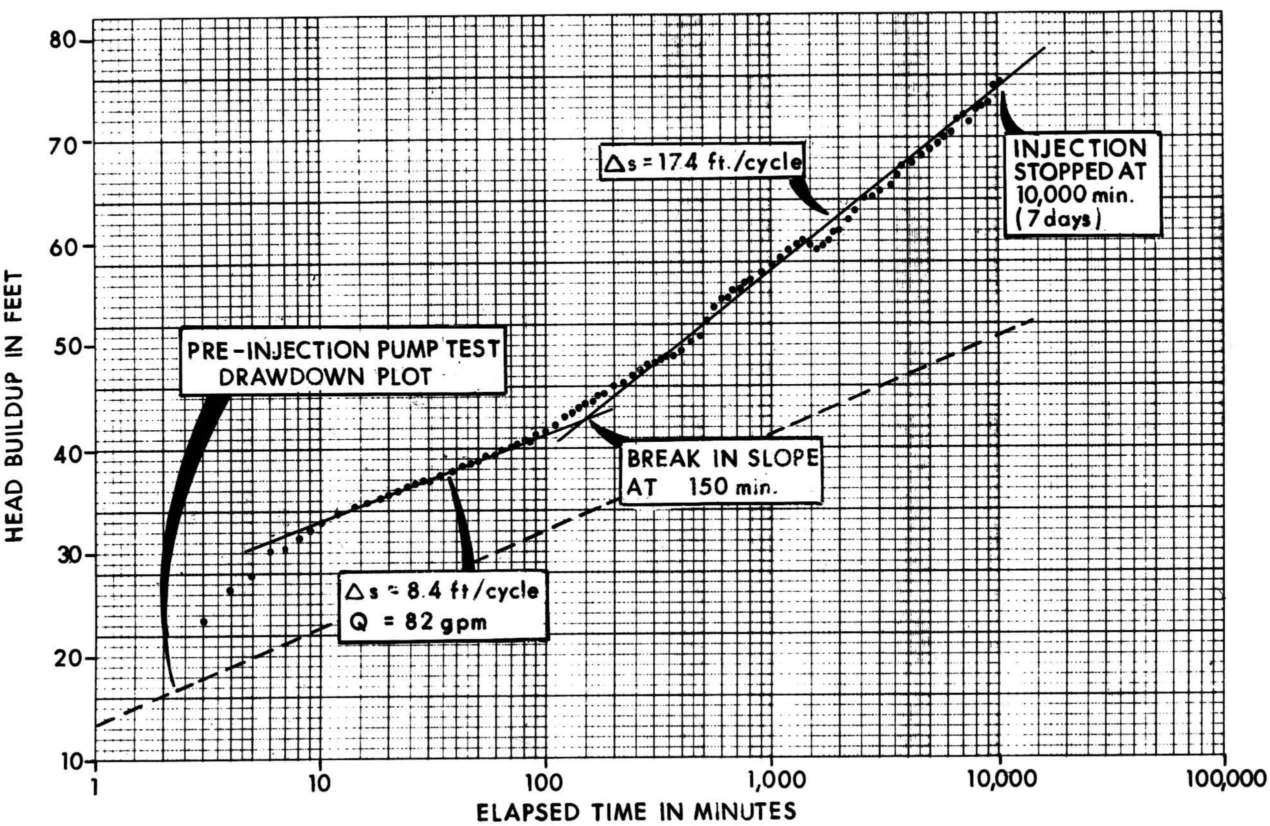
Sc = 2.2 gpm/ft. at 1 day (projected)

NOTES:

1) TEST CONDUCTED ON FEBRUARY 5, 1987

2) STATIC WATER LEVEL - 167.9 FT. FROM TOP OF CASING.

COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY **CHERRY CREEK WATER RESOURCES PROJECT**
PRE - INJECTION PUMP TEST WATER LEVEL DRAWDOWN PLOT
MORRISON-KNUDSEN ENGINEERS, INC. JOHN C. HALEPASKA & ASSOCIATES, INC. DATE: FEB, 1987 FIGURE: 5.2



PARKER NORTH DAWSON WELL
CONSTANT DRAWDOWN SOLUTION

TRANSMISSITIVITY

FOR THIRD INJECTION RUN
BEFORE BREAK IN SLOPE

$$T = \frac{264\,(Q)}{\Delta s}$$

$$T = \frac{264\,(82)}{8.4}$$

T = 2577 gpd/ft.

NOTES:

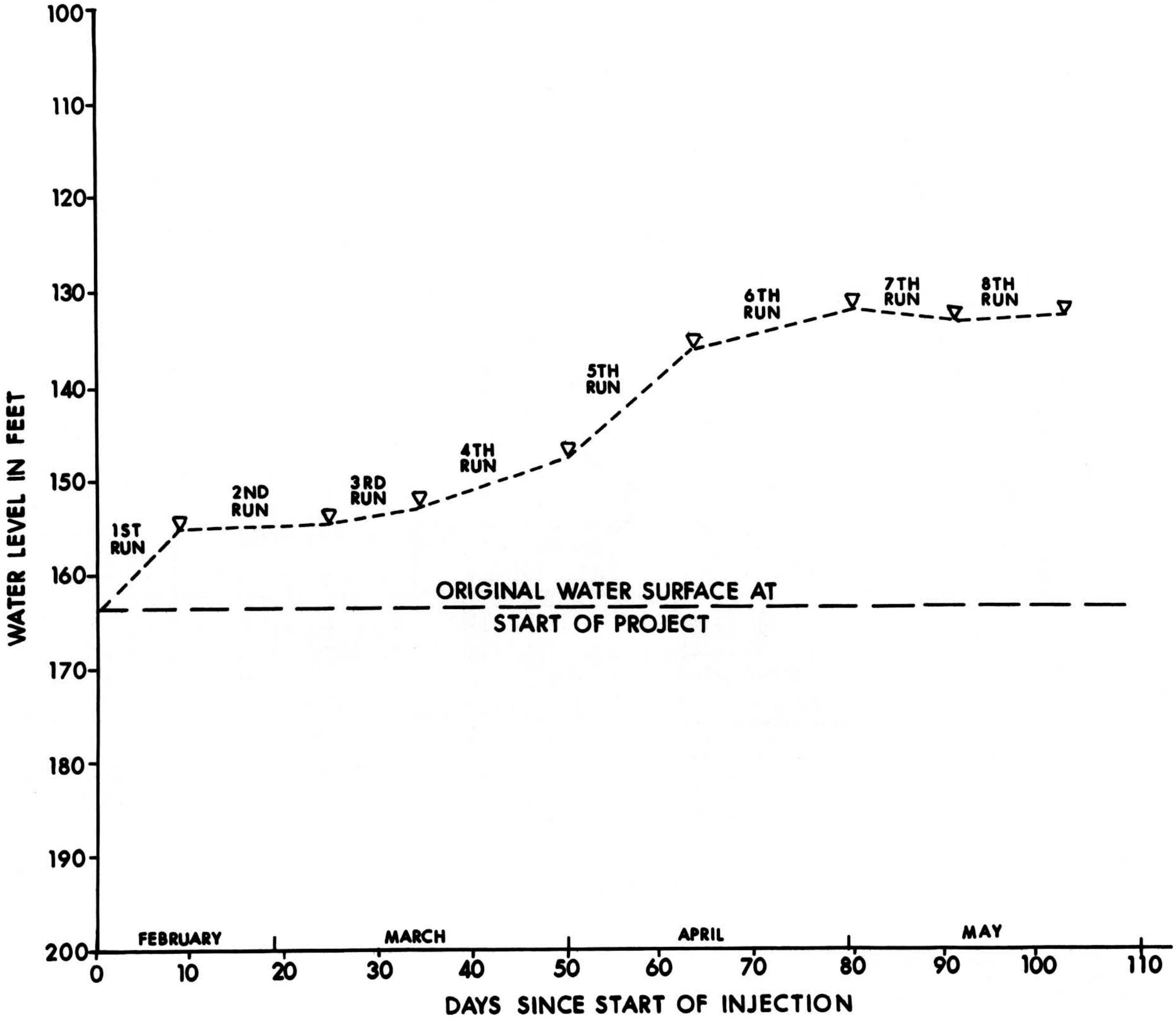
1) THIRD INJECTION RUN CONDUCTED MARCH 6-13, 1987.

2) AVERAGE INJECTION RATE WAS 78.5 gpm FOR A TOTAL OF 785,415 GALLONS (2.41 ACRE FEET)

3) WATER LEVEL AT START OF TEST WAS 155.8 FT. BELOW TOP OF CASING.

4) PRE-INJECTION TRANSMISSIVITY T= 2,442 gpd/ft

COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY CHERRY CREEK WATER RESOURCES PROJECT
THIRD INJECTION RUN HEAD BUILDUP PLOT
MORRISON-KNUDSEN ENGINEERS, INC. JOHN C. HALEPASKA & ASSOCIATES, INC. DATE: MAR 1987 FIGURE: 5.3



COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
CHERRY CREEK WATER
RESOURCES PROJECT

CHANGE IN POTENTIOMETRIC SURFACE
AS THE RESULT OF THE INJECTION PROGRAM

MORRISON-KNUDSEN ENGINEERS, INC.
JOHN C. HALEPASKA & ASSOCIATES, INC.
DATE: MAY, 1987 FIGURE: 5.4

6.0 FORMULATION OF ALTERNATIVE PLANS

6.1 APPROACH

The previous three chapters have outlined the study parameters, selected water demands, identified and characterized potential water supplies, examined surface storage facilities, and investigated deep ground-water injection. That information was used to formulate a range of viable alternatives and assesses their general technical and economic feasibility.

The usual procedure for formulating water development alternatives is to identify and quantify water demands, then search for the most economical means to provide the needed supply. In this study, it was known that the most economical intermediate-term plan is to continue maximum utilization of the nontributary ground-water resource. Therefore, the traditional approach was somewhat modified to seek a range of alternatives which decreased the dependency on the deep ground-water supply.

This was accomplished by first identifying a broad range of water development options, varying from complete dependence on the deep ground water to complete importation of the necessary water to meet the future water demand. Using an evaluation and screening process, four of the options were selected. These four options were refined and reformulated as the preferred alternatives. These alternatives represent a broad range of supply systems which combine a variety of water sources and vary the use of deep ground water.

This chapter summarizes the screening process, describes the final four alternatives, and presents the cost and constraints associated with each. It should be kept in mind that these alternatives were formulated for the area and time frame selected for this study. The potential remains for joint development with other adjacent entities.

6.2 SCREENING OF WATER DEVELOPMENT OPTIONS

The purpose of this section is to present a number of combinations of water supplies and facilities that could be utilized in a Cherry Creek Basin water project to meet the 35,300 af of additional demand estimated to be required by year 2010. Nine water development options, which span a wide range of development possibilities, were conceptually formulated. Table 6.1 summarizes the type and quantity of the water supply sources used in Water Development Options A through I.

For each option, the primary goal was to select a variety of compatible supply sources capable of meeting the annual water demand. Options A through D were selected to emphasize the use of the nontributary ground water source, while Options G through I were selected to rely heavily on the imported surface supply sources. Some of the options relying on imported supplies include both surface and subsurface storage within the Cherry Creek Basin.

The water development options use a wide variety of supply sources to satisfy future water needs. A brief description of each option follows:

- Option A - High Nontributary Ground Water

The objective of this water development option is to maximize the use of nontributary ground-water supplies and water reuse to meet year 2010 water demands. The massive aquifers which form the Denver Basin can adequately supply the 27,300 af necessary for this water development option. Water reuse was estimated to supply the remaining 8000 af annually.

The water reuse system would reduce the amount of nontributary ground water withdrawn so that aquifer life could be slightly extended. Some water purveyors in the area already have components of water reuse systems, and others are developing reuse plans. The reuse system comtemplated for this water development option consists of a nonpotable distribution system for irrigation of parks, green belts, and golf courses, and a flow augmentation plan which allows additional diversions of tributary water supplies. About 2000 af will irrigate open space, and 6000 af will augment Cherry Creek flows to allow an equal volume of pumpage from the tributary aquifers.

- Option B - High Local Supplies with Nontributary Ground Water

Local surface and ground-water supplies are emphasized in this water development option. Nontributary ground water, Cherry Creek surface water, tributary ground water, and water reuse are the sources of water used to meet the basin's future water needs.

TABLE 6.1

Summary of Water Sources for Initial Screening of Nine Water Development Options
(Supply in average acre-feet per year)

Water Source	Option A: High Nontributary Ground Water	Option B: High Local Supplies with Nontributary Ground Water	Option C: High Local Supplies with Flood Control and Nontributary Ground Water	Option D: Excess Treated Supplies with Nontributary Ground Water	Option E: Balanced Arkansas River Importation and Nontributary Ground Water	Option F: Balanced South Platte River Importation and Nontributary Ground Water	Option G: High Arkansas River Importation	Option H: High South Platte Importation	Option I: Exclusive Use of South Platte Conditional Rights
Cherry Creek Native Flow	0	3,000	5,000	0	0	0	0	0	0
Local Tributary Ground Water Purchases	0	800	800	800	800	800	0	0	0
Upper South Platte Treated Excess	0	0	0	6,000	0	0	0	0	0
Lower South Platte River Basin Import	0	0	0	0	0	13,000	0	26,300	35,300
Lower Arkansas River Basin Import	0	0	0	0	14,000	0	27,300	0	0
Agricultural Dry Year Leases	0	0	0	0	0	1,000	0	1,000	0
Deep Nontributary Ground Water	27,300	23,500	21,500	20,500	12,500	12,500	0	0	0
Reuse of Imports and Nontributary Ground Water	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	0
Total	35,300	35,300	35,300	35,300	35,300	35,300	35,300	35,300	35,300

Nontributary ground water couldsupply the bulk of the project demands, about 23,500 acre-feet annually. Castlewood Reservoir, located in the upper Cherry Creek Basin, could develop about 3000 af of new surface water supplies using 27,000 af of storage, and purchases of tributary ground-water rights could add another 800 af of yield. The water reuse plan produces 8000 af by flow augmentation and urban irrigation of parks, golf courses, and green belts.

o Option C - High Local Supplies with Flood Control and Nontributary Ground Water

This water development option uses Cherry Creek Lake for conservation storage and surface water regulation, instead of a reservoir upstream. Castlewood Reservoir is still needed on upper Cherry Creek to provide flood control storage in exchange for conservation space at Cherry Creek Lake. Local surface and ground-water supplies are emphasized by developing 21,500 af of nontributary ground water, 5000 af of Cherry Creek surface water, 800 af of tributary ground water, and 8000 af from water reuse.

o Option D - Excess Treated Supplies with Nontributary Ground Water

The emphasis in formulating this water development option is on using treated water supplied by the Denver Water Department (DWD), when it's available, pumping nontributary and tributary ground water, and reusing reclaimed waste water. No surface storage reservoirs are needed for this development option.

Treated water was assumed available 30 percent of the time during the winter months. The average annual yield expected from this source would be 6000 af. Treated water would first be used to meet project demands, then to recharge the nontributary aquifers.

Nontributary ground water supplies would yield 20,500 af annually, and the return flows from reclaimed waste water would provide an additional 6000 af by flow augmentation and 2000 af by nonpotable reuse for urban irrigation. Senior tributary ground-water rights would be purchased to provide 800 af annually.

o Option E - Balanced Arkansas River Importation and Nontributary Ground Water

This option utilizes 14,000 af of surface water supplies imported from the Arkansas River in conjunction with 12,500 af of deep ground- water withdrawals. The objective of this option is to approximately balance the long-term volume supplied from the two sources and to maximize water reuse. The plan also includes deep ground-water injection of imported water supplies during periods when the supplies exceed demands. Water reuse and tributary ground water withdrawals would provide 8000 and 800 af of annual yield, respectively.

o Option F - Balanced South Platte River Importation and Nontributary Ground Water

Option F is very similar to Option E, except that the water supply is obtained from the Lower South Platte River Basin instead of the Arkansas River. The yield from imported water supplies would be approximately 14,000 af, of which 1000 af result from leasing agricultural water during dry years. The remaining supply components are the same as Option E.

o Option G - High Arkansas River Importation

The objective of this option is to present a plan that does not make use of any new nontributary ground-water supply. The plan utilizes the estimated maximum reuse component of 8000 af. The remaining 27,300 af of supply would be imported by pipeline to the headwaters of Cherry Creek and collected in the Bridge Canyon Reservoir. When supplies exceed demands, imported water would be treated and injected into the deep aquifers for later recovery.

o Option H - High South Platte Importation

This option makes maximum use of water rights purchased from existing South Platte Basin agricultural users. The plan is similar to Option F, except that no Cherry Creek Basin deep ground water or alluvial ground water would be used, and the additional water supply would be provided by larger South Platte importations. A yield of 27,300 af could be expected from the importation supply component of this plan.

o Option I - Exclusive Use of South Platte Conditional Rights

Option I portrays a water supply system which relies completely on importing water from the South Platte River. The entire 35,300 af would be supplied from Narrows Reservoir after acquiring a portion of the conditional storage rights. A pumping plant and pipeline would convey the water to the Cherry Creek Basin. This development option is the only one which does not reuse reclaimed waste water.

All of the water development plans require surface storage, except Option A, which is wholly dependent on deep ground water, and Option D, which uses only deep ground water and available excess treated water supplies already developed by other entities. Options that depend on imported sources from the South Platte or Arkansas River Basins include storage near or at the points of diversion. In addition, a terminal storage component is needed near the Cherry Creek service area to allow for emergency delivery, in case the pumping plants or pipelines delivering the imported supply are damaged.

The remainder of this section of the report consists of a discussion of the key differences between the options, the potential constraints for implementation, and any major advantage or disadvantage of each water development option. This summary will assist in selecting the final study water development alternative plans. Table 6.2 presents a summary of facilities and costs for each water development option.

The project purpose differs among the water development options. Options A and D are single-purpose projects only serving municipal users. The remaining options provide recreational opportunities and fish and wildlife enhancement. Options C and I provide flood protection. These other benefits may become important factors in encouraging the regional growth and development needed to finance a water project.

The most commonly used comparison of water development plans is the cost. Table 6.2 lists the capital cost, annual cost, and annual unit cost of water for each option. For the initial screening of water development options, the costs associated with financing, debt service reserves, engineering, permitting, contract administration, and contingencies were not included. Therefore, the total capital costs presented for the water development

TABLE 6.2

Summary of Facilities and Costs for Initial Screening of Nine Water Development Options

	Option								
	A	B	C	D	E	F	G	H	I
Facilities	High Nontributary Ground Water	High Local Supplies with Nontributary Ground Water	High Local Supplies with Flood Control and Nontributary Ground Water	Excess Treated Supplies with Nontributary Ground Water	Balanced Arkansas River Importation and Nontributary Ground Water	Balanced South Platte River Importation and Nontributary Ground Water	High Arkansas River Importation	High South Platte Importation	Exclusive Use of South Platte Conditional Rights
Tributary Wells No.	8	9	9	9	9	9	8	8	0
Nontributary Wells No.	70	60	55	67	40	40	50	50	0
Injection System	No	No	No	Yes	Yes	Yes	Yes	Yes	No
Reuse System	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Pipeline Length/ Capacity	None	None	11 miles 14 cfs	12 miles 56 cfs	121 miles 33 cfs	98 miles 33 cfs	121 miles 53 cfs	98 miles 53 cfs	110 miles 94 cfs
Pumping Stations No. and Total Lift	None	None	1	1	6 lifts 7350 feet	4 lifts 4820 feet	6 lifts 6390 feet	4 lifts 4040 feet	5 lifts 3200 feet
Storage Near Imported Source	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Storage in Cherry Creek Basin (AF)	None	27,000	102,000	None	7,500	7,500	7,500	7,500	7,500
Capital Cost (million $)	47.5	68.2	66.5	58.2	196.0	150.9	294.8	203.0	562.3
Annual Cost (million $)	6.1	7.8	7.6	7.3	34.9	24.9	55.6	36.5	77.8
Unit Cost of Water ($/acre-foot)	170	220	210	210	990	710	1,580	1,030	2,200

options are not directly comparable to those of the final study alternatives, which are discussed in more detail later in this report.

The cost comparisons of Option A through Option I indicate one fairly obvious conclusion: the more surface water supply that is employed in the plan, the higher the unit cost of water. From a strict, short-term economic standpoint, Options A through D, with the dominant use of nontributary ground water, are the least expensive. Over a long time frame (100 years or more), new surface water supplies could become so scarce that the only available supply might be from conversion of remote agricultural water rights to municipal use or interbasin water transfers. The short-term least cost alternative could therefore become the most expensive in the long term. That general comparison becomes the central issue of the water resources planning for the Cherry Creek Basin. The question becomes, how dependent should the area become on less costly non-renewable ground-water supplies, as opposed to more expensive, renewable surface water sources.

One of the potential physical features of five of the nine plans is deep ground water injection. The primary function of a ground-water injection component is to allow the underground aquifer to be used for storage. This can only be accomplished if there is excess water from an external surface water source available. Options G and H include injection systems and do not deplete the nontributary ground water.

Option I, with the high unit cost of water and initial capital cost, appears to be the least suitable for Cherry Creek Basin users who do not have a large enough existing population for the tax base, or bonding capacity to initiate such a large project. The project would become more reasonable with joint development.

Options, A, C, E, and F were selected to be refined for further study. The estimated costs, reliability of the water supplies, potential for project participation by other entities, and the extent of nontributary aquifer use were the primary criteria for selection. Although potential constraints were examined for each option, no single constraint, in and of itself, eliminated any of the options. These plans were chosen to represent a broad variety of possible solutions to the water problems in the basin.

6.3 DESCRIPTIONS AND CHARACTERISTICS OF SELECTED ALTERNATIVES

The water development options selected in the initial screening activities were reformulated and refined during the remainder of the plan formulation process. The four alternatives developed for additional analysis are:

- o Alternative 1 - High Ground-Water Use
- o Alternative 2 - Maximum Local Surface Supply
- o Alternative 3 - Arkansas Importation
- o Alternative 4 - South Platte Importation

Most of the basic water supply components and physical features remain the same as in the initial screening; however, water reuse can conserve more water for meeting project demands than originally estimated. This conservation reduces the volumes needed from imported water sources and ground water. Table 6.3 summarizes the water sources and amounts for the four alternatives. The remainder of this section will describe and characterize the components of each alternative, as well as present information about project costs and potential development constraints.

TABLE 6.3

Water Sources for the Water Development Alternatives

	Annual Supply (af)			
Source	Alternative No. 1	Alternative No. 2	Alternative No. 3	Alternative No. 4
Nontributary Ground Water	21,400	9,700	8,500	8,500
Tributary Ground Water	-	800	800	800
Cherry Creek above Castlewood Dam	-	3,500	-	-
Cherry Creek above Cherry Creek Lake	-	8,700	-	-
Imported from Arkansas River	-	-	12,000	-
Imported from South Platte River	-	-	-	12,000
Subtotal	21,400	22,700	21,300	21,300
Reuse	13,900	12,600	14,000	14,000
Total Supply	35,300	35,300	35,300	35,300

Table 6.4 lists the total investment cost estimates and the components that make up that cost. The "subtotal construction cost" is the first summarized component which represents the best estimate of actual construction cost, including costs for rights of way, access roads, and relocations. Other cost components are then added, as noted in the summary.

Table 6.5 utilizes the total investment cost on an annualized basis in combination with other annual cost estimates to arrive at a total annual cost for each alternative. This total annual cost, dividied by 35,300 af of yield for each alternative results in the estimated unit cost of yield for each alternative.

6.3.1 Alternative I - High Ground-Water Use

The primary water source for this alternative is the nontributary ground water. Implementation of this plan would require formation of a regional water supply entity, such as a water conservancy district. The residential, commercial, industrial, and public lands within the district would need to subordinate their nontributary ground-water use rights to the district. Each entity would be compensated for water supplies brought into the regional district. This would allow more efficient well spacing, and make it possible for water conveyance and distribution within District boundaries to serve the more densely populated areas. Well fields could be designed to minimize and uniformly distribute drawdowns of the piezometric surface in the aquifers.

The primary raw water supply component for this alternative consists of 54 nontributary wells, each about 1,600 ft deep, located throughout the project service area. The lift required will vary from 750 to 1250 ft, with an average of about 1000 ft. An additional 80 to 90 psi would be needed to pressurize the distribution system. The wells would have an average capacity of 500 gpm each. Figure 6.1 conceptually illustrates the major project features.

A secondary, but more expensive component of this alternative, is the water reuse system. Two percent of the pumped nontributary ground water must, by present law, be returned to the stream system. The remainder can be reused if it can be controlled. By reclaiming waste water, the nontributary ground water could be reused until fully consumed.

TABLE 6.4

Summary of Total Investment Cost
Water Development Alternatives
(Cost in $1,000)

Item	Alternative No. 1	Alternative No. 2	Alternative No. 3	Alternative No. 4
Subtotal Construction Cost	$ 23,914	$ 28,082	$ 144,733	$ 47,441
Contingencies	4,783	5,529	23,243	8,992
Direct Construction Cost	28,697	33,611	167,976	56,433
Engineering, Legal, Permitting, and Administration	3,876	4,443	17,338	8,617
Total Construction Cost	32,573	38,054	185,314	65,050
Interest During Construction	0	1,131	11,717	2,944
Total Capital Cost	32,573	39,185	197,031	67,904
Debt Service Fund	0	1,281	8,202	2,466
Financing Expenses	0	376	1,769	886
Total Investment Cost	32,573	40,822	207,002	71,346

TABLE 6.5

Summary of Annual Cost
Water Development Alternatives
(Cost in $1,000)

Item	Alternative No. 1	Alternative No. 2	Alternative No. 3	Alternative No. 4
Annualized Investment Cost	$ 2,731	$ 3,424	$ 17,359	$ 5,950
Operation, Maintenance, and Replacement	573	525	1,890	1,327
Power Cost	2,154	1,697	5,535	3,495
Water Treatment Costs	10,214	11,902	19,110	15,687
Total Annual Cost	15,672	17,548	43,894	26,459
Unit Cost of Firm Yield $/af per year(1)	444	497	1,243	750

(1) Cost includes full water treatment and tertiary waste water treatment because these are components of the water reuse component of each alternative. Chlorination and secondary waste water treatment would be required for any water system and represents a unit cost of approximately $130 per af of new yield.

Increasing phosphorus concentrations in Cherry Creek Lake are forcing more stringent waste water treatment requirements to allow expansion of the population and industrial base in the area. By using advanced water treatment procedures, reclaimed waste water return flows could be used to augment the tributary stream system, and recovered at downstream locations for use in the potable water supply system. In this alternative, the plan is to inject treated waste water into the alluvial Cherry Creek aquifer between Franktown and Cherry Creek Lake. One-to-three large advanced waste water treatment plants would be required with a total capacity of approximately 12 mgd. A total of 90 recharge wells would be needed to inject return flows into the alluvial aquifer, and eighteen 1000 gpm recovery wells would be employed to return the water to the supply system. Recharge ponds may be substituted for some of the recharge wells.

Using the estimated pumping heads, the total energy consumed on an annual basis would be about 37 million kWh for pumping from both the confined and alluvial aquifers. When the pressure on the nontributary aquifers is lost and unconfined conditions prevail, this energy requirement would increase dramatically.

With the exception of the large waste water treatment plants, the features of this alternative can be constructed to provide water supply capacity that very closely matches the water demand build-up. Steadily replenished sinking funds supplied from water revenues, tap fees, or property taxes, could allow this alternative to be implemented without issuing bonds or borrowing state funds.

The operational characteristics of this alternative are relatively simple. Supplies withdrawn from the nontributary ground-water aquifers will be used and reused continuously, in a pattern that closely resembles the monthly demand curve. This type of system could easily be integrated with existing water supply systems in the basin.

Currently, the nontributary ground-water aquifers supply the vast majority of the water needed in the basin. To continue this trend would require additional development of 21,400 af for meeting year 2010 demands. Water reuse would contribute 13,900 af, if an overall reuse efficiency of 65 percent of the quantity of ground water pumped were attained. To reach a reuse efficiency of 65 percent, municipal return flows were estimated as 50 percent of the supply, and an 80 percent efficiency was assumed to account for operational losses. Under present state laws, pumping could continue at this rate for about 130 years before the volume pumped would equal the 100-year legal entitlement.

This alternative is very economical because financing costs are small, and excess system capacity is minimized. Table 6.6 presents a summary of the annual costs for this alternative. The annual cost includes amortization of total investment costs plus operation, maintenance, and replacement (OM&R), and power and treatment costs for both the waste water and water treatment. It was necessary to determine the cost of a delivered potable supply rather than a raw water supply because quality of the source water was highly variable between alternatives.

6.3.2 Alternative 2 - Maximum Local Surface Supply

Every available surface water source within the basin was used in formulating this alternative to avoid large ground-water withdrawals. The Maximum Local Surface Supply Alternative, illustrated in Figure 6.2, is the only formulated plan which includes multiple functions—municipal, flood control, and recreation. Although there is still a need to use the nontributary ground water, the annual withdrawal is considerably less than Alternative 1.

TABLE 6.6

Annual Cost Summary - Alternative 1
High Ground Water Use

Item	Annual Cost ($1,000)	Unit Cost of Yield ($/af/yr)[1]
Nontributary Well System and Pumping	$ 4,994	$ 233
Reuse System including Waste Water Treatment, Recharge, and Recovery	10,678	768
Total Annual Cost	15,672	

Unit Cost of Firm Yield is $444/af/yr.

(1) Unit cost includes cost of full water supply treatment and of tertiary waste water treatment. Chlorination and secondary waste water treatment would be required for any water system and represents a unit cost of approximately $130 per af of new yield.

A key element of this alternative is a dam and reservoir for storing and regulating Cherry Creek streamflow. Two reservoirs have been integrated into the plan: 1) A new dam and reservoir in Castlewood Canyon; and 2) The existing Cherry Creek Lake.

Due to the U.S. Army Corps of Engineers' (COE) need to increase the flood handling capability of Cherry Creek Lake, there is a possibility of a COE flood control dam being proposed at the Castlewood Dam site. This alternative uses the Castlewood Dam site for a 102,000 af joint use dam and reservoir. Cherry Creek Basin water users have been allocated 7000 af of active storage, with 91,000 af allocated to flood control. A pool of 4000 af would be allocated for recreation and sediment storage.

With the additional basin flood control capability at a large Castlewood Dam, some space could be made available at Cherry Creek Lake for use as water supply storage. This existing reservoir is located at the downstream end of the Cherry Creek Basin service area, where it could control and collect treated waste water return flows which would be part of the water reuse system. In addition, the runoff characteristics of the land area upstream will change significantly in the future; urbanization will increase runoff into Cherry Creek and into the reservoir. With an active storage capacity of only 2500 af in Cherry Creek Lake, a very efficient operation could be implemented by pumping the collected water back to the service area. The storage sizing criteria was based on achieving minimal impact on existing recreation facilities. Table 6.7 shows the storage-yield relationship for Cherry Creek Lake operations. Using 2500 af of additional storage at Cherry Creek Lake increases the normal water surface by less than 3 ft. This alternative, therefore, employs a pumping station and pipeline capable of conveying up to 50 cfs when the supply is available.

As more and more urban development occurs, there will be a reduction in agriculture within the valley. This alternative assumes that 800 af of senior water rights could be purchased and converted to municipal use. One alluvial well could bring this water into the distribution system.

Nontributary ground-water wells would still be needed for some base supply and for peaking. In this alternative 24 500-gpm deep aquifer wells are employed. Reuse of this water would require advanced waste water treatment facilities, along with recharge and collection systems in the alluvial aquifer along Cherry Creek.

TABLE 6.7

Cherry Creek Lake Storage-Yield Relationship

Reservoir Storage (af)	Average Yield(1) (af)
1,000	8,100
2,500	8,700
5,000	9,500
10,000	10,700

(1) Average yield without storage in Cherry Creek Lake is approximately 7,600 af/yr.

The annual energy requirement for operation of facilities in this plan would be approximately 28 million kWh. This is the least amount of energy required for the four alternatives evaluated.

Reservoir operation studies conducted for this alternative resulted in an estimated average annual yield of 3500 af from Castlewood Reservoir and 8700 af from Cherry Creek Lake. Nontributary ground water and tributary alluvial ground water would each supply 9700 and 800 af, respectively. An additional 12,600 af would be obtained from a flow augmentation plan for reclaiming waste water through reuse.

The net annual evaporation from Cherry Creek Lake and Castlewood Reservoir average about 1800 and 400 af, respectively. Almost all of the evaporation from Cherry Creek Lake occurs as a result of current operations. Using both of these reservoirs as portrayed in Alternative 2 would only deplete streamflows by an additional 400 af due to evaporation.

The nontributary aquifers would provide the long-term carryover storage necessary to satisfy municipal water requirements during prolonged dry periods, as well as contribute to summer supplies. For this alternative, the useful life of the Denver Basin aquifers has been estimated as 210 years.

Recreational opportunities would be enhanced throughout the basin if this alternative is implemented. The operating level of the existing Cherry Creek Lake would increase a maximum of about 2.7 feet, which would enlarge the surface area by about 90 acres. At

Castlewood Reservoir, water levels would fluctuate between elevation 6446 and 6472, and the surface area between 190 and 350 acres. During prolonged droughts when inflows are very low, evaporation could reduce the water level to elevation 6440 with a surface area of only about 160 acres. If additional studies are conducted on this alternative, operating schemes may be developed which minimize these fluctuations, or a larger minimum storage level could be selected.

Even though this alternative portrays Castlewood Reservoir as the upstream storage site on Cherry Creek, the potential exists for using the Bridge Canyon site instead. The project costs and operating characteristics for a reservoir at Bridge Canyon are almost identical to the Castlewood site. If the COE decides to modify Cherry Creek Dam to accommodate the PMF without upstream storage, the Bridge Canyon Dam would be substituted for Castlewood, because the smaller reservoir could provide the necessary conservation storage more economically.

Table 6.8 presents a summary of the annual costs of the various components of this alternative. This alternative is nearly as economical as Alternative 1.

TABLE 6.8

Annual Cost Summary - Alternative 2
Maximum Local Surface Supply

Item	Annual Cost ($1,000)	Unit Cost of Yield ($/af/yr)(1)
Nontributary Ground Water - Wells and Pumping	$ 2,232	$ 230
Tributary Ground Water - Wells, Water Rights, and Pumping	360	450
Reuse System - Treatment, Recharge, Recovery	9,080	721
Castlewood Dam Active Storage	553	158
Cherry Creek Lake Storage(2)	5,323	612
Total Annual Cost	17,548	

Unit Cost of Firm Yield is $497/af/yr.

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(1) Unit cost includes cost of full water supply treatment and of tertiary waste water treatment. Chlorination and secondary waste water treatment would be required for any water system and represents a unit cost of approximately $130 per af of new yield.

(2) Includes some recovery and pumping of reuse water.

6.3.3 Alternative 3 - Arkansas Importation

The Arkansas Importation Alternative could convey water from Horse Creek Reservoir, located north of Las Animas, to the headwaters of Cherry Creek. Project sponsors could purchase water rights from FORT-CO, a group of farm operators which controls 65 percent of the outstanding stock in the Fort Lyon Canal Company. In addition, alluvial and nontributary ground water in the Cherry Creek Basin would provide substantial quantities of water to help meet the total demand.

In recent years, the drop in agricultural commodity prices, coupled with high interest rates and higher farm operating costs, have made it very difficult for Colorado's irrigated farm operators to stay in business. During the past three years, the Cities of Colorado Springs and Aurora have purchased water rights used for irrigation in the Arkansas Valley and have begun to transfer them to municipal use. Many of the irrigation companies in the Arkansas Valley, between Pueblo and John Martin Dam, have expressed a desire to sell portions of their water rights.

The Fort Lyon Canal Company is one of the largest diverters of water in the Arkansas River Basin within Colorado. The Fort Lyon system delivers irrigation water to approximately 93,000 acres in Otero, Bent, and Prowers Counties along the north side of the Arkansas River. Shareholders controlling approximately 54,000 acres have voted to sell their water and have formed a separate company, FORT-CO, to handle sale negotiations.

Colorado Interstate Gas Company (CIGO), located in Colorado Springs, has conducted confidential feasibility studies of the potential to purchase Arkansas River water and build a conveyance system to transport it into the South Platte drainage basin. CIGO already owns the right-of-way and can reduce operation and maintenance costs by following its gas pipeline routes. Less expensive fuel would also be available to power CIGO's multiple pumping plants. The plan developed by CIGO involves a water conveyance system capable of transporting about 50,000 af/yr. The economies of scale, achieved by having additional project participants, would reduce the cost of this alternative considerably. At the time of this report, no cost estimates of the CIGO plan had been made public.

Although there are other water rights available for sale in the Arkansas Valley, Alternative 3 portrays importation of water from the Fort Lyon canal system. This alternative, shown on Figure 6.3, would only utilize 12,000 af of the 92,000 af of consumptive use estimated to be transferable to municipal use outside the basin. Storage in Horse Creek Reservoir, located northeast of the City of Las Animas, would be used to regulate the supply.

The conveyance system would consist of a pump intake from Horse Creek Reservoir and a 157-mile pipeline to the upper portion of the Cherry Creek Basin service area. There would be six relift pumping stations along the way, with a discharge capacity of approximately 28 cfs. Based on reconnaissance designs, a 30-inch steel, mortar-lined, concrete-coated pipeline would be suitable for the pipeline.

Arkansas River water does not meet drinking standards due to high concentrations of total dissolved solids, sodium, sulfate, uranium, and total hardness. For this alternative, conventional water treatment would be performed near the intake. Once the supply reaches the basin, advanced treatment could be used to make this source suitable for injection into the deep aquifer. For direct comsumption, either advanced treatment or blending with better quality supplies would be necessary.

Additional facilities, similar to Alternative 2, include nontributary wells; tributary wells; and waste water treatment, recharge, and recovery systems. Alternative 3 also includes injection of imported supplies during the winter and spring months, when the supply exceeds the service area demand. Should there be a disruption in the pipeline or pumping system, the required deliveries could be made temporarily by means of the deep well pumps.

Operationally, reuse of reclaimed waste water and ground-water recharge reduce the need for more water and large storage reservoirs. The alternative includes a plan to inject imported water into the aquifers when the supply exceeds demands, so that a surface reservoir is not necessary. Arkansas River imports account for 12,000 af of project yield, of which 10,000 af would be delivered directly to the service area to satisfy basin needs in an average year, and 2000 af would be injected into the Denver Basin aquifers for later withdrawal.

Combination recharge and recovery wells would be used to inject imported water supplies into the nontributary aquifers and deliver it to basin users. Recharge would occur only when imported supplies exceed the basin demand. The operational goal is to evacuate Horse Creek Reservoir, in the Arkansas River Basin, as fast as possible to minimize reservoir spills. Most of the ground- water recharge is anticipated to happen in the winter and spring before all of the production wells are needed to satisfy peak summer demands.

The nontributary and alluvial ground-water aquifers add 9300 af to the project water supply. Deep ground water from the Denver Basin formations supplies 8500 af of this total, and the deep bedrock aquifers provide the carryover storage necessary to accommodate seasonal and annual variations in water requirements. At this rate of withdrawal, the 100-year entitlement to nontributary ground water for this alternative would not be exhausted for about 220 years.

The water reuse component of this water development alternative uses the alluvial aquifer for storage and recovery of 14,000 af of reclaimed waste water per year. Cherry Creek alluvial materials would be recharged by injection wells after advanced water treatment of the waste water. Spreading basins in the alluvium could serve as an alternative recharge method. A separate downstream well field would facilitate recovery of the water.

Large capital expenditures would be required to construct the importation system. Project financing would require a major bond issue, most likely with state support.

Table 6.9 presents a summary of the annual cost of the key components that make up Alternative 3.

6.3.4 Alternative 4 - South Platte Importation

Over the past two decades, there have been numerous water development projects proposed within the South Platte Basin. With a total drainage basin of over 23,000 square miles, the South Platte River is estimated to produce a long-term average of 1,800,000 af annually. This supply is augmented by return flows from transmountain diversions from west of the Continental Divide.

TABLE 6.9

Annual Cost Summary - Alternative 3
Arkansas Importation

Item	Annual Cost ($1,000)	Unit Cost of Yield ($/af/yr)(1)
Nontributary Ground Water - Wells, Pumping, Treatment(2)	$ 2,134	$ 251
Tributary Ground Water - Wells, Water Rights, Pumping, Treatment	360	450
Reuse System - Treatment, Recharge, Recovery	10,678	762
Importation from Arkansas Valley - Pipeline Pumping Plants, Power, Water Rights, Water Treatment	30,722	2,560
Total Annual Cost	43,894	

Unit Cost of Firm Yield is $1,243/af/yr.

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(1) Unit cost includes cost of full water supply treatment and of tertiary waste water treatment. Chlorination and secondary waste water treatment would be required for any water system and represents a unit cost of approximately $130 per af of new yield.

(2) Includes cost of injection wells for recharge and recovery pumping.

While streamflow at the state line has averaged approximately 350,000 af/yr, the annual and seasonal variation is extreme. In 1973 and 1983, the annual streamflow at the Julesburg gage, 3 miles upstream from the Nebraska state line, was 1,101,000 and 2,087,000 af, respectively. However, in dry years, such as 1955 and 1956, annual outflow was only 73,000 and 55,000 af, respectively.

Proposed projects to develop this resource have involved some large surface storage reservoirs, either on the main stem or on major tributaries of the South Platte. Potential projects within the basin, which contain storage reservoirs as key features, and their approximate location are: Two Forks Reservoir - Upper South Platte; Clear Creek Reservoir - Clear Creek; Coffintop Reservoir - St. Vrain; Grey Mountain and Glade Reservoirs - Cache la Poudre; Hardin Reservoir - Lower South Platte; and Narrows Reservoir - Lower South Platte. These projects include relatively large reservoirs capable of taking advantage of seasonal peak flows and providing multiple year carryover.

Depending on location and the water demand pattern, 5 to 7 units of reservoir active storage are required to produce 1 unit of firm annual yield.

There are a number of these projects that could supply water for the Cherry Creek Basin, but all individually produce a yield much larger than required for the importation component of this alternative. Cherry Creek users could participate jointly in some of the above-mentioned projects, but the high cost of storage coupled with the needed conveyance system would be prohibitively expensive.

Another type of storage system along the South Platte River that has been used for years is the alluvial aquifer. Conjunctive use systems and augmentation plans have been evaluated at a number of locations. The Beebe Draw Diversion and Augmentation Program (Hydrotriad, 1985) and the Badger-Beaver Creeks Recharge Program (USGS, 1980) were two proposed projects evaluated. Although either system could be intergrated into a Cherry Creek/South Platte importation plan, the Badger-Beaver Creeks system was selected, since it has no water right or active project sponsors.

The South Platte Importation Alternative brings water from the Lower South Platte River to the Cherry Creek Basin. During the non-irrigation season, diversions in irrigation off-seasons through the Bijou Canal, or by some other means, could supply water for direct pumping to the project service area, or water for recharge into the alluvial aquifer of Badger Creek. Water would be recharged when supplies exceed demands. The entire supply would receive conventional water treatment prior to conveyance to the service area.

The diversion and alluvial recharge/recovery facilities used in Alternative 4 are shown on Figure 6.4 and consist of constructing 15 miles of canal near the end of the Bijou Canal, building 22 recharge ponds, drilling 15 recovery wells, and constructing a pipe collection system from the wells to a small regulating reservoir. This reservoir would serve as the intake for the conveyance system to the Cherry Creek Basin. Prior to being pumped, the water would be fully treated to meet drinking water standards and be suitable for direct use or deep well injection. The pipeline would cross Interstate-70 between Bennett and Strasburg, and would have the potential of being enlarged to serve eastern sections of Aurora.

The pumping and pipeline system would traverse approximately 67 miles and require a total lift of 3,760 feet at peak flow, consisting of 1,500 feet of elevation change, and 2,260 feet of friction loss. Four pumping stations are planned to convey the flow of approximately 17 cfs through a 22-inch buried pipeline. Except for short maintenance downtime, the discharge would be constant and deliver about 33 af per day or 12,000 af annually.

During the winter months, this imported supply, along with local reuse water, would be more than adequate to meet the demands. Excess supplies would be injected for longer term storage in the deep ground-water aquifers. During dry periods, the water recharged would be recovered for delivery to the service area.

Additional water supplies would come from purchase of tributary ground-water rights in the Cherry Creek alluvial aquifer (800 af) and development of nontributary ground water in the Denver Basin (8,500 af). Reuse of reclaimed waste water also plays a major role in this alternative and is maximized to the greatest extent possible. About 14,000 af of waste water are reclaimed and reused annually.

During the winter, when deliveries from the Lower South Platte Basin exceed the project demands, the nontributary aquifers would be recharged beneath the Cherry Creek service area. Later in the summer, this water would be recovered and used to help meet peak monthly demands. By implementing this alternative, the 100-year entitlements to nontributary ground water would last for about 220 years.

The annualized costs for implementing Alternative 4 are summarized in Table 6.10. Water reuse components are similar to the other alternatives, and are used to conserve supplies and improve water use efficiencies. The annual energy requirement for this plan is about 77 million kWh.

6.4 POTENTIAL CONSTRAINTS

Potential project constraints were evaluated for each water development alternative. The constraints were grouped into the following general categories:

TABLE 6.10

Annual Cost Summary - Alternative 4
South Platte Importation

Component	Annual Cost ($1,000)	Unit Cost of Yield ($/af/yr)(1)
Nontributary Groundwater - Wells, Pumping, Treatment (2)	$ 2,134	$ 251
Tributary Groundwater - Wells, Water Rights, Pumping, Treatment	360	450
Reuse System - Treatment, Recharge, Recovery	10,678	762
Importation from South Platte - Diversion, Alluvial Storage, Pipeline, Pumping Plants, Power, Water Rights, Treatment	13,287	1,107
Total Annual Cost	26,459	

Unit Cost of Firm Yield is $750/af/yr.

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(1) Unit cost includes cost of full water supply treatment and of tertiary waste water treatment. Chlorination and secondary waste water treatment would be required for any water system and represents a unit cost of approximately $130 per af of new yield.

(2) Includes cost of injection wells for recharge and recovery pumping.

1. Physical/Technical
2. Legal/Institutional
3. Socioeconomic
4. Environmental

Table 6.11 lists the potential constraints which must be addressed as part of future project investigations. The severity of potential impacts have been assessed qualitatively, and possible problems were judged to have a high, medium, or low degree of severity. If no impact was anticipated, the potential constraint was evaluated as not applicable.

Potential Constraints for the Water Development Alternatives[1]

Constraints	Alternative 1 High Ground-Water Use	Alternative 2 Maximum Local Surface Supply	Alternative 3 Arkansas Importation	Alternative 4 South Platte Importation
Physical/Technical:				
Infiltration rates for recharge may decline with time. Extensive testing is needed.	L	L	H	H
Water quality of supplies is poor.	L	L	H	M
Future nontributary water level declines and limited ground-water supply.	H	M	M	M
Controlling Cherry Creek phosphorus levels will require extensive future waste water treatment.	H	H	H	H
Compatibility of injection water with aquifer materials and ground water may affect recharge activities.	L	L	H	M
Alluvial aquifer characteristics are needed.	M	M	M	M
Damsites must have adequate foundations.	NA	M	NA	NA
Future Cherry Creek streamflows need close examination.	NA	M	NA	NA
Construction materials must be fully tested.	NA	M	L	L
Legal/Institutional:				
Joint development of nontributary ground water may not be allowed.	M	L	L	L
Conversion of agricultural water rights to municipal use is needed; point of diversion must also be changed.	NA	L	M	L
Cherry Creek Lake recreation facilities need relocation.	NA	M	NA	NA
Cherry Creek Lake flood control space needs reallocation to conservation storage.	NA	M	NA	NA
Interstate compact litigation between Colorado and Kansas may impact water transfers.	NA	NA	L	NA
Dominion and control issues related to recharge water need resolution.	L	L	M	M
Water rights are needed for project implementation.	L	M	L	M
Federal, state, and local permits need to be obtained.	L	H	M	H
State will administer South Platte calls on Cherry Creek.	L	M	L	L
Socioeconomic:				
Local agricultural economies will decline with conversion of agricultural water rights to municipal use.	NA	L	H	L
Water reuse needs public acceptance.	H	H	H	H
Small water imports limit opportunities for economies of scale.	NA	NA	M	M
Land or easements are needed from many owners.	NA	L	H	H
Large up-front capital expenditures are required.	L	M	H	H
Future operating costs are dependent on energy prices.	M	L	H	H
Environmental:				
Potential adverse effect on threatened and endangered species.	NA	M	NA	H
Mitigation needed for local effects from construction of facilities.	L	H	L	M

(1) H - High degree of severity anticipated.
M - Medium degree of severity anticipated.
L - Low degree of severity anticipated.
NA - Not applicable to this alternative.

The relative merits of the water development alternatives cannot be judged from the constraints alone. Many other facts enter into the selection of the preferred development alternative including public acceptance, project benefits, financial plans, ease of implementation, construction schedules, and project costs. Although receiving equal treatment in this tabulation, some of the potential constraints listed on the table carry considerably more weight in the evaluation process than others. Based on the preliminary evaluations of this study, the potential constraints for each of the alternatives can be satisfactorily resolved prior to project implementation. The remainder of this chapter will highlight the constraints of greatest concern in implementing the water development alternative plans.

6.4.1 Physical/Technical

The physical and technical constraints involve the workability and reliability problems associated with implementing alternatives. The limitations of the water resources are considered, along with the possible engineering and operating problems associated with developing a functional plan. The potential problems of greatest concern include the limited extent of the ground-water resources, water quality, and state-of-the-art of artificial recharge technology.

The expected usable life of the deep ground-water aquifers depends to a large extent upon the future level of pumping in the Cherry Creek Basin. It also depends on aquifer development in surrounding areas. The extent of ground- water development in the project service area ultimately affects all of the existing and potential users which overlie the Denver Basin. Problems which may arise, such as contamination or higher pumping heads, are shared by all users of the nontributary aquifers. For these reasons, the estimated aquifer life is a major evaluation criteria for alternative comparisons. Good management practices would seem to indicate a preference toward a balanced water supply system, which emphasizes development of additional sources of supply. This would eliminate complete dependence on nontributary ground water, and would be the preferable future course of action.

The estimated life of the deep ground-water supplies ranges from 130 years for implementation of Alternative 1 to 220 years for Alternatives 3 and 4. None of the alternative water development plans completely eliminate reliance on nontributary ground water. However, plan elements could be combined in other ways to formulate additional plans which avoid expansion of the existing use of deep ground water, if that is desired by local water suppliers. The most reasonable and prudent approach would seem to use nontributary supplies in moderation and strive for a mix of water supply sources to minimize future risk.

Water quality is a large concern in the Cherry Creek Basin for two reasons. First, phosphorus concentrations have been increasing at Cherry Creek Lake, and a basinwide management group, the Cherry Creek Basin Authority, was established to specifically address the issue. Secondly, water supplies must meet municipal drinking water standards for potable use and must be suitable for ground-water injection.

Phosphorus loading is tightly controlled in the basin. Regulations have been established to control point and non-point sources of pollution. The impact of these regulations on future growth could be immense. When the projected population densities are realized, advanced waste water treatment will definitely be required. Without advanced treatment, population densities would be restricted to near present levels.

Water from the Arkansas River is of poor quality and requires conventional or advanced treatment, or blending with better quality water. South Platte River water needs conventional water treatment for potable use. Local surface supplies are generally of good quality and need minimal treatment. Nontributary and alluvial ground water is only chlorinated before distribution.

Good quality water is required for ground-water injection to avoid: (1) chemical incompatiblity with the aquifer materials and ground water; (2) biological growth; and (3) clogging of the well and aquifer with suspended sediments. These potential problems need to be avoided to maintain high injection rates and reduce operation and maintenance costs. Extensive field testing would be needed prior to final design of recharge facilities. Additional field research would be conducted during the staged construction of recharge facilities. Injection results would be closely monitored, and future additions to the recharge system adjusted based on actual performance.

6.4.2 Legal/Institutional

Obtaining permits for construction and changing the point of diversion and use of existing water rights would be the most time consuming constraints. Permitting issues associated with Alternatives 2 and 4 will be the most difficult to resolve because of expected depletions to the South Platte River where threatened and endangered species have been identified. Great strides have been made in the last two years toward establishing a method for resolving these disputes in the South Platte River Basin. Recent negotiations have led to the purchase and management of additional habitat in Nebraska, as a means of relieving jeopardy opinions imposed on South Platte projects by the U.S. Fish and Wildlife Service.

Definitive procedures have been established for facilitating water right transfers in Colorado's water courts. The process usually allows the historical consumptive use to be transferred out of basin; however, the procedure is time consuming. Alternative 3 requires water rights acquisitions, changes of use, and changes in the point of diversion. Many rights along the Arkansas River have already been purchased and converted from agriculture to municipal use. Costs associated with the legal process have been included in the contingencies of the project cost estimates.

6.4.3 Socioeconomic

Public acceptance of water reuse plans, project financing, future energy costs, and impacts on local economies from converting irrigated farmland to dryland conditions are the primary socioeconomic issues. These potential constraints involve all of the alternatives, but in varying degrees. Alternatives 3 and 4, which involve imported water supplies, are most affected.

Water reuse is an important operational element in every alternative. Waste water is proposed to be treated to potable standards, injected into the alluvial aquifer, and recovered downstream for municipal use. Direct consumption of reclaimed waste water is not envisioned; rather treated effluent would be exchanged for alluvial ground water. Many other types of reuse plans are currently being pursued within the basin, so the public is expected to accept this efficient and cost effective management technique in the future.

Alternatives 3 and 4, which import water supplies from other areas, involve substantial investments in facilities. The importation components of these plans increase system capacity substantially, but require large initial capital investments. Issuing bonds to finance these alternatives requires residents to begin repayment of principal and interest before full demand development, thereby reducing financial capacity for other infrastructure needs.

Energy requirements are largest for Alternatives 3 and 4. Appropriate costs have been reflected in the project cost estimates to allow comparisons among alternatives, but the future direction and magnitude of energy prices is highly speculative. Energy costs can most likely be expected to increase, but the magnitude depends largely on future world events rather than historic trends. The alternatives which pump imported water supplies into the Cherry Creek Basin are most dependent on energy costs, and would be impacted more than Alternatives 1 and 2.

The conversion of water rights from agricultural to municipal use impacts the local economy most in the Arkansas Importation Alternative. Water would be removed from the basin, and irrigated agriculture would be replaced with dryland farming or range land. Local merchants and agricultural product markets would be adversely affected. Some of the residents, who sold their water rights, would move to other areas. A positive aspect to this situation is that the proceeds from the water sales may prevent some individuals from losing their farms due to the current status of the agricultural economy.

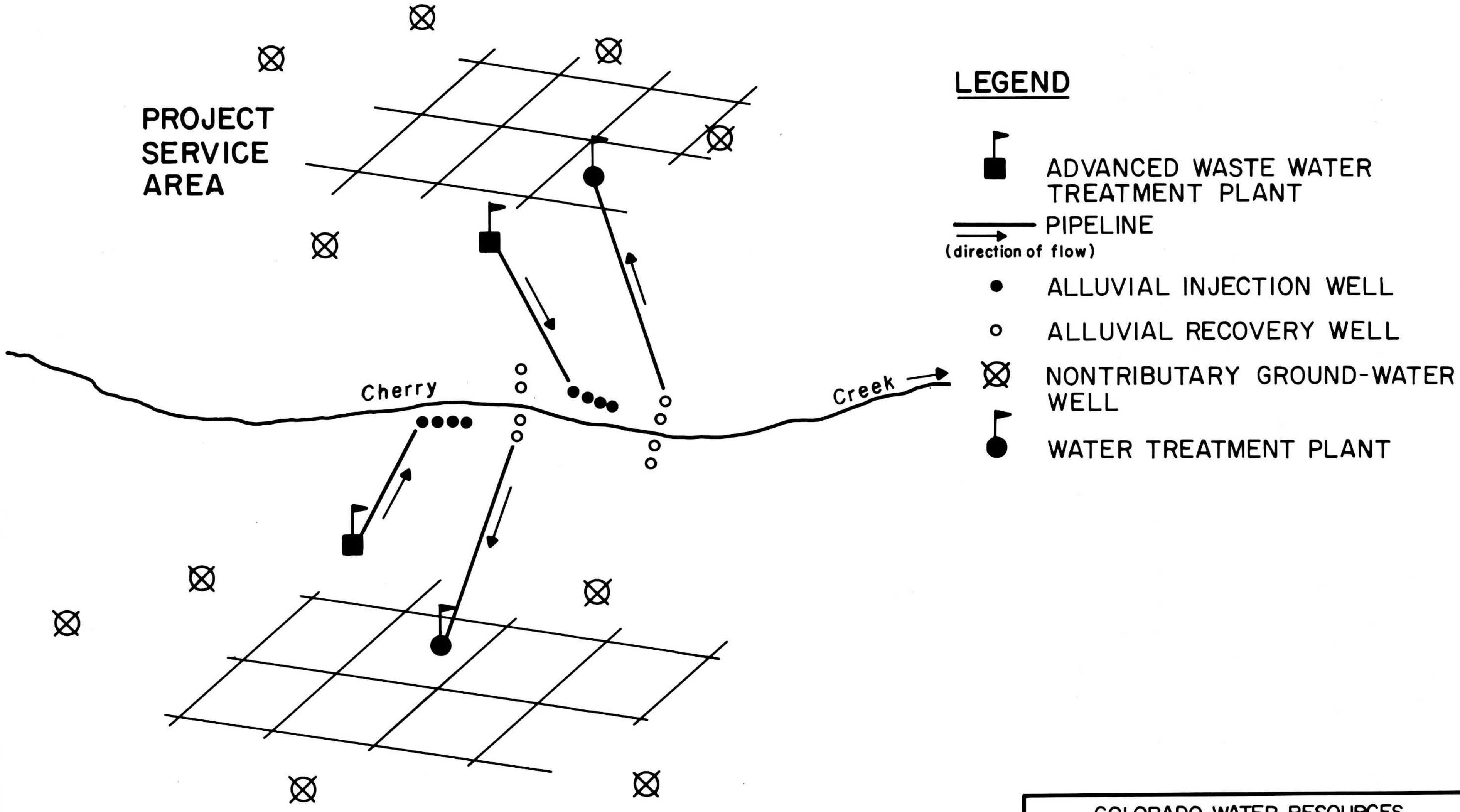
6.4.4 Environmental

Effects on threatened and endangered species are of particular concern for diversions from the South Platte River. Mitigation would be necessary to balance the environmental effects of constructing large reservoirs. These are the two major environmental constraints. Lesser environmental concerns would involve temporary disturbances during construction.

Any streamflow depletions to the South Platte River could potentially impact the threatened and endangered species which reside in Nebraska. Numerous biological opinions issued by the U.S. Fish and Wildlife Service have indicated that projects proposed for the Platte River may jeopardize the continued existence of one or more of the endangered species. The whooping crane, bald eagle, piping plover, and least tern are the species of greatest concern. Several Federal agencies, and the state agencies of Colorado, Wyoming, and Nebraska have attempted to develop a method for allocating costs of managing the habitat of particular importance to the survival of these species.

After two years of study, a procedure is beginning to develop. Even though impacts on endangered species are major concerns to Alternatives 2 and 4, a resolution of these issues is possible.

Construction of Castlewood Dam and Reservoir would eliminate terrestrial and riverine habitat in the reservoir area. Mitigation, in the form of additional land acquisition and habitat management, would most likely be necessary. This is not a major impediment to Alternative 2 because many additional benefits would accrue to the area, such as recreation, flood control, and fishery enhancement.

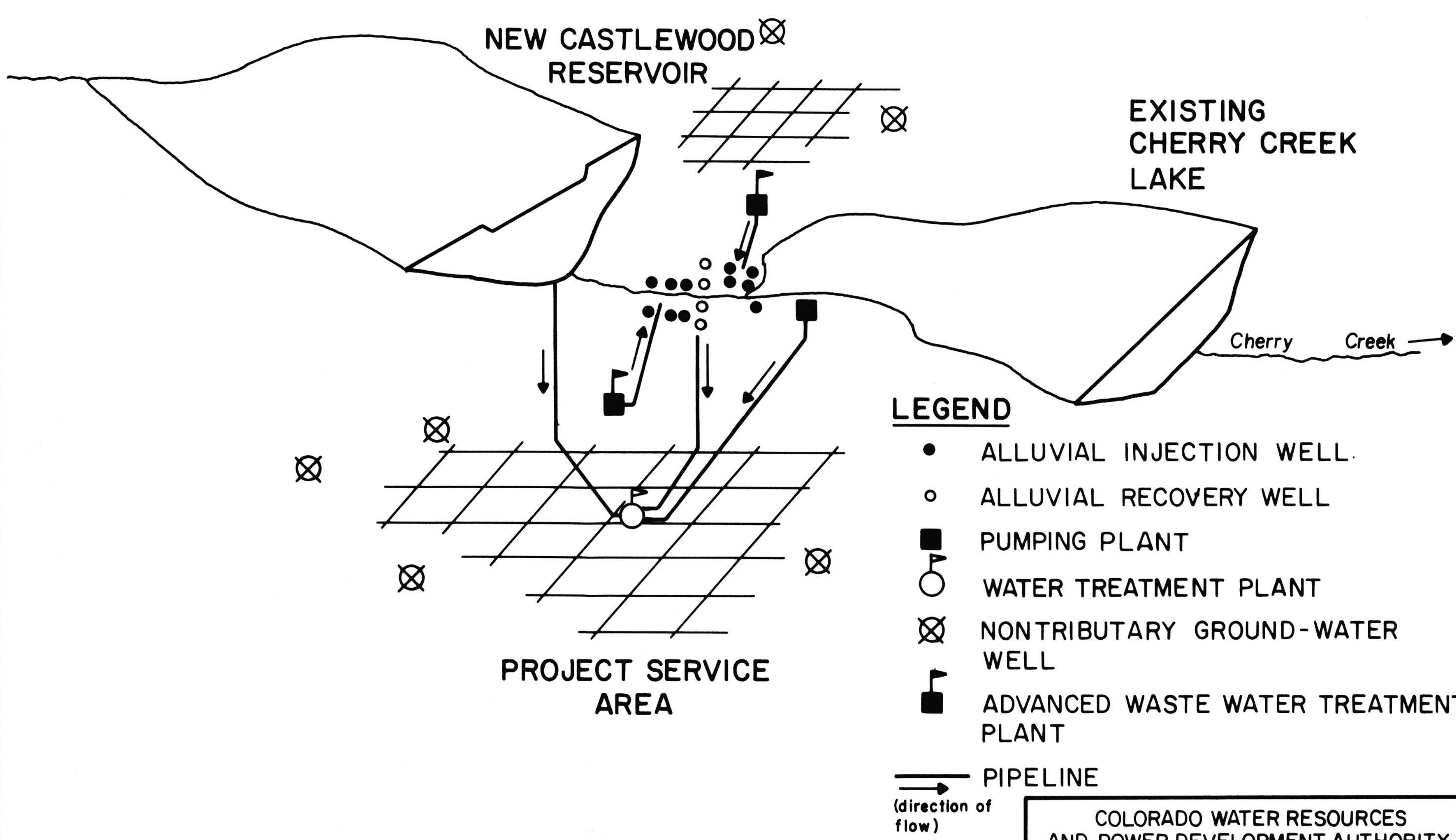


ALTERNATIVE I
HIGH GROUND-WATER USE
NOT TO SCALE

COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
CHERRY CREEK WATER
RESOURCES PROJECT

WATER DEVELOPMENT
ALTERNATIVE I-PLAN

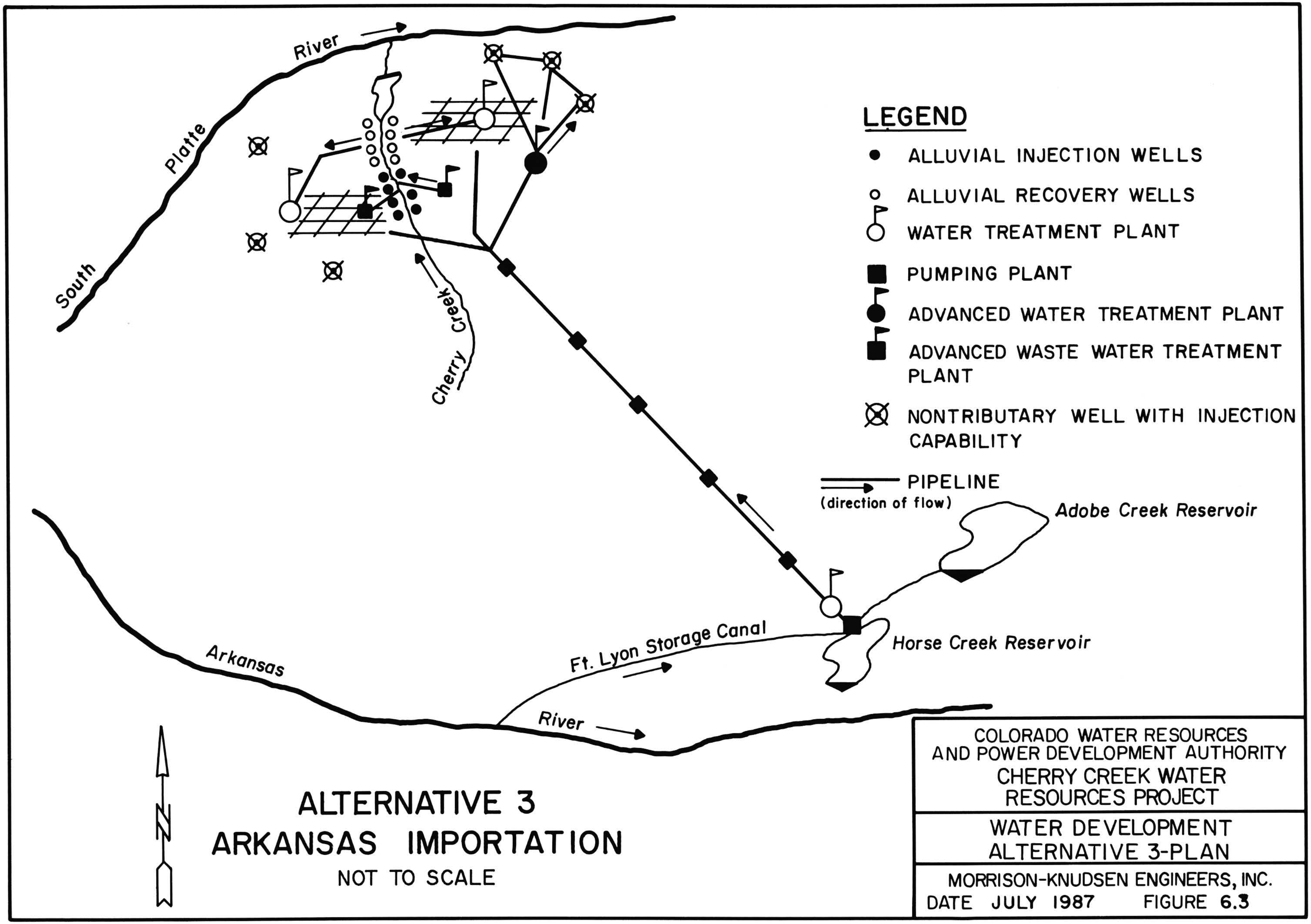
MORRISON-KNUDSEN ENGINEERS, INC.
DATE JULY 1987 FIGURE 6.1

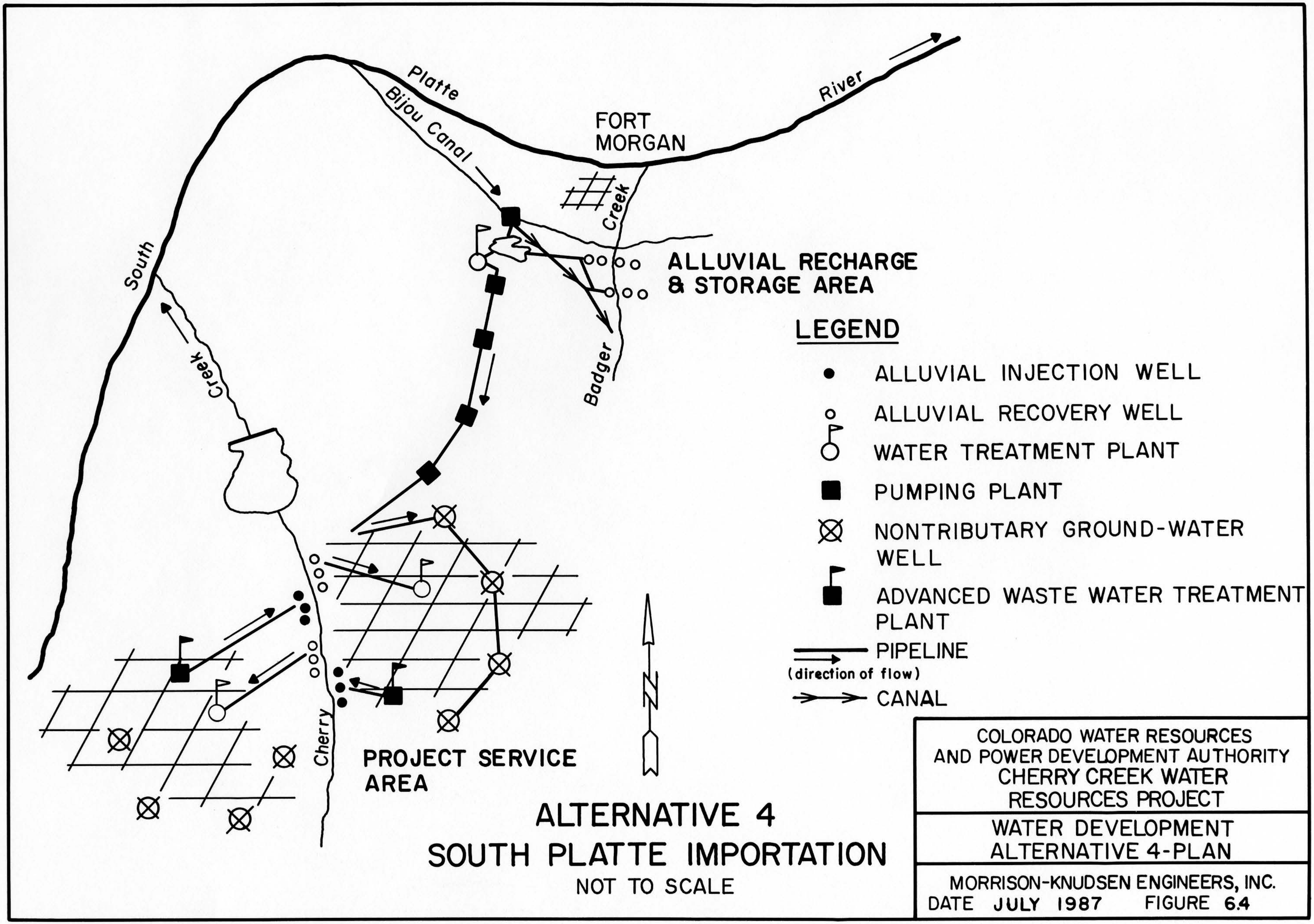


ALTERNATIVE 2
MAXIMUM LOCAL SURFACE SUPPLY

NOT TO SCALE

COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY CHERRY CREEK WATER RESOURCES PROJECT
WATER DEVELOPMENT ALTERNATIVE 2-PLAN
MORRISON-KNUDSEN ENGINEERS, INC. DATE JULY 1987 FIGURE 6.2


South Platte River
Cherry Creek
LEGEND
ALLUVIAL INJECTION WELLS
ALLUVIAL RECOVERY WELLS
WATER TREATMENT PLANT
PUMPING PLANT
ADVANCED WATER TREATMENT PLANT
ADVANCED WASTE WATER TREATMENT PLANT
NONTRIBUTARY WELL WITH INJECTION CAPABILITY
PIPELINE
(direction of flow)
Adobe Creek Reservoir
Horse Creek Reservoir
Ft. Lyon Storage Canal
Arkansas River
ALTERNATIVE 3
ARKANSAS IMPORTATION
NOT TO SCALE
COLORADO WATER RESOURCES
AND POWER DEVELOPMENT AUTHORITY
CHERRY CREEK WATER
RESOURCES PROJECT
WATER DEVELOPMENT
ALTERNATIVE 3-PLAN
MORRISON-KNUDSEN ENGINEERS, INC.
DATE JULY 1987 FIGURE 6.3



Platte
River
Bijou Canal
FORT MORGAN
Creek
Badger
South
Creek
Cherry
ALLUVIAL RECHARGE & STORAGE AREA
PROJECT SERVICE AREA
LEGEND
ALLUVIAL INJECTION WELL
ALLUVIAL RECOVERY WELL
WATER TREATMENT PLANT
PUMPING PLANT
NONTRIBUTARY GROUND-WATER WELL
ADVANCED WASTE WATER TREATMENT PLANT
PIPELINE (direction of flow)
CANAL
ALTERNATIVE 4
SOUTH PLATTE IMPORTATION
NOT TO SCALE
COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY
CHERRY CREEK WATER RESOURCES PROJECT
WATER DEVELOPMENT ALTERNATIVE 4-PLAN
MORRISON-KNUDSEN ENGINEERS, INC.
DATE JULY 1987 FIGURE 6.4

7.0 EVALUATION OF ALTERNATIVES

7.1 GENERAL

The previous chapters have presented a description of the facilities, water operations, costs, and constraints of the four water development alternatives. In this chapter, comparative evaluations are made of the alternatives, and conclusions presented in regard to significant factors that favor or limit implementation of each alternative. Since each alternative water development plan yields 35,300 af, the following comparisons will emphasize the costs and constraints involved in project implemention.

In the Cherry Creek Basin, the apparent water plan at the present time is to fully exploit the deep bedrock aquifers, which comprise the Denver Basin. This complicates the evaluation process because continued implemention of such action by numerous water purveyors could have severe long-term consequences. The nonrenewable nature of the nontributary ground-water resources limits future water availability, and necessitates replacement supplies sometime in the future. This overriding issue, of how long to make the deep ground-water supply last, makes straightforward single criteria comparisons of the alternatives extremely difficult.

In this study, the use of the nontributary aquifers has been limited to the maximum withdrawal rates allowed by present Colorado statutes. These rates could be either increased or decreased in the future if the state chooses to alter the nontributary ground-water allocation process. Additional regulations and restrictions could also be imposed by local governments. For example, in 1986 El Paso County proposed to require new land developments to guarantee a water supply for 300 years. The practical implications such a regulation has on developers is either to lower population densities, develop renewable surface water supples, increase reliance on imported supplies, or limit withdrawals from the deep ground-water aquifers to one-third the amount presently allowed by the state.

This study has not attempted to define all of the potential adverse situations that could arise with continued expansion of nontributary ground-water development. However, some of the conditions which may occur in the future include aquifer contamination, ground surface subsidence, and severe water level declines resulting from greater withdrawals by surrounding users. Some of these factors would decrease well yields, while others may render portions of the aquifers unusable.

These possible future scenarios are important because their occurrence is beyond the control of the Cherry Creek Basin users, yet each problem could lead to additional restrictions on ground-water pumping. Most of the large water users located within the boundaries of the Denver Basin aquifers, such as Denver and Aurora, have decided to limit reliance on the deep ground-water supplies for these reasons.

Examination of the cost estimates for each of the formulated alternatives leads to the conclusion that the larger the component of renewable water sources used in the plans, the more expensive the unit cost of yield. Conversely, those alternatives that utilize more of the renewable water sources automatically extend the period of time that the nontributary ground water will last. The relationship between cost and aquifer life is of central importance to this study, and will ultimately guide the recommendations of this final report. Even though recommendations are made in this study, the final decision on the direction of future water resources development in the Cherry Creek Basin resides with the concerned and affected local and state entities. Figure 7.1 utilizes the cost data and corresponding aquifer life of the study alternatives to project a broad relationship between the unit cost of firm yield and the Denver Basin aquifer life for the portion of the aquifer serving the project service area.

Several of the plan features and functions are common to all of the water development alternatives. Each plan uses nontributary ground water and water reuse systems to provide a firm municipal supply. The amount of deep ground- water withdrawals vary among the alternatives in inverse additive proportion to the quantity of local surface water or imported supplies used in the alternative. The water reuse components are about the same for each alternative.

Alternative 2 differs from the other alternatives with regard to project benefits. Construction of a large Castlewood Dam provides flood protection for the area between the dam and Cherry Creek Lake. It would also assist the COE in accommodating the probable maximum flood at Cherry Creek Dam. The recreation benefits associated with an upstream reservoir should broaden project support and promote additional residential and commercial development. This is one of the few features in the alternatives that presents distinct multi-purpose use capabilities.

7.2 PROJECT COSTS

Since each of the alternatives have been formulated to provide an identical new yield, both the total cost and the unit cost per af of yield can be compared directly. Table 7.1 presents a summary of the total annual cost and unit cost per acre-foot of yield for the four alternatives. The table also presents, for comparative purposes, a cost for providing 35,300 af entirely from pumping nontributary ground water. The unit cost per acre-foot for the entire ground-water supply condition was based upon the nontributary cost component of Alternative 1.

The water treatment required for improving the quality of supplies to meet potable standards, and reclaiming waste water for reuse, are significant cost elements in each of the alternatives. Care must be taken when comparing the unit cost of yield to other projects which only include raw water supplies at the project site. All of the alternatives also include advanced waste water treatment costs not normally included in raw water supply comparisons. Although there will be other waste water quality associated costs, a substantial portion of such costs is included in the cost summaries presented in this study.

TABLE 7.1

Cost Comparison of Cherry Creek Water Development Alternatives

Alternative	Total Investment Cost	Total Annual Cost	Unit Cost of Yield ($/af)
Base Condition - Entire Supply Nontributary Ground Water	$ 40,405,000	$ 8,238,000	$ 233
Alternative 1 High Ground-Water Use	32,573,000	15,672,000	444
Alternative 2 Maximum Local Surface Supply	40,822,000	17,548,000	497
Alternative 3 Arkansas Importation	207,002,000	43,894,000	1,243
Alternative 4 South Platte Importation	71,346,000	26,459,000	750

Another comparison is offered to put these unit costs of yield in perspective. The Two Forks Project on the South Platte River has been estimated to cost about $505 million and produce 98,000 af of new yield. The annualized cost of this project, with this study's criteria of 8 percent interest and a 40-year repayment, would be $42,400,000 per year, or $432 per acre-foot. Treatment cost for this supply is approximately $0.30 per 1000 gal (Weir, 1986), which is $100 per af. If the Cherry Creek Basin were to take the entire 35,300 af demand from this source, a pipeline of about 15 miles, with approximately a 100 cfs capacity, would be needed along with a pumping plant. These conveyance facilities are estimated to cost approximately $80 per af of yield. Therefore, the total cost of delivering treated water to the Cherry Creek service area from this project would be approximately $610 per acre-foot.

7.3 FINANCING

The cost of financing components of the various alternatives have been partially incorporated into the project cost estimates. The large capital cost of the pipeline and pumping plants associated with Alternatives 3 and 4 present situations where financing will be difficult. The construction of those types of facilities cannot be effectively staged, and the required financing could easily exceed the bonding capacity of a regional water development entity. State participation in the financing of such a project would be almost mandatory, yet might be difficult to justify on the basis of the present population base.

Alternative 1 would require the least assistance in financing, as the singular addition of wells represent small incremental capital expenditures that could probably be recovered in advance through water revenues and tap fees. The advanced waste water treatment plants needed for reuse plans, however, would require financing packages consisting of state or regional bonds, loans, or grants.

Alternative 2 would require financing for the reuse facilities, Castlewood Dam and Reservoir, and the Cherry Creek Lake pump-back facilities. All of these features are not required simultaneously, however, and staged construction would spread out the overall financing burden.

In the entire basin, the overriding financial problem is that current residents and businesses must pay for water projects to serve the needs of the year 2010 population and industrial base. Placing the financial burden on present users for a six-fold increase in population means that long-term financing, which defers repayment into the future, will be vital. Mill levys, water revenues, and tap fees would be necessary in the future to generate a stream of revenues sufficient to repay the long-term debts.

The total investment cost of a project is an indicator of how large a financial package would have to be arranged. The total investment cost is the sum of the construction cost subtotal; contingencies; engineering, legal, and administration costs; interest during construction; debt service reserve fund; and financing expenses. Table 7.2 presents these cost components for each of the alternatives, as well as the annual operating costs and the amortized total investment cost.

TABLE 7.2

Cost Component Summary of the Water Development Alternatives (Cost in $1,000)

Item	Alternative No. 1	Alternative No. 2	Alternative No. 3	Alternative No. 4
Subtotal Construction Cost	$ 23,914	$ 28,082	$ 144,733	$ 47,441
Contingencies	4,783	5,529	23,243	8,992
Direct Construction Cost	28,697	33,611	167,976	56,433
Engineering, Legal, Permitting, and Administration	3,876	4,443	17,338	8,617
Total Construction Cost	32,573	38,054	185,314	65,050
Interest During Construction	0	1,131	11,717	2,944
Total Capital Cost	32,573	39,185	197,031	67,904
Debt Service Fund	0	1,281	8,202	2,466
Financing Expenses	0	376	1,769	886
Total Investment Cost	32,573	40,822	207,002	71,346
Annualized Investment Cost	2,731	3,424	17,359	5,950
Operation, Maintenance, and Replacement	573	525	1,890	1,327
Power Cost	2,154	1,697	5,535	3,495
Water Treatment Costs	10,214	11,902	19,110	15,687
Total Annual Cost	15,672	17,548	43,894	26,459
Unit Cost $/af	444	497	1,243	750

7.4 CONSTRAINTS

The major project constraints to each alternative are highlighted in Appendix D. Table 6.7 summarizes the potential constraints for each of the water development alternatives and evaluates the degree of severity with regard to project implementation. The following discussion will compare the potential constraints among alternatives.

Alternative 1, which emphasizes the use of deep ground-water supplies, has the least number of implementation constraints among the alternatives. The problems of greatest concern involve the rate of nontributary ground-water depletion, public acceptance of the water reuse system, and controlling phosphorus concentrations in Cherry Creek. The last two concerns are of critical importance in all of the alternatives. The extent of ground-water withdrawal in Alternative 1 is greater than the other plans, and results in an estimated useful aquifer life of 130 years.

By adding local surface water supplies to the ground-water supply component, Alternative 2 would reduce ground-water withdrawals. However, while lessening the impacts on the ground-water aquifers, the construction of Castlewood Dam increases the problems associated with obtaining permits and mitigating environmental effects, resulting from inundating aquatic and terrestial habitats in the reservoir area. The permit and mitigation issues are typical of any dam and reservoir project, and are not viewed as major impediments to project development.

The Arkansas Importation Alternative has many potential technical and socioeconomic constraints. Agricultural economies in the Arkansas Valley would gradually decline from conversion of agricultural water rights to municipal use, and exportation of the water. Changes in the type of use and point of diversion would require an approval by the state through its judicial process. The water court proceedings are time-consuming, but could be conducted the same time as final design and not result in project delays. The technical concerns about the plan center on the poor water quality of the supply. Advanced water treatment is necessary for ground-water injection and for direct use in the potable distribution system. Injection rates could be reduced, and aquifer contamination problems could occur as a result of using this water supply for ground-water recharge.

Alternative 4 diverts water from the South Platte River for either direct conveyance to the service area or recharge in the alluvial aquifer of Badger Creek for later recovery. Technical concerns about the recharge components of the plan would need resolution prior to full development. Staged construction of the facilities would allow design of most of the features to be based upon actual system performance. The primary concern with developing this alternative is the effect of streamflow depletions on the threatened and endangered species which reside downstream in Nebraska. Similar concerns would occur with implementation of Alternative 2, but to a lesser degree. Recent progress in allocating responsibility for maintaining critical habitat areas has resulted in an expectation for resolving this issue by purchasing habitat for these species.

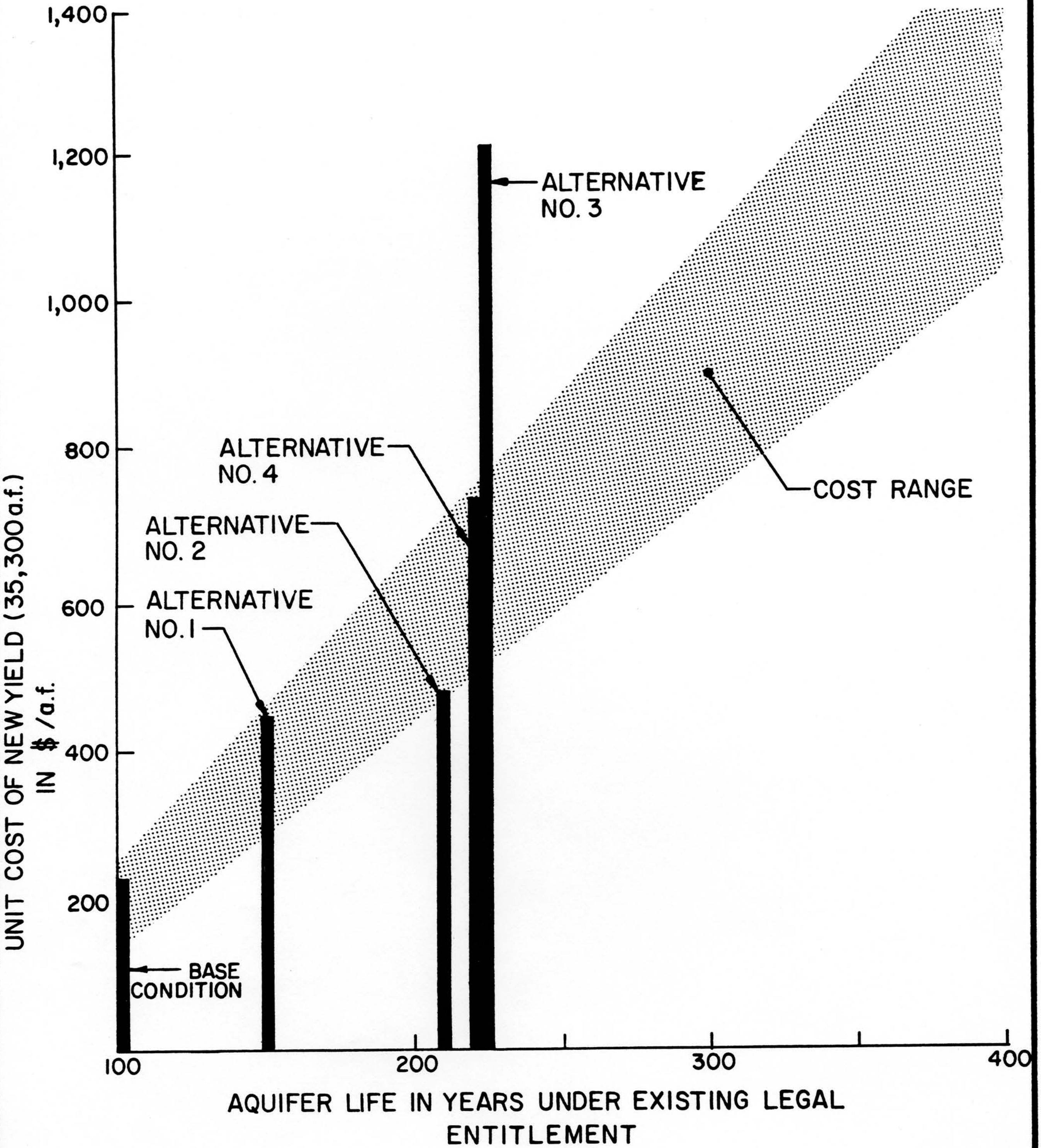
7.5 COMPARISON OF ALTERNATIVES

Selecting a preferred water development plan is always a difficult and controversial process. Public acceptance and the concurrence of state and local agencies are necessary before proceeding with implemention. This chapter has presented a comparison of the alternatives, primarily based on costs, financing needs, and potential development constraints. The selection of a preferred plan is strongly influenced by value judgments with regard to the expected importance and severity of the potential implementation constraints, and in this case, with the desired degree of dependence on deep ground-water supplies by those residing in the basin. The remainder of this chapter and the two subsequent chapters will present comparisons and factors that should assist the basin water users in directing the course of selecting and refining a water development plan.

The High Ground-Water Use Alternative advantages are its low initial cost and ease of implementation and financing. The combination of ground-water development and water reuse is the most economical method of providing a municipal water supply to the project service area. The primary drawback is the relatively rapid depletion of the nontributary ground-water aquifers, and nearly total dependence on a single water source.

Alternative 2, Maximum Local Surface Supply, has many positive attributes, as it reduces depletion of the Denver Basin aquifers in an economical manner. Castlewood Dam and Reservoir was viewed as a feature which would encourage future growth because of the recreational opportunities and flood protection. The potential development constraints of the alternative were not judged severe enough to limit implemention of the plan.

Costs for Alternatives 3 and 4 are higher than either Alternative 1 or 2. The large imported supply components associated with both of these alternatives increase the financing requirements in order to construct the conveyance, treatment, and injection/recovery systems. The socioeconomic and technical concerns about these alternatives were also greater. Importation, however, is the only way that the nontributary ground water aquifer life can be extended beyond approximately 210 years.



COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY

CHERRY CREEK WATER RESOURCES PROJECT

COST OF YIELD VERSUS DENVER BASIN AQUIFER LIFE

MORRISON-KNUDSEN ENGINEERS, INC.

DATE JULY 1987 FIGURE 7.1

8.0 CONCLUSIONS

During the process of screening options, formulating alternatives, conducting operations studies, preparing cost estimates, and making comparisons, a number of conclusions were reached regarding water resources development for the Cherry Creek Basin. These conclusions are presented in four categories: (1) project costs, (2) water demands, (3) technical issues, and (4) institutional issues. These conclusions should be given consideration in determining the future direction of water resources development for the Cherry Creek Basin.

8.1 Project Costs

- o Non-tributary ground water, a component of each alternative, supplies approximately 60 percent of the water for Alternative 1 and 25 percent for Alternatives 2, 3, and 4. The costs for non-tributary ground water are based on pumping from the Denver Basin aquifers under confined conditions. As the Denver Basin aquifers gradually change from confined to unconfined conditions, unit costs of producing water will gradually increase over those shown in this report.

- o Each alternative has been formulated with the potential to be expanded to serve a larger population, either in areas adjacent to the Cherry Creek Basin and/or in years beyond the 2010 planning horizon used in this initial study. Increased participation by other areas may reduce costs per acre foot of delivered water.

- o Staging of construction activities, resulting in potential lower costs, is possible for each of the four alternatives, but is not reflected in the costs shown in this report. The effect of staging on the unit costs of producing water will need to be evaluated in future studies.

- o Treatment of imported supplies at the point of diversion may provide opportunities for participation by other water users along the pipeline route, and should reduce the pipeline and pumping system cost per acre foot of water delivered.

- Advanced waste water treatment, combined with reuse operations, allows maximum conservation of the water supply in all of the proposed alternatives. Future technology and large volume treatment plants may lower the unit costs significantly.

- Project costs for Alternative 2 will be affected to some extent by the proposed Cherry Creek Dam and Reservoir modifications eventually selected by the Corps of Engineers.

8.2 Water Demands

- Based on a projected population of 301,800 within the Cherry Creek Basin in the year 2010, with a total unconstrained water demand projected to be 70,000 af/yr, there is a need for a new water development project to supply half of this demand. The remaining demand would be met by water conservation, existing supplies, and planned future water development by others.

- Of the projected unconstrained water demand within the Cherry Creek Basin in the year 2010, it is anticipated that 35 percent will be supplied through conservation measures, which include water reuse.

8.3 Technical Issues

- Future residential, commercial, and industrial development will become restricted if the basin's only source of additional water supply is dee ground water. For some districts, the allowable nontributary ground-water supplies are not capable of supporting the projected growth levels for the basin for the year 2010.

- Surface water storage, located downstream of areas projected for urban development, can significantly increase the yield from local water sources. The water supply for Alternative 2 is partially dependent on the additional runoff which will occur from newly created impervious areas (roofs, parking lots, etc.) in the basin upstream from Cherry Creek Lake.

- Upper basin active storage of 7,000 to 10,000 af, at either the Castlewood or Bridge Canyon Dam sites, in combination with a smaller volume of storage at Cherry Creek Lake, provides the flexibility necessary to regulate, control, and maximize the use of in-basin surface water resources.

- Future Cherry Creek Basin water quality problems and solutions are very much dependent on the water supply plan adopted for the basin. Close coordination of water resources development plans with the water quality activities of the Cherry Creek Basin Authority is extremely important.

- The water quality of potential imported water sources identified in the Arkansas River Basin and the lower South Platte River Basin is poor and would require treatment at the source for municipal use.

- The technical feasibility of injection of surface water into the deep ground-water aquifers has been partially demonstrated in this study. Plans that depend upon injection need additional field testing with actual water sources to demonstrate acceptable levels of performance and required levels of treatment.

- A successful deep ground-water recharge system should have an established procedure approved by the State Engineer for administering the operations of the recharge/recovery system.

- Deep ground-water recharge systems are viable plan components only when the water available from imports and reuse exceeds total basin demands. This condition usually occurs for two to four months during those years with at least average runoff.

- A deep ground-water injection system requires a minimum imported supply of 10,000 af/yr.

- Implementation of the reuse component for each of the four alternatives may depend on approval of this technology by one or more state and/or federal agencies and may also entail a pilot program prior to full implementation.

- Importing water from the South Platte River presents opportunities for leasing agricultural water during dry years, thereby reducing carryover storage requirements.

8.4 Institutional Issues

- A regional water supply development organization is needed to implement any of the alternatives and allow population densities to increase to those projected for the year 2010. Even implementation of Alternative I, involving only deep ground- water use and water reuse, would need an umbrella entity with rights to withdraw nontributary ground water underlying a large surface area.

- Opportunities may exist for joint participation with water users adjacent to the Cherry Creek Basin; this may reduce unit costs and increase project feasibility by taking advantage of economies of scale.

- Continuing contacts are necessary with potential participants in this water supply project; contacts must also be maintained with the three major water purveyors in the region: Denver, Aurora, and Colorado Springs.

- Developing a regional water supply system which balances water supply components from many sources, will reduce the risk of not meeting future municipal water demands.

- Many other entities are currently studying flood control needs, water quality issues, recreational needs, water rights, ground- water aquifers, and water development plans. A continuous interchange of ideas and information is necessary to assure that current information is used in subsequent investigations.

- Importation of water from the lower South Platte will require agreements with owners of the ditches and other property, which is required for the diversion and artificial recharge scheme in Alternative 4. These agreements would need to provide incentives to the agricultural community in that area.

- The potential technical, institutional, environmental, and socioeconomic constraints are minimal for Alternatives 1 and 2. Potential constraints for Alternatives 3 and 4 include technical problems, related to water quality and ground-water injection, and socioeconomic constraints involving right-of-way acquisition for the importation pipelines. Several known endangered species in Nebraska may be impacted by Alternatives 2 and 4.

9.0 RECOMMENDATIONS

The results and conclusions of this study provide the basis for the following recommendations:

1. The water supply components of Alternatives 1, 2, and 4 should be further evaluated in sufficient detail to select which of these components are preferable based on a comparison of technical, legal, environmental, and economic issues.

2. Alternative 3 should not be considered any further due to the relatively high cost compared to the other three alternatives.

3. A regional water development entity should be formed. This new regional entity would become the local project sponsor, eventually responsible for project implementation. The entity should consist of the water providers in the Cherry Creek Basin, as well as providers in adjacent basins with interest in pursuing joint water resources development.

4. Discussions should continue with other entities studying water-related problems in the Cherry Creek Basin, in particular, the U.S. Army Corps of Engineers, Cherry Creek Basin Authority, Colorado State Engineer's Office, U.S. Geological Survey, and the Colorado Division of Parks and Outdoor Recreation. These discussions should lead to cooperative efforts to jointly resolve the water supply, water quality, flood control, and water- based recreation issues on Cherry Creek.

5. The public information program initiated under this study should be continued with the specific objective of providing detailed information to those water purveyors in the region with a potential interest in this water supply project.

6. Contact should be maintained with the major water purveyors adjacent to this region, namely, Denver, Aurora, and Colorado Springs. The potential for cooperative efforts should be explored with these entities.

7. A detailed scope of work for the next level of investigations should address the following subjects:

- Physical and legal availability of water supplies in the Cherry Creek Basin and for diversion from the lower South Platte River.

- Ground water studies to include artificial recharge, storage, and recovery of water from the Denver Basin aquifers, Cherry Creek alluvial aquifers, and lower South Platte alluvial aquifers.

- Water supply storage, water quality, flood control, and recreational issues related to the existing Cherry Creek Lake.

- Studies for water storage at the Castlewood and Bridge Canyon Dam sites to include geotechnical investigations, water quality issues, and preliminary environmental and recreational assessments.

- Technical and institutional investigations related to water reuse.

- Formation of a regional water development entity through cooperative discussions with water purveyors.

It should be re-emphasized that a regional water development entity is necessary to provide for long-term water development needs. The plan formulation and yield analysis for the water development alternatives structured in this investigation have assumed that regional interest in joint development will be established, and have led to the stated recommendations. Upon formation of the regional entity, water demands and development plans will need to be further refined to allow development of construction implementation schedules and more detailed project cost estimates.

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a. Appendix 1 - Final Work Plan
b. Supplemental Work Plan No. 1 - Site Specific Work Scope
c. Supplemental Work Plan No. 2 - Systemwide Modifications
d. Appendix 2 - Future Water Demands
e. Future Water Demands Fact Sheet
f. Future Water Demands - Technical Review Fact Sheet
g. Appendix 3 - Existing Water Supply
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i. Appendix 4A - Water Sources Not Selected for Use in Alternative Scenarios
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k. Appendix 4C - Water Sources Selected for Site-Specific Analysis
l. Appendix 5 - Development and Evaluation of Water Supply Scenarios
m. Survey Report
n. Household User Survey Tabular Data and Selected Cross Tabulations
o. Survey Report Fact Sheet

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11.0 GLOSSARY

abutment - the support at the end of a dam, arch or bridge.

acre - a measure of area; equivalent to 43,560 square feet.

acre-foot - the volume of water equal to the quantity required to cover an acre of land to a depth of 1 foot, or 43,560 cubic feet.

active storage - reservoir capacity used to store and regulate streamflow to meet established reservoir operating requirements.

adjudication date - the date associated with a water right that determines its priority as a result of formal court proceedings which recognize the appropriation for beneficial use.

aggregate - a mixture of sand and gravel graded to be suitable for use in producing concrete.

alluvial aquifer - an aquifer consisting of deposits of alluvium.

alluvium - unconsolidated sediments deposited by running water.

appraisal-level study - an investigation performed to formulate a preliminary plan for project implementation, as well as make possible selection between alternatives, and to assess the desirability for continued, more detailed analyses.

appropriation - the volume or rate of flow of water that is legally allocated to an individual, municipality, corporation, or government entity for an identified beneficial use.

aquifer - a geologic formation that has the capability to yield water to wells and springs.

artificial recharge - augmenting the natural movement of surface water into an aquifer by means other than what occurs in nature.

augmentation - enlarging or increasing the quantity of an item, as increasing the flow of a stream or river.

average flow - the mean or mid-point of flow rates over a period of time.

bed - the smallest division of a stratified series and marked by a more or less well-defined division plane from its adjacent beds above and below.

bedrock - any solid rock exposed at the surface of the earth or overlain by unconsolidated material.

calcareous - containing calcium carbonate.

call - a situation in water right administration where junior water rights are not allowed to divert streamflow in order to satisfy more senior water rights.

capital cost - the amount of money paid for project construction and interest during construction.

clast - a fragment of rock material.

claystone - rocks that contain a high percent of clay, or which are largely composed of clay, generally lacking the laminations found in shale.

colluvial debris - a deposit of unconsolidated material transported by gravity from its original position.

concretions - a hard mass of mineral matter, normally subspherical, found in sedimentary rock.

concrete gravity dam - a dam made of concrete which withstands the water pressures of the reservoir and resists sliding or overturning by virtue of its massive weight.

conditional decree - a decree of the court awarding a priority date to an appropriation of water that reserves eventual water use for a facility planned, but not yet operational.

confined aquifer - a water-bearing zone in which the water is under pressure due to being capped by an impervious layer. When penetrated by a well, the water level in the well will rise above the water-bearing zone.

conglomerate - a cemented mixture of sand and gravel-sized particles in a natural deposit.

conservation storage - reservoir capacity used to store and regulate streamflow to meet established reservoir operating requirements.

construction cost - the amount paid for building project facilities plus appropriate contingencies, as well as engineering, legal, and administrative expenses.

consumptive water use - the volume of water that is used for a process or activity, is not directly returned to the water source, and results in a reduction of the water source.

contingency factor - an additional amount added to cost estimates in recognition of unknown factors that could result in higher actual costs.

cubic feet per second - the volume of water measured in cubic feet that passes a specific point in one second; equals 724 af per year or 449 gpm.

debt service - principal and interest payments necessary to retire the debt incurred in financing a project.

Denver Basin - the geographic area overlying the base of the Laramie-Fox Hills aquifer and extending from approximately Greeley to Colorado Springs along its north-south axis and from Golden to Last Chance in the west to east direction. The Denver Basin aquifers include the Dawson, Denver, Arapahoe, and Laramie-Fox Hills Formations.

depletion - the reduction in flow of a stream, or the reduction in volume of a lake or reservoir due to withdrawals, evaporation, or seepage.

diligence - efforts that must be undertaken by conditional water rights holders to demonstrate their intention of eventually constructing facilities by applying water to beneficial use.

direct diversion - the diversion of water from a natural flowing stream.

drawdown - the decrease in elevation of a lake or reservoir due to a release or discharge from the lake or reservoir; also a drop in the piezometric surface in or around a pumping well.

evaporation - the process by which water is transferred from the liquid state to vapor.

eutrophication - a process whereby surface water storage becomes enriched by nutrients that promote excessive plant growth in the water.

fault - a fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

filtration - a process of passing water through a porous medium to remove suspended matter.

firm yield - the amount of water that a water system can reliably supply during a critical dry period.

flocculation - a process in water treatment to collect and separate suspended sediment from water.

gross alpha concentration - a measure of radioactivity in water.

ground-water gradient - the rate of change of potential head per unit distance of flow at a given point and in a given direction.

grout curtain - a water barrier in a dam foundation formed by inserting chemicals or cement through drilled holes.

hydroelectric - the production of electricity by use of water power.

impervious material - fine-grained materials, such as clays, that strongly impede the seepage of water.

inflow design flood - the size of flood that a dam, spillway and reservoir are designed to accommodate without overtopping the dam.

injection - the process of placing water into an aquifer through a well.

in situ - in its natural position or place.

intermittent stream - a stream that flows for only a portion of the year.

investment cost - the amount required for payment of the capital cost, establishing a debt service reserve fund, and financing expenses.

joint - fracture in rock along which no appreciable movement has occurred.

kilowatt hour - a unit of energy equal to 1000 watts over a period of one hour.

nontributary ground water - in a physical sense, it is ground water whose removal will not deplete a surface stream. Senate Bill 5-85 defines it as ground water whose withdrawal causes a stream depletion less than one-tenth of one percent after 100 years of pumping.

outcrops - exposure of geologic formations on the land surface.

outlet works - a gated or valved conduit at a dam and reservoir used to regulate the storage.

per capita use rate - the average amount of water used within a geographical boundary divided by the population. Usually expressed in units of gallons per person per day.

permeability - the measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

physiography - the study of the structure and phenomena of the earth's surface, especially its land formation and climate.

piezometric surface - the elevation to which water will rise in a well.

potable water - water of quality adequate to meet established drinking water standards.

pre-feasibility level study - investigations of reconnaissance or appraisal level conducted in advance of a full feasibility study, and used to determine if feasibility studies are warranted.

probable maximum flood - the estimated flood that would result if all factors that contribute to a flood were to reach the most critical combination of values that could occur simultaneously.

reconnaissance-level study - an investigation performed to conceptually identify a range of plans that may have merit for further study.

rockfill dam - a dam consisting primarily of gravel to boulder-sized particles, with a zone of impervious material to provide watertightness.

roller compacted concrete dam - a dam constructed by a technique that places a relatively dry mixture of cement, water, and aggregates with construction methods similar to that used on earthen dams. The concrete later hardens and provides a rigid mass concrete structure.

sandstone - a cemented or otherwise compacted detrital sediment composed predominantly of sand-sized grains.

saturated zone - the thickness of an aquifer in which the void space is filled with water.

sedimentation - the process by which solid particles are eroded, transported, and deposited, usually by flowing water.

sediment storage - the volume of a reservoir set aside to store incoming sediments that are deposited in the reservoir over the useful life of the project.

seepage - the process by which surface water flows into and through the ground or through a dam.

shale - a laminated sediment in which the constituent paticles are predominantly of clay size.

shell zone - the outer portion of a rockfill dam consisting of gravel to boulder-sized particles.

specific conductance - a measure of the ability of water to conduct an electrical current. This is closely related to the dissolved solids concentration in the water.

storage right - a type of water right that allows storing streamflow in a reservoir for subsequent beneficial use.

suspended sediment - the solid particles that are in suspension in water.

syncline - a fold in a geologic formation in which the flanks are tilted toward the center (bowl shaped, as opposed to a dome).

topographic - of, relating to, or concerned with the configuration of the earth's surface, including its relief and the position of its natural and man- made features.

transmountain - the crossing or extending over or through a mountain.

tributary ground water - includes seepage, underflow, and percolating water that will eventually become part of a natural stream.

unconfined aquifer - a water-bearing zone in which the water surface is at atmospheric pressure.

unconstrained water demand - the water demand within a region without application of water conservation measures.

water demand - the amount of water required to serve a specific geographic area. Water uses may be predominantly municipal, industrial, or agricultural.

water level - the height of water in an aquifer, well, or reservoir.

water right - a legal right to use the water of a natural stream or the water beneath the surface for a specific beneficial purpose such as irrigation, municipal, or industrial use, which is subject to other rights in the system.

water source - the location of origin of water prior to diverting it for beneficial use.

water supplies - water controlled and regulated in quantity and quality, by man-made features, to meet the water demands of a specific area.

water table - the upper limit of the part of the soil or underlying rock material that is wholly saturated with water.

yield - amount of water that a water system can reliably supply each year.