JOINT-USE RESERVOIR AND GREEN MOUNTAIN EXCHANGE PROJECTS

SUMMARY REPORT

PRELIMINARY HYDROLOGIC ANALYSIS

prepared for the

Colorado Water Resources & Power Development Authority

August, 1986

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Colorado Water Resources and
Power Development Authority
Attention: Mr. Dan Law, Associate Director
1580 Logan Street, Suite 620
Denver, Colorado 80203

August 28, 1986

RE: JOINT-USE RESERVOIR AND GREEN MOUNTAIN EXCHANGE PROJECTS, SUMMARY REPORT OF HYDROLOGIC ANALYSIS

Dear Mr. Law:

We are pleased to submit this report summarizing the results of the preliminary hydrologic analysis performed as part of the Phase 2 investigation of the Joint-Use Reservoir and Green Mountain Exchange Projects.

Phase 1 of the Joint-Use Reservoir and Green Mountain Exchange Projects involved the initial screening analysis. It was designed to eliminate at an early stage, those reservoir sites that would not be suitable for a joint-use or replacement reservoir. The Initial Screening Report summarizing the results of Phase 1 was submitted on January 22, 1986.

Phase 2 involves the detailed hydrologic, operational and water rights analysis of the remaining sites and a recommendation of sites for Phase 3 analysis. Phase 3, the reconnaissance study phase will involve detailed geotechnical investigations and preliminary design and cost estimates.

As a part of Phase 2, we have evaluated six reservoir sites including Wolford Mountain Site A', Wolford Mountain Site C, Red Mountain, Wolcott, Azure and Una Reservoir sites to determine their ability to meet the Project requirements. The analyses show that all six reservoir sites can produce the necessary yield to meet the Joint-Use Reservoir requirements (approximately 30,000 af). In addition, Wolcott Reservoir alone

and several reservoir combinations can meet the replacement requirements of the Green Mountain Exchange Project. It is therefore recommended that all sites be investigated further as part of Phase 3.

We look forward to proceeding with Phase 3 of the Joint-Use Reservoir and Green Mountain Exchange Projects.

Very truly yours,

BOYLE ENGINEERING CORPORATION

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DN-C10-100-04

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1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

This study of the Joint-Use Reservoir and Green Mountain Exchange Projects was initiated by the Colorado Water Resources and Power Development Authority at the request of the Colorado River Water Conservation District (CRWCD) and the Board of Water Commissioners for the City and County of Denver (DWB). It is intended to provide reconnaissance-level engineering and hydrology information on the Projects.

The objective of the Joint-Use Reservoir Project is to provide additional water to Western Colorado and the Denver Metropolitan Area. The reservoir(s) designed to meet this need should have the capability and flexibility to increase the firm annual yield of the Dillon Reservoir/Roberts Tunnel System by about 15,000 acre-feet (af) and provide about 15,000 af of firm annual yield for use in Western Colorado. For the purpose of this study, the firm annual yield is defined as the constant volume of water that can be supplied every year without any shortage during the study period of 1951 through 1983.

The Green Mountain Exchange Project is intended as a potential alternative to previously identified water diversion and storage projects. The objective of this exchange is to provide additional water to Dillon Reservoir and the Denver Metropolitan Area. This would be accomplished by regulating existing flows and by pumping water directly from Green Mountain Reservoir to Dillon Reservoir while providing a new reservoir(s) to replace the existing functions of Green Mountain Reservoir.

The study has been conducted in three phases. The Phase 1 investigation was to collect and evaluate existing data on nine candidate reservoir sites for initial screening purposes. Reservoir

sites that would not be suitable as a joint use or replacement reservoir were to be eliminated. The nine reservoir sites were:

- Wolford Mountain Site A on Muddy Creek
- Wolford Mountain Site C on Muddy Creek
- Red Mountain on the Colorado River
- Azure on the Colorado River
- Wolcott on Alkali Creek
- Una on the Colorado River
- Haypark on East Troublesome Creek
- Lower Piney on the Piney River
- Iron Mountain on Homestake Creek

As a result of the Phase 1 investigation, Haypark, Lower Piney and Iron Mountain Sites were eliminated from further consideration because of limited water yield or geotechnical problems. The Wolford Mountain Site A was replaced with a site approximately 3,500 feet upstream. This new site, designated as Wolford Mountain Site A', appears to be more favorable for dam construction in light of geotechnical and topographic iterations. The Initial Screening Report, issued in January, 1986, describes in detail the efforts and recommendations made in the Phase 1 investigation.

Phase 2 involves two aspects: in-depth hydrologic, operational and water rights analyses using a hydrologic simulation model, and an evaluation of the Green Mountain to Dillon conveyance system to determine the pumping system configuration and the estimated cost. This memorandum presents the results of these preliminary analyses performed as part of the Phase 2 investigation.

During Phase 3, the reconnaissance study phase, preliminary designs and cost estimates will be prepared for those reservoir sites not eliminated as a result of the Phase 2 analyses. In addition, detailed geotechnical investigations will be conducted if necessary. The Phase 3 report will present a comparative analysis of these remaining sites. A final report will then be prepared

which will incorporate the results of the evaluations relating to the storage sites and the conveyance facility.

1.2 HYDROLOGIC ANALYSIS OBJECTIVE

The main purpose of the Phase 2 hydrologic analysis is to estimate the yield from each reservoir site and the amount of water exchangeable under the implementation of the Green Mountain Exchange Project. In accordance with the Plan of Study dated June 20, 1985, the following analyses were made:

- A water rights analysis was made to estimate the monthly flows physically and legally available for storage at six sites for the 1951 to 1983 hydrologic study period. The analysis was performed for existing conditions and two levels of future development of conditional water rights.

- A reservoir operation analysis was performed to estimate the firm annual yield of each reservoir site. In consultation with the Authority, the firm annual yield was defined as the volume of water that can be provided every year without any shortage.

- The Green Mountain Reservoir was analyzed in detail to estimate its yield based on existing operating policies and on existing Colorado River operations. The amount of exchangeable water available for the Green Mountain Exchange Project was also determined.

To facilitate the computations involved in hydrologic and water rights data management, and to perform a reservoir operation analysis, a monthly hydrologic simulation model was used which incorporates the Colorado water rights priority system and other legal and institutional arrangements identified during the study. The modeling area covers the Upper Colorado Basin above the Cameo gage.

2.0 HYDROLOGIC CHARACTERISTICS

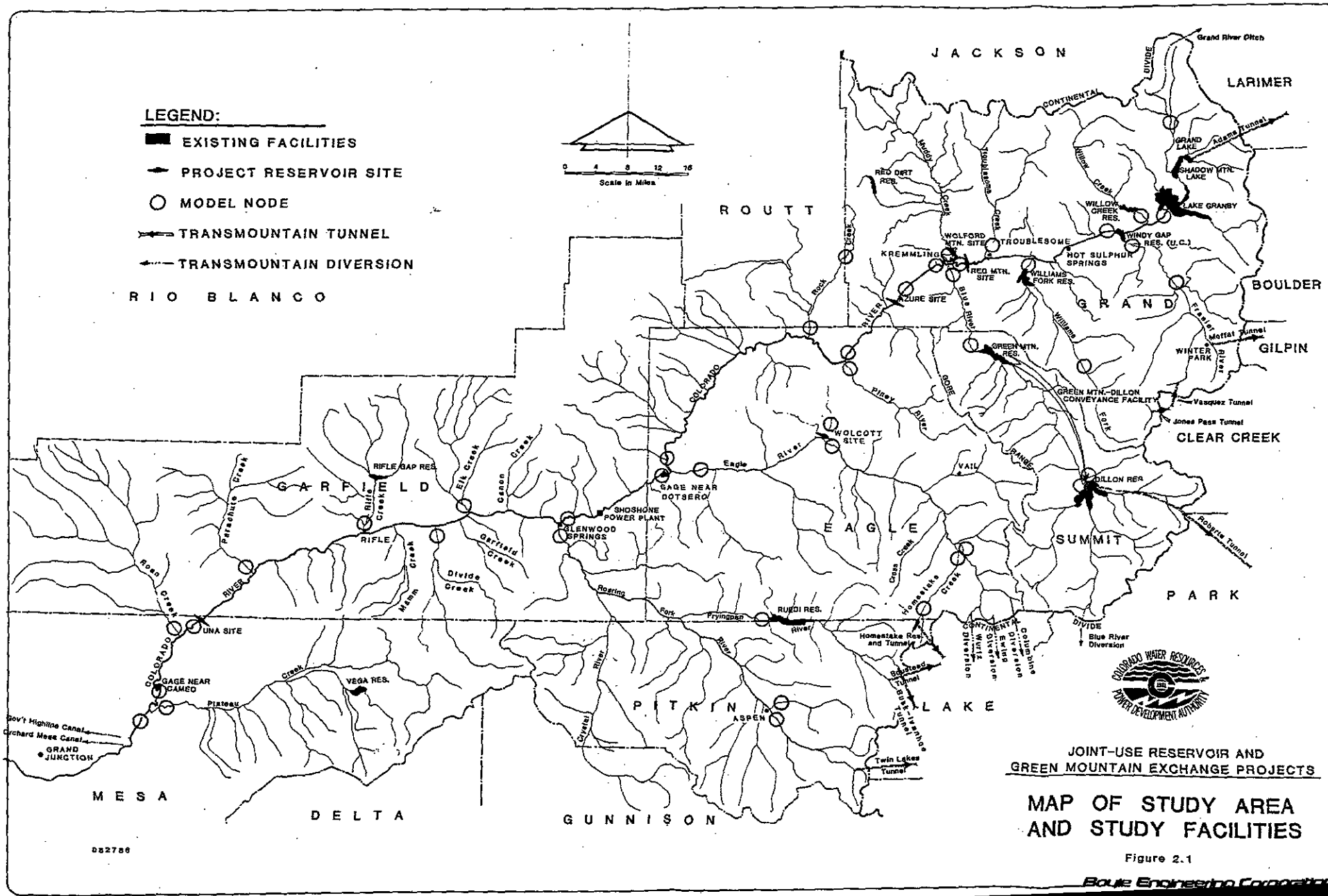
2.1 WATERSHED DESCRIPTION

The Upper Colorado River watershed, which is the subject of this study, extends from the Continental Divide at an elevation in excess of 10,000 feet to the Cameo gage near Palisade at an elevation of about 4,800 feet (see Figure 2.1). The drainage area above the Cameo gage is approximately 8,000 square miles.

The major tributaries to the Colorado River in the study area are: the Fraser, Williams Fork, Blue, Piney, Eagle, and Roaring Fork Rivers. Smaller streams which also contribute to the Colorado River include Willow, Troublesome, Muddy, Rock, Divide, Elk, Rifle, Parachute, Roan, and Plateau Creeks. Principal reservoirs located in the Upper Colorado River Watershed include Shadow Mountain Lake, Lake Granby, Willow Creek Reservoir, and Green Mountain Reservoir, all operated by the U.S. Bureau of Reclamation (USBR) as part of the Colorado-Big Thompson Project (CBT); Williams Fork and Dillon Reservoirs owned by the DWB; Homestake Reservoir, jointly owned by the cities of Colorado Springs and Aurora; and Ruedi Reservoir operated by the USBR as part of the Fryingpan-Arkansas Project.

Precipitation varies dramatically within the study area. At the higher elevations, precipitation exceeds 30 inches per year, whereas in Garfield County annual precipitation is as low as 10 inches per year. Snowfall in the study area begins as early as October and ends as late as the end of April.

Average annual virgin flow of the Colorado River (based on 1951-1983 historical flows adjusted for major diversions and reservoirs as described in Section 4.0) ranges from about 0.5 million af at the headwaters near Hot Sulphur Springs to 3.3 million af at the Cameo gage. A wide variation in total annual virgin flow is characteristic of the river as illustrated by annual extremes at


LEGEND:
EXISTING FACILITIES
PROJECT RESERVOIR SITE
MODEL NODE
TRANSMOUNTAIN TUNNEL
TRANSMOUNTAIN DIVERSION
Scale in Miles
0 4 8 12 16
JACKSON
LARIMER
ROUTT
RIO BLANCO
GRAND
BOULDER
GILPIN
CLEAR CREEK
SUMMIT
EAGLE
GARFIELD
PARK
LAKE
PITKIN
MESA
DELTA
GUNNISON
Grand River Ditch
CONTINENTAL DIVIDE
GRAND LAKE
Adams Tunnel
SHADOW MTN. LAKE
LAKE GRANBY
RED DIRT RES.
WILLOW CREEK RES.
WINDY GAP RES. (U.C.)
WOLFORD MTN. SITE
TROUBLESOME
HOT SULPHUR SPRINGS
KREMMLING
RED MTN. SITE
WILLIAMS FORK RES.
AZURE SITE
GREEN MTN. RES.
Moffat Tunnel
WINTER PARK
GREEN MTN.-DILLON CONVEYANCE FACILITY
Vasquez Tunnel
Jones Pass Tunnel
WOLCOTT SITE
VAIL
DILLON RES.
Roberts Tunnel
RIFLE GAP RES.
GAGE NEAR DOTSERO
SHOSHONE POWER PLANT
GLENWOOD SPRINGS
RIFLE
UNA SITE
RUEDI RES.
Homestake Res. and Tunnel
Boustead Tunnel
Busk-Ivanhoe Tunnel
Twin Lakes Tunnel
ASPEN
VEGA RES.
GAGE NEAR CAMEO
GRAND JUNCTION
Gov't Highline Canal
Orchard Mesa Canal
Blue River Diversion
COLORADO WATER RESOURCES AND POWER DEVELOPMENT AUTHORITY
JOINT-USE RESERVOIR AND GREEN MOUNTAIN EXCHANGE PROJECTS
MAP OF STUDY AREA AND STUDY FACILITIES
Figure 2.1
Boyle Engineering Corporation
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the Cameo gage of 1.7 million af in 1977 and 5.2 million af in 1983.

2.2 RIVER OPERATION

The administration of the Upper Colorado River is largely affected by two major senior demands - Cameo and Shoshone. The most senior of these is the Cameo Demand which consists of a number of senior rights for the Grand Valley Canal and the Grand Valley Irrigation Project. The Grand Valley Irrigation Project includes the Government Highline Canal and the Orchard Mesa Canal rights which divert at the Grand Valley Diversion Dam. With operation of a "check" which allows the tailwater from the Orchard Mesa power plant to be used by the Grand Valley Canal, the Grand Valley demand measured at the Cameo gage is approximately 1,650 cubic feet per second (cfs) during the summer.

The Shoshone Demand has a priority date of 1902 and a decreed diversion rate of 1250 cfs. It supplies the Shoshone hydroelectric plant in Glenwood Canyon and is a year round non-consumptive use. The plant also has a junior right for 158 cfs with a priority date of 1929. In most years, when the Shoshone Demand (1902 right) is satisfied, there is sufficient water to meet the summer Cameo Demand since the Colorado River flow is supplemented by tributary inflow downstream of the Shoshone Power Plant, largely from the Roaring Fork River.

Many junior diversions in the Upper Colorado River basin have been protected from the Shoshone or Cameo calls by the replacement function of several reservoirs. For example, the major function of the Williams Fork Reservoir is to allow for out-of-priority diversions by the Denver systems, and the function of Ruedi Reservoir is partly to protect diversions by the Fryingpan-Arkansas Project. Green Mountain Reservoir also has a replacement function which warrants the following detailed description because of its significance to this project.

Green Mountain Reservoir, located on the Blue River, is a feature of the CBT West Slope Collection and Storage System constructed by the USBR. Construction of Green Mountain dam was completed in 1943.

The reservoir has a total storage capacity of 153,639 af, with a dead storage of 6,860 af. It has an original storage right of 154,645 af and a refill right of 6,316 af. The operating policy of Green Mountain Reservoir is set forth in Senate Document 80 (Act of August 9, 1937, 50 Stat. 564) and reaffirmed in subsequent court decrees and stipulations including:

Consolidated Cases (Civil Actions) Nos. 2782, 5016, and 5017
October 12, 1955 Stipulation and Decree
April 16, 1964 Stipulation and Decree
November 2, 1977 Memorandum Opinion and Order
February 9, 1978 Supplemental Judgement and Decree

Senate Document 80 specifies that 52,000 af of storage in the Green Mountain Reservoir is to be reserved to supply replacement water to the Colorado River for out-of-priority CBT project diversions. The balance of about 100,000 af is to be used primarily for power generation and secondly for irrigation and domestic uses in western Colorado not satisfied by natural flows. Under Senate Document 80, one of the uses of the Reservoir in such circumstances, is to augment irrigation and domestic uses that existed in 1937 and, to the extent storage water is thereafter available for release, to augment similar needs which subsequently arise. Approximately 66,000 af of water was released from storage in 1977 to supplement natural flow shortages in western Colorado.

The water rights for Green Mountain Reservoir have a priority date of 1935, and are senior to those of Roberts Tunnel and Dillon Reservoir, Denver's Blue River diversion. Following the 1964 Stipulation and Decree, it was conceded that, upon approval of the

Secretary of Interior, Denver can store out-of-priority water in Dillon Reservoir during the spring snowmelt runoff season. This out-of-priority storage is permitted on the condition that if Green Mountain Reservoir does not fill, water is released later to satisfy the fill requirement of Green Mountain Reservoir. Water can be released either from Dillon Reservoir to flow into Green Mountain Reservoir, or from Williams Fork Reservoir to meet the Green Mountain Reservoir obligations. Another condition was that energy lost to the Green Mountain Power plant because of reduced flow, is replaced in kind.

On December 22, 1983, the USBR published an operating policy for Green Mountain Reservoir (Federal Register Vol. 48, No. 247) December 22, 1985) with a provision that releases from the 100,000 af power pool shall be made available without charge to meet natural water shortages for perfected irrigation and municipal uses with a priority date senior to October 16, 1977. Releases for these purposes shall not exceed 66,000 af per annum. The remaining water from the power pool is to be made available for use on the western slope, through "water sales". The amount of water sales and the analysis of their impact are described in the Draft Water Marketing Program Environmental Statement issued in June 1985.

3.0 PROJECT RESERVOIRS

3.1 RESERVOIR DESCRIPTION

The hydrologic analyses performed as part of the Phase 2 investigation entailed estimating the yields for six single reservoirs and three combinations of reservoirs and performing an operation analysis to evaluate their replacement capabilities for the Green Mountain Exchange Project. Table 3.1 shows the site storage capacity for each reservoir and combination. A brief description of the reservoirs are provided below. The average annual flows mentioned in the subsequent paragraphs are based on historical flows for the period of 1951 through 1985.

Wolford Mountain Site A' - The site is located on Muddy Creek, approximately 1.5 miles upstream from Kremmling. The reservoir inflow is to be supplemented with pumping from the Colorado River during the snowmelt runoff season. Two alternative sites for pumping intake were considered: one immediately upstream of the Blue River and the other downstream of the Blue River. The average annual historical flow of Muddy Creek at the site is approximately 64,000 af. The average annual historical flows at the proposed diversion sites above and below the Blue River are 357,000 and 678,000 af respectively.

Wolford Mountain Site C - This site is located on Muddy Creek, approximately 4 miles north of Kremmling. Muddy Creek flows at both Site A' and C are considered to be approximately the same since no major tributaries contribute to Muddy Creek in this reach.

Red Mountain Site - This site is located on the Colorado River, approximately 1 mile east of Kremmling. The average annual historical flow at this site is 357,000 af.

TABLE 3.1

PROPOSED RESERVOIRS

RESERVOIR	MAXIMUM STORAGE (af)	MINIMUM POOL (af)
Single		
Azure	85,000	5,300
Red Mountain	140,000	5,600
Una	196,000	45,000
Wolcott (w/Colo. & Eagle Div)	350,000	14,000
Wolcott (w/Eagle Div)	160,000	14,000
Wolford A'(w/Colo. Div)	120,000	6,500
Wolford C	80,000	6,500
Combinations		
Wolcott (w/ Eagle Div) & Red Mountain	160,000 140,000 300,000	14,000 5,600 19,600
Wolcott (w/Eagle Div) & Azure	160,000 85,000 245,000	14,000 5,300 19,300
Una & Red Mountain	196,000 140,000 336,000	45,000 5,600 50,600

Azure Site - This site is located on the Colorado River at the upper end of the Lower Gore Canyon, about 10 miles downstream from Kremmling. The average annual historical flow at this site is 742,000 af.

Wolcott Site - This site is located 1 mile north of the town of Wolcott on Alkali Creek, a minor tributary to the Eagle River. Two alternatives were analyzed. The first involves pumping from the Eagle River and the Colorado River. The other alternative provides a smaller reservoir capacity with pumping from the Eagle River only. The average annual historical flow is 800 af for Alkali Creek at the reservoir site; 277,000 af at the Eagle River diversion site; and 796,000 af at the Colorado River diversion site.

Una Site - This site is on the Colorado River at the Mesa - Garfield county line between the towns of Parachute and DeBeque. It is downstream from the Shoshone power plant diversion but lies upstream from the Grand Valley diversions. Because of its geographic location, the Una site alone would not substitute for the functions of the Green Mountain Reservoir as specified in Senate Document 80 and the Consolidated cases. However, the reservoir has merits in providing the largest water yield and hydroelectric power production. An evaluation was made of its capability to replace the Green Mountain Reservoir when combined with one of the upstream reservoirs mentioned above. The average annual historical flow at this site is 2,597,000 af.

Combination Reservoirs - With the exception of Wolcott Reservoir, the single reservoirs can not meet the requirements of a replacement reservoir for the Green Mountain Exchange Project due to their limited yield or geographical location. Several alternatives were considered using a combination of two reservoirs to meet the project objectives. Among them are the following combinations:

- Wolcott (with Eagle diversion only) and Red Mountain Reservoirs
- Wolcott (with Eagle diversion only) and Azure Reservoirs
- Una and Red Mountain Reservoirs

Detailed evaluations of these combination reservoirs were made to estimate their yields and replacement capabilities. Besides the three reservoir combinations that were analyzed, there are many other possible combinations. For example, Wolcott Reservoir could be combined with Wolford A'. This combination would result in a yield that would be very similar to the Wolcott-Red Mountain combination. Such comparable combinations were not evaluated separately in this hydrologic analysis.

3.2 SEDIMENT STORAGE OR MINIMUM POOL REQUIREMENT

The minimum pool requirements for each reservoir utilized in this study is the structural allowance or the sediment storage allowance, whichever is greater, as determined by previous investigations. For reservoirs that lacked this information, it was assumed that the minimum pools would contain estimated sediment yields for a 100-year period. Table 3.1 presented in the previous section includes information on the minimum pool for each single reservoir or combination of reservoirs.

3.3 CONDITIONAL STORAGE WATER RIGHTS

Water rights decreed or filed for the reservoir sites considered in this study are summarized in Table 3.2. Although the location of Wolford Site A' is different from that of Site A as specified in the water right decree, for this analysis it was assumed that Site A' had the same priority date as Site A.

TABLE 3.2

WATER RIGHTS SUMMARY FOR PROJECT RESERVOIRS

STUDY RESERVOIR	WATER RIGHT DECREED	WATER RIGHT PENDING	DATE OF RIGHT (1)	OWNER OR CLAIMANT (3)
Wolford Mountain (Site A)	119,600 af	- -	1981	Grand Co.
Wolford Mountain (Site A)	- -	119,600 af	1983	CRWCD, MPWCD
Diversion from Colorado River (Ice Water Pumping Plant and Gore Canyon Power Plant Conduit)	- -	2.000 cfs		& Grand Co.
Wolcott	- -	350,000 af	1971	DWB
Eagle River Pumping Plant	- -	2,500 cfs	1971	
State Bridge (Colo. R) Pumping Plant	- -	3,000 cfs	1971	
Una	195,984 af		1966	CRWCD
Red Mountain (2)	- -	149,000 af	1984	CRWCD
Azure, Original	25,584 af		1962	MPWCD
First Enlargement	63,804 af		1967	CRWCD
TOTAL	89,388 af			

NOTES:
(1) Year of Appropriation or Year Filed for Pending Rights
(2) Pending Claim is a for Gabriel Reservoir at the same site
(3) CRWCD - Colorado River Water Conservation District
MPWCD - Middle Park Water Conservancy District

4.0 WATER RESOURCES UTILIZATION

4.1 GENERAL

Water availability for the various reservoirs analyzed as potential Joint-Use reservoirs or components of the Green Mountain Exchange Project was evaluated under three levels of water utilization in the basin: the existing level of use and two future levels of use under increased development in the basin.

In all three operating scenarios, the major projects to be operated and their average annual target demands were specified by the Authority in consultation with the DWB and the CRWCD. Demands used in the operating simulations for all three development scenarios were furnished by the DWB for their Fraser River, Williams Fork and Blue River diversion systems for operation both with and without the Green Mountain exchange. These demands assumed construction of Two Forks Reservoir with a storage capacity of 1.1 million af. Demands for the proposed Rock Creek Reservoir, Indian Creek Reservoir, reformulated West Divide Project and Red Cliff Project were furnished by the CRWCD.

4.2 EXISTING LEVEL USE

The Existing Level Use Scenario consists of operation of the Colorado River basin under its 1983 level of development with several exceptions. The exceptions, which consisted of expanded demands in all cases, fall into two general categories of use: 1) increased diversions by existing transmountain diversion systems which are not presently operating at their full capacity; and 2) diversions by project features or proposed facilities which are not yet constructed. These diversions are:

1. Expanded Operation of Existing Systems
   - CBT/Windy Gap Project (Adams Tunnel)
   - Fryingpan-Arkansas Project (Boustead Tunnel)
   - Fraser River Diversion System (Moffet Tunnel)
   - Blue River Diversion Project (Roberts Tunnel)
   - Homestake Project (Homestake Tunnel)

2. New Facilities not Presently in Existence
   - Williams Fork Collection System Extension (Gumlick Tunnel)
   - Straight Creek Diversion (Roberts Tunnel)

Table 4.1 contains a comparison of the average levels of annual diversions for the major transmountain diversion systems as historically recorded and as operated in the Existing Level Use Scenario with increased demands by those systems listed above.

The in-basin demands for the present level of irrigation, municipal and industrial use in the basin were estimated based on evaluation of the historic diversion records for ditches and structures having entitlements of 5.0 cfs and larger. Recorded diversions for the entire 33-year study period were first compared with the associated decreed water rights. Major discrepancies between the listings were resolved. Where the diversion records were incomplete, the beginning years of diversion were assumed on the basis of the decreed dates of appropriation for the rights. Incomplete diversion records were extended and/or filled in by comparison with the available portions of the diversion record and/or by correlation with other diversions. Finally, the aggregate of the adjusted diversion records for each basin were compared with the consumptive use estimates prepared by the USBR to resolve inconsistencies.

TABLE 4.1

AVERAGE ANNUAL TRANSMOUNTAIN
DIVERSION DEMANDS
(1000 af/yr)

Structure	Recorded 1951-83	Recorded 1973-83	Existing (2) 1951-83
Adams Tunnel (1)	219.7	230.6	288.2
Boustead Tunnel	16.2	45.7	52.5
Busk-Ivanhoe Tunnel	5.9	6.9	6.0
Columbine Ditch	1.5	1.7	1.6
Ewing Ditch	1.0	1.0	1.1
Grand River Ditch	17.0	17.1	17.0
Gumlick Tunnel	5.0	4.6	27.1
Homestake Tunnel	12.3	24.2	29.4
Hoosier Tunnel	7.7	7.9	8.2
Moffat Tunnel (excluding Gumlick Tunnel Diversion)	45.4	52.4	72.4 (73.3)
Roberts Tunnel	29.6	62.0	153.4 (278.4)
Twin Lakes Tunnel	42.8	43.7	42.8
Wurtz Ditch	2.5	2.9	2.5
TOTAL	406.6	500.7	702.2 (828.1)

NOTE: (1) Includes CBT and Windy Gap diversions.
(2) Demands in ( ) are increased for Green Mountain Exchange scenario.

Table 4.2 shows the estimated present level of irrigation demands in the Colorado River Basin above Cameo for the major segments of the basin. Also shown on Table 4.2 are the average irrigation efficiencies at which the irrigation rights in each segment of the basin were operated. These efficiencies represent the amounts of depletion of the streamflows in terms of percent of the diversions. The average annual use of water for irrigation in the Colorado River Basin above Cameo has not changed significantly over the 33-year study period.

It is estimated that municipal water use in the basin has doubled during the span of the 33-year study period, based on analysis of recorded diversions. "Municipal water use" in this analysis includes as a minor component, some industrial water uses that are associated with mining. Table 4.3 indicates the estimated average annual municipal demands by five-year increments during the study period. A total aggregate demand of 38,700 af per year was operated in the Existing Level Use Scenario for all years. Consumptive depletions of diversions for municipal uses varied from 20 to 100 percent depending on the location and nature of the demand.

4.3 FUTURE LEVEL USE

The two future level operating scenarios consisted of increasing the demands of certain existing projects and adding presently undeveloped conditional projects to the Existing Level Use Scenario to produce target levels of water demand under projected moderate and high levels of future development in the basin. The projects to be expanded and developed in the future and the target levels of demand were established by the Authority in consultation with the DWB and the CRWCD.

Table 4.4 lists the additional projects and expansion of existing projects operated in the two Future Level Use Scenarios along with their additional average annual depletions above the Existing Level

TABLE 4.2

ESTIMATED IRRIGATION DIVERSIONS
FOR MAJOR WATER RIGHTS

UPPER COLORADO BASIN
(1951 - 1953 Average Annual)

Water District	Geographic Location	Estimated Diversion (1000 af)	Estimated Irrigation Efficiency (%)
36	Blue River	17.7	50
50,51	Fraser River Muddy Creek Troublesome Creek Upper Colorado River near Kremmling	58.7	60
37	Eagle River	28.1	60
38	Roaring Fork River	83.6	45
52,53	Colorado River between Kremmling and Glenwood Springs	29.6	50
39,45,70	Colorado River between Glenwood Springs and Cameo	101.9	60
	TOTAL	319.6 (1)	

(1) Accounts for more than 90% of all irrigation diversions upstream of Cameo

TABLE 4.3

ESTIMATED ANNUAL IN-BASIN
MUNICIPAL DEMANDS

UPPER COLORADO RIVER BASIN

PERIOD	DEMANDS (1000 af/yr)
1951 - 1955	18.2
1956 - 1960	18.2
1961 - 1965	21.3
1966 - 1970	28.2
1971 - 1975	31.4
1976 - 1980	34.5
1981 - 1983	38.7
Existing Level	38.7

TABLE 4.4

PROJECTS/FACILITIES INCLUDED IN
MODERATE AND HIGH FUTURE LEVEL USE SCENARIOS

PROJECT OR FACILITY	RIVER OR CREEK	AVE.DEPLETION (1000 af/yr) MOD. FUT. LEVEL	AVE.DEPLETION (1000 af/yr) HIGH FUT. LEVEL	ASSUMED ANNUAL DEMAND PATTERN
Homestake Project				
Homestake II	Eagle	21	21	Constant
Eagle-Arkansas	Eagle	0	6	Constant
Continental-Hoosier	Blue	0	6	Constant
Pueblo/Eagle Systems	Eagle	0	3	Constant
Ruedi Res. Marketing	Fryingpan	3	40	Variable
Rock Creek Reservoir	Rock	13	13	Constant
Indian Creek Res.	Eagle	1	1	Constant
West Divide Project	Divide	0	25	Variable
Red Cliff Project	Eagle	0	25	Constant
Oil Shale Projects	Colorado & Main Elk	0	93	Variable
TOTAL		38	233	

Use Scenario. In the Moderate Future Level Use Scenario, the water use in the basin was increased above the Existing Level by an annual average of 17,000 af of in-basin M & I depletions and 21,000 af of transmountain diversions.

In the High Future Level Use Scenario, the average annual water use was increased to provide an additional 61,000 af for in-basin irrigation, municipal and industrial uses other than oil shale; 133,000 af for oil shale development; and 36,000 af for transmountain diversions.

An estimated total future demand averaging 136,000 af per year was used in the operating simulation for oil shale development in the Colorado River Basin. This figure was based opn those projects which filed Biological Consultations with the U.S. Fish and Wildlife Service and upon quantities requested in applications to USBR under the Green Mountain Reservoir and Ruedi Water Sales Programs. Of this total, 3,000 af was supplied from the Green Mountain Reservoir Water Marketing Sales in all three scenarios; and 3,000 af and 40,000 af were provided under the Ruedi Reservoir Water Marketing Sales in the Moderate and High Future Level Use Scenarios, respectively. The balance of the 93,000 af annual demand for oil shale in the High Future Level Use Scenario was assumed to be supplied from the Colorado River in the vicinity of Parachute and DeBeque and in the Main Elk Creek Basin.

A comparison of the total water demands in the Colorado River basin above Cameo used in the simulations for the three levels of development is displayed in Table 4.5.

TABLE 4.5

DEMAND BY CATEGORY OF USE FOR DEVELOPMENT SCENARIOS

Category of Use	Average Annual Demand - (1000 af) Existing	Moderate Future	High Future
Transmountain Diversions	702	723	738
Irrigation	320	320	336
Municipal	36	50	84
Oil Shale	3	6	136
TOTAL	1,061	1,099	1,294

5.0 RESERVOIR YIELDS

5.1 HYDROLOGIC SIMULATION MODEL

The Boyle Engineering Stream Simulation Model (BESTSM) was applied to analyze the Upper Colorado River Basin and to estimate yields from the proposed reservoir sites under various water development conditions. Briefly, BESTSM is an accounting type model which keeps track of monthly water volumes for inflows, diversions, return flows, river gains and losses, and outflows for each segment of the stream system. For reservoirs, a complete water accounting is also performed. Some of the factors considered include reservoir inflow, pumping from adjacent streams, bypass requirements to meet senior downstream rights and minimum instream flows, reservoir releases, spills, seepage, and evaporation. The model allocates water based on the Colorado water rights priority system and other legal and institutional arrangements in the Colorado River Basin which are discussed in previous sections.

The modeled area covers the Upper Colorado Basin above the Cameo gage. The study system is divided into 56 segments. The model incorporates over 800 major diversion structures each having an aggregate water right greater than 5 cfs. This accounts for more than 90 percent of the total diversions in the basin. The total number of water rights associated with these structures is approximately 1600. All existing major reservoirs are simulated in the model. These include Lake Granby, Willow Creek, Green Mountain, Williams Fork, Dillon, Homestake, and Reudi Reservoirs. The total storage and minimum pool for these existing reservoirs are summarized in Table 5.1.

TABLE 5.1

EXISTING RESERVOIRS

RESERVOIR	TOTAL STORAGE (af)	MINIMUM POOL (af)
Lake Granby	539,760	74,190
Willow Creek Reservoir	10,553	6,675
Williams Fork Reservoir	96,820	3,183
Green Mountain Reservoir	153,639	6,860
Dillon Reservoir	254,000	3,270
Homestake Reservoir	43,500	0
Ruedi Reservoir	102,369	1,089

In addition, reservoirs simulated under future development scenarios are: Rock Creek Reservoir, planned by the CRWCD; Iron Mountain Reservoir for the Red Cliff project; Kendig Reservoir for the West Divide Project; and Main Elk Reservoir for oil shale development. Major operating rules incorporated in the BESTSM are as follows:

- The Grand Valley demand measured at the Cameo gage was assumed to equal 1650 cfs from April to October of each year and 800 cfs from November to March.

- The Shoshone Hydroelectric Power Plant demand measured at Dotsero is equal to 1250 cfs all year long.

- The 52,000 af replacement pool of Green Mountain Reservoir has first priority for filling and is reserved to provide replacement water for out-of-priority CBT project diversions.

- Releases from the 100,000 af power pool of Green Mountain Reservoir are used to make up natural water shortages for perfected irrigation and domestic uses with a decreed date senior to 1977. Annual release of up to 66,000 af is allowed during the irrigation season (assumed to be April through October) to satisfy the Grand Valley demand and to relieve shortages to other irrigation diversions senior to 1977 caused by the Shoshone or Cameo call.

- The remaining water available from the 100,000 af power pool in Green Mountain Reservoir is used to meet the demands for water sales.

- During the non-irrigation season (assumed to be November through April) releases from Green Mountain Reservoir are made for power production and replacement of CBT out-of-priority diversions. Winter releases are used to drawdown the reservoir to a level between 40,000 and 60,000 af by April depending on the anticipated inflows during the snowmelt season.

- Williams Fork Reservoir provides replacement for out-of-priority diversions by the Fraser River Diversion Project, the Williams Fork Diversion Project, the Roberts Tunnel, and storage in Dillon Reservoir.

- Dillon Reservoir is allowed to store out-of-priority to Green Mountain Reservoir under the condition that it satisfies the one fill requirement by Green Mountain Reservoir by the end of the water year. Calls on Green Mountain Reservoir are met first by releases from

Williams Fork Reservoir up to its power plant capacity (assumed to be 300 cfs for this study). When Williams Fork is not able to provide water, the call is transferred to Dillon Reservoir. These releases are credited against the Green Mountain fill requirement. Any unsatisfied amount owed to Green Mountain is transferred in September from Dillon Reservoir to Green Mountain Reservoir.

- Homestake Reservoir is operated to provide water to Aurora and Colorado Springs through the Homestake Tunnel.

- Under the Existing Level Use Scenario, Ruedi Reservoir is operated to provide replacement water for Fryingpan-Arkansas Project diversions made out of priority. For Future Level Use Scenarios, the release requirement for water sales is additionally incorporated.

- Windy Gap is operated as a transbasin diversion limited by a 600 cfs capacity.

- The instream flow requirements incorporated in the model are summarized in Table 5.2. For the proposed reservoirs, it is assumed that releases are made to meet downstream demands and the releases can be credited as a part of the instream flow requirements.

The model was initially applied to historic conditions using the appropriate operation rules for calibration and validation purposes. The basic input data used were virgin flows (historic flows adjusted for diversions and reservoirs) and estimated or recorded diversion data discussed in Section 4.0. The recorded and simulated flows at several locations of the Colorado River were compared. They are presented in Table 5.3. The historic and simulated reservoir contents for Green Mountain Reservoir were also compared. They are shown in Figure 5.1. In both cases, the

TABLE 5.2

INSTREAM FLOW REQUIREMENTS

LOCATION	REQUIREMENT
Below Granby Reservoir	20 cfs Oct - Apr 75 cfs May - July 40 cfs Aug 20 cfs Sept
Below Willow Creek Reservoir	7 cfs Oct - Apr
Below Windy Gap	90 cfs Oct - Sept
Below Williams Fork Reservoir	15 cfs Oct - Sept
Below Dillon Reservoir	50 cfs Oct - Sept
Below Green Mountain Reservoir (1)	60 cfs Oct - Sept
Below Homestake Reservoir	24 cfs Oct - Sept
Below Hunter Creek Diversion	21 cfs Oct - Sept
Below Ruedi Reservoir	39 cfs Nov - Apr 110 cfs May - Oct
Below Azure Reservoir (1)	150 cfs Oct - Sept
Below Red Mountain Reservoir	150 cfs Oct - Sept
Below Wolford Mountain Reservoir (1)	10 cfs Oct - Sept
At Wolford Colo. R. pump site (1)	150 cfs Oct - Sept
At Wolcott Eagle R. pump site	45 cfs Oct - Mar 110 cfs Apr - Sept
At Wolcott Colo. R. pump site (1)	150 cfs Oct - Sept

NOTE: (1) Based on estimated or proposed values.

TABLE 5.3

COMPARISON BETWEEN
AVERAGE ANNUAL RECORDED
AND SIMULATED FLOWS
(1973 - 1983)

Gage	Recorded (1000 af)	Simulated (1000 af)
Colo. R. at Sulfur Springs	174	174
Fraser R. at Granby	101	101
Blue R. below Green Mtn Reservoir	293	290
Colo. R. near Kremmling	728	712
Colo. R. near Dotsero	1,509	1,496
Colo. R. near Debeque	2,647	2,642
Colo. R. near Cameo	2,727	2,724

AVERAGE CONTENTS 1973–1983

GREEN MOUNTAIN RESERVOIR

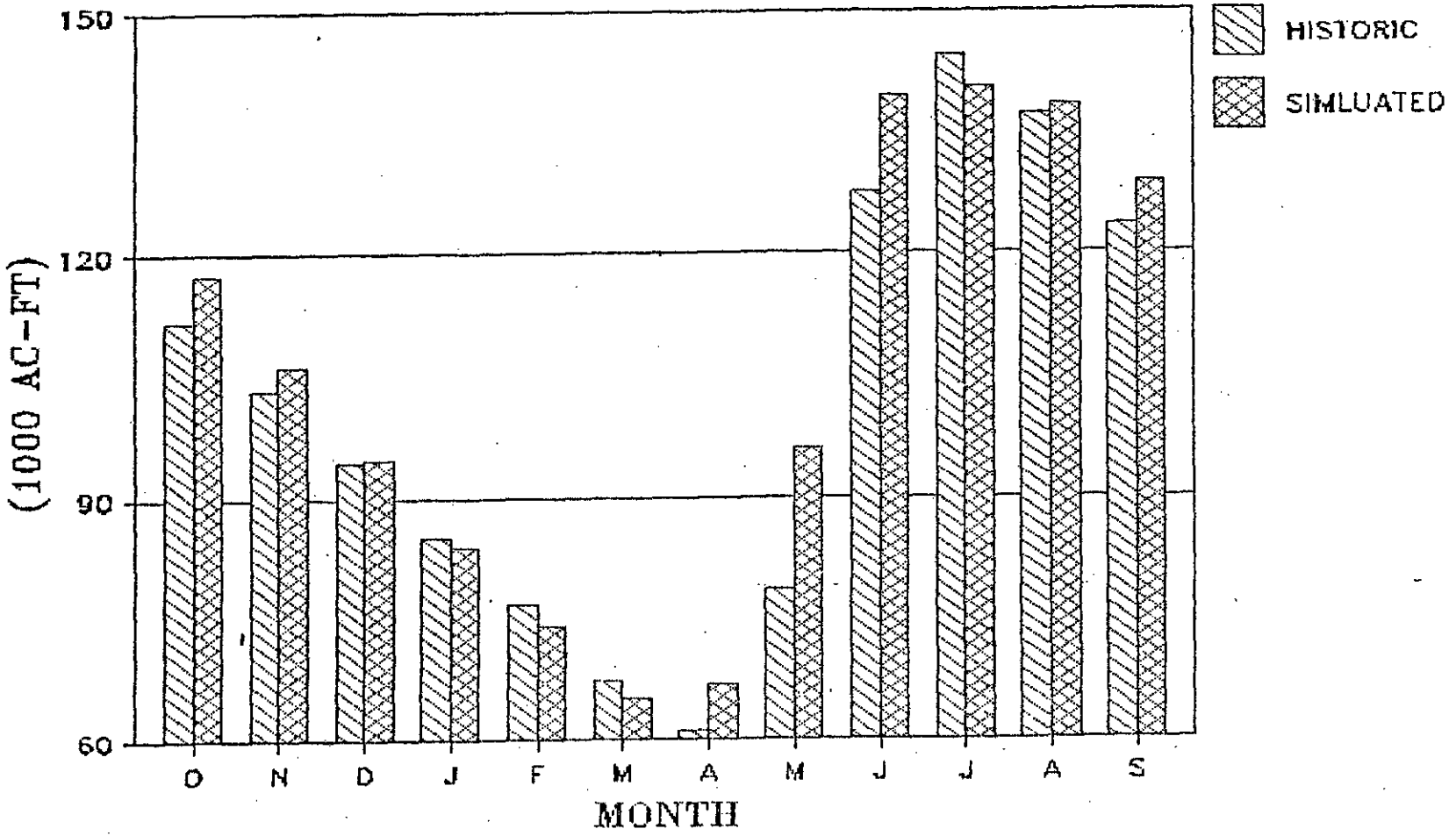


Figure 5.1

simulated results are in good agreement with recorded data. Some discrepancies in the Green Mountain Reservoir contents during April through June are due to difficulties in duplicating historical power release schedules which were highly variable during this period.

5.2 PROJECT RESERVOIR YIELDS

The hydrologic simulation model was applied to estimate storable water at each proposed reservoir site under the three development scenarios discussed in Section 3.0. Under each development scenario, two different conditions for the operation of Green Mountain Reservoir were assumed. One condition, referred to as "Without Pumpback", assumes that Green Mountain Reservoir will continue to operate in accordance with Senate Document 80. The other condition assumes that water will be pumped from Green Mountain Reservoir to Dillon Reservoir. This second condition reflects one of the alternatives envisioned under the Green Mountain Reservoir Exchange concept. Two alternative pumpback capacities were studied. The "154,000 Pumpback", alternative assumes that the entire storage of Green Mountain Reservoir, (approximately 154,000 af) be made available for pumpback to Dillon Reservoir except for the required 60 cfs minimum flow requirement. The other alternative analyzed in this study assumes that the active storage of 52,000 af be kept in Green Mountain Reservoir to be used to satisfy CBT out-of-priority diversions, while the remaining power pool be used to supply water to Dillon Reservoir. This alternative is referred to as "100,000 Pumpback".

Subsequent to the hydrologic analysis which provided estimates of storable flows, the reservoir operation analysis was performed to estimate the firm annual yield of each reservoir. The firm annual yield is defined for the purpose of this study as the constant volume of water that can be supplied every year without any shortage during the study period of 1951 through 1983. It was

assumed that the monthly release schedule would be uniform throughout each year.

The study period (1951-1983) includes the two significant drought periods of 1954-1956 and 1977. These become critical periods for determining the firm annual yield. Based on a drought frequency analysis performed in the screening phase of this study, it is estimated that the 1954-195 drought would occur once in 50 to 100 years while the 1977 drought would occur once in 30 to 50 years depending on location of the stream. Accordingly, the firm annual yield presented in this report indicates the safe amount of water that can be supplied during these two drought periods.

For each single reservoir, several reservoir capacities were selected to develop a relationship between capacity and yield. The results are summarized in Table 5.4.

Wolford Mountain Site A' and Wolcott were analysed for use as off-stream storage sites. The Wolford Mountain Site A' analysis considered two alternate diversion locations on the Colorado River, one above the confluence with the Blue River and one below. Wolcott Reservoir could store water from the Eagle River and the Colorado River. The analysis of the combination reservoirs are based on the following capacities.

TABLE 5.4

ESTIMATED RESERVOIR FIRM YIELD (1)
(1000 af/yr)

RESERVOIR	CAPACITY (1000 af)	EXISTING		MODERATE FUTURE		HIGH FUTURE	
		W/O PUMPBACK	W/ PUMPBACK(2)	W/O PUMPBACK	W/ PUMPBACK(2)	W/O PUMPBACK	W/ PUMPBACK(2)
Wolford A' w/ Div Above Blue	120	54	44	50	42	50	42
	80	42	35	38	32	38	32
	60	33	27	29	25	29	25
Wolford A' w/ Div Below Blue	120	56	49	51	46	51	45
	80	43	36	39	34	39	33
	60	35	28	31	26	30	26
Wolford C	80	32	31	31	30	31	29
	60	26	24	25	24	25	23
Red Mountain	140	59	58	58	56	56	54
	110	52	51	49	48	47	47
	84	43	42	39	38	36	36
Wolcott w/ Eagle & Col Div	350	183	175	178	168	163	159
	220	132	126	129	122	121	112
	160	99	97	95	89	90	82
Wolcott w/ Eagle Div	160	96	88	93	81	80	75
	140	89	83	85	75	74	68
	100	65	58	63	54	57	49
Azure	85	53	53	51	51	48	48
	60	38	38	36	36	33	33
	40	26	26	24	24	20	20
Una	196	150	150	150	150	150	150
	140	95	95	95	95	95	95
	100	55	55	55	55	55	55
Red Mt and Wolcott	300	111	103	109	101	106	98
Azure and Wolcott	245	146	134	141	132	131	124
Red Mt and Una	336	209	208	208	206	206	204

(1) Firm Annual yield is defined as the constant volume of water that can be supported every year without any shortage during the study period of 1951 through 1985.

(2) NOTE: For 154000 Pumpback

Red Mountain and Wolcott Reservoirs

Red Mountain Reservoir:	140,000 af
Wolcott Reservoir :	160,000 af
(w/Eagle Diversion only)	
Total	300,000 af

Azure and Wolcott Reservoirs

Azure Reservoir:	85,000 af
Wolcott Reservoir:	160,000 af
(w/Eagle Diversion only)	
Total	245,000 af

Red Mountain and Una Reservoirs

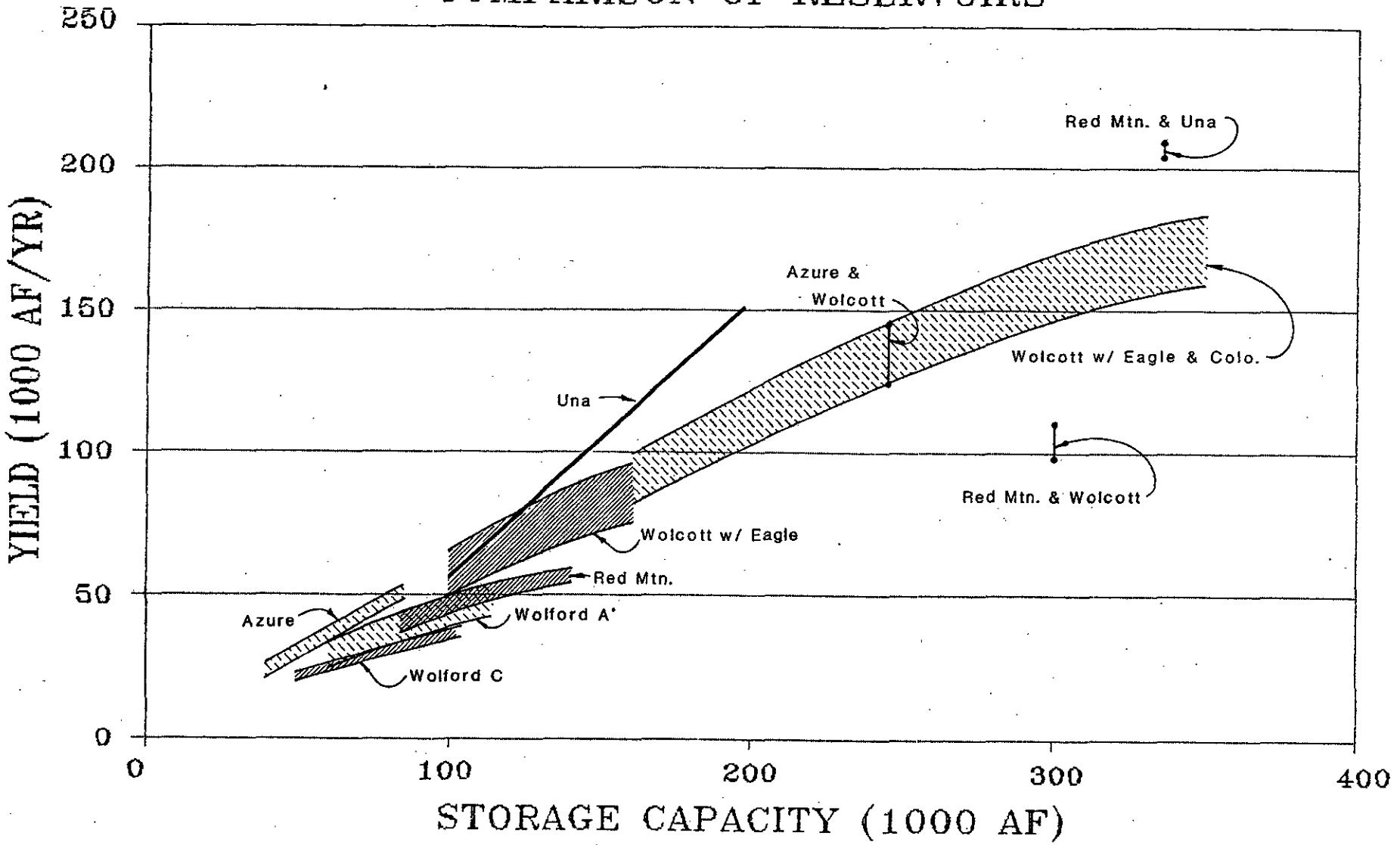
Red Mountain Reservoir:	140,000 af
Una Reservoir:	196,000 af
Total	336,000 af

The capacity and yield relationship are depicted in the Figure 5.2 for the range of yields and capacities analyzed. The upper boundary of the shaded area represents the relationship under the Existing Level Use Scenario without the pumpback system. The lower boundary represents the relationship under the High Future Level Use Scenario with the 154,000 af pumpback system. These two conditions represent extremes of the yields estimated for various conditions analyzed in this study.

It is evident from the figure that all six reservoir sites can produce the necessary yield to meet the Joint-Use Reservoir requirement (approximately 30,000 af). From the standpoint of storage efficiency (water yield capacity per unit volume of storage), Una Reservoir becomes the most efficient followed by Wolcott Reservoir with Colorado and Eagle Diversions. It should also be noted that for most reservoir sites the yield-storage

ESTIMATED RESERVOIR YIELD

COMPARISON OF RESERVOIRS



NOTES:

1 - Firm annual yield is defined as the constant volume of water that can be supported every year without any shortage during the study period of 1951 through 1983.

2 - The upper line indicates the yield relationship under the Existing Scenario without the Pumpback System and the lower line indicates the yield relationship under the High Future Scenario with the Pumpback System.

3 - Wolford A' displays the relationship for the alternative with the diversion intake above the Blue River.

Figure 5.2

relationship curve becomes flat at the maximum capacity considered in this study. An increase beyond the indicated maximum capacity would not substantially increase the yield. An exception to this case is the Una site where the yield to active storage relationship becomes almost one to one. Also, the yield from the Una site would not be reduced under Future Level Use Scenarios. The yields for the combination reservoirs are shown only for one set of capacities.

6.0 GREEN MOUNTAIN RESERVOIR EXCHANGES

6.1 GREEN MOUNTAIN RESERVOIR WATER SUPPLY

As discussed in the previous sections, releases from Green Mountain Reservoir are to be used for out-of-priority CBT Project diversions, in-basin use to supplement natural flow shortages, water sales and power generation. In addition, the reservoir supplies supplemental water for the Silt Project, an irrigation project located near Silt, Colorado. The operation study was performed to estimate each of these Green Mountain Reservoir Water uses. The demands for water sales and the Silt Project used for this study are based on figures presented in the Green Mountain Reservoir Water Marketing Program EIS issued in September, 1985.

Table 6.1 presents a summary of the results. The in-basin water uses presented in the table include those for the Silt Project and Water Sales. The total indicates a combination of the replacement for CBT out-of-priority diversion and the in-basin uses.

The USBR has maintained the Colorado River Accounting Sheets since 1964. These include accounts of the Green Mountain Reservoir water uses. The average annual release made for CBT out-of-priority replacement was 21,600 af during the period of 1964 through 1982. The release estimated in this study for the same period is 21,200 af which compares well with the recorded data.

TABLE 6.1

ESTIMATED ANNUAL RELEASE REQUIREMENT (1000 af/yr)
FROM GREEN MOUNTAIN RESERVOIR
(Water Years 1951 - 1983)

	LOW (1)	HIGH (1)	AVE
CBT Replacement	8.9 (1965)	44.7 (1963)	23.1
In-Basin Uses	8.0 (1970)	80.5 (1956)	25.3
Total	20.5 (1971)	105.5 (1956)	48.4

NOTE (1) Low and High total demands do not occur in the same year as the Low and High CBT Replacement and In-Basin demands occur. The figure in parenthesis indicates the year of occurrence.

6.2 REPLACEMENT CAPABILITY OF THE PROJECT RESERVOIRS

Reservoir operation analyses were performed to evaluate the capabilities of each single reservoir or combinations of reservoirs to meet the Green Mountain Reservoir release requirements as estimated in the previous section.

Two alternative systems of pumping water from Green Mountain Reservoir to Dillon Reservoir were considered, the 100,000 af and 154,000 af Pumpback Systems. These are described in section 5.2

For the 100,000 af Pumpback Alternative, evaluation was made of Wolford Mountain Site A', Red Mountain, Azure and Wolcott (with diversion from the Eagle River only) Reservoirs. It was assumed that these reservoirs are required to supplement natural water shortages, and to meet the Silt Project demand and water sales.

For the 154,000 af Pumpback Alternative, an analysis was made of Wolcott Reservoir (with diversions from the Eagle and Colorado Rivers) and combinations of reservoirs including Wolcott and Red Mountain; Wolcott and Azure; and Red Mountain and Una Reservoirs.

Wolcott Reservoir when combined with another reservoir, includes diversions from the Eagle River only. It was assumed that these single and combinations of reservoirs are required to provide the replacement water for CBT out-of-priority diversions in addition to the in-basin use, Silt Project, and water sales requirements.

The combination of Red Mountain and Una Reservoirs was analyzed with the assumption that Red Mountain Reservoir would provide water to supplement natural water shortages for in-basin uses (with a perfected water right senior to 1977) and water sales above Dotsero. This would relieve them from the Shoshone call. Una Reservoir would be used to replace the supplemental water diverted for those rights and water sales downstream of Dotsero and to satisfy the Cameo demands. The average annual demands for this breakdown for upstream and downstream of Dotsero are estimated to be 31,600 af and 16,800 af, respectively.

The operational analysis results are summarized in Table 6.2. Presented in this table are the amounts of storage shortage and surplus. Shortages are indicated by a sign of (-) and surpluses indicated by a sign of (+). All storage shortages shown in the table are the result of the early 1950's drought. For example, it is estimated that the Wolford Mountain Site A' is incapable of meeting the in-basin demand by 25,300 af during the 1950's drought period. If additional carryover storage equal to this amount could be provided, the in-basin demand would be satisfied.

TABLE 6.2

PROJECT RESERVOIR'S CAPABILITY TO MEET
GREEN MOUNTAIN RESERVOIR DEMANDS
FOR STUDY PERIOD 1951 - 1983

RESERVOIR	MAX. STORAGE (1000 af)	STORAGE SHORTAGE/SURPLUS (1000 af)(1) EXISTING	MODERATE FUTURE	HIGH FUTURE
100,000 PUMPBACK TO MEET IN-BASIN/SALES DEMANDS				
Wolford A'	120	- 25	- 38	- 44
Red Mountain	140	- 13	- 21	- 29
Azure	85	- 2	- 3	- 7
Wolcott (w/Eagle Div)	160	+ 64	+ 64	+ 64
154,000 PUMPBACK TO MEET CBT/IN-BASIN/SALES DEMANDS				
Wolcott (w/Eagle & Colo. Div)	350	+201	+196	+192
Wolcott (w/Eagle Div) + Red Mountain	300	+105	+102	+ 97
Wolcott (w/Eagle Div) + Azure	245	+ 90	+ 87	+ 81
Una + Red Mountain	336	+134	+123	+115

NOTE: (1) (-) Indicates storage shortage.
(+) Indicates storage surplus.

7.0 RECOMMENDATIONS

The analyses show that all six reservoir sites can produce the necessary yield to meet the Joint-Use Reservoir requirements (approximately 30,000 af). In addition Wolcott Reservoir alone, and reservoir combinations can meet the replacement requirements of the Green Mountain Exchange Project. It is therefore recommended that all sites be investigated further as part of Phase 3.

Phase 3 investigations will involve reconnaissance-level design, cost estimates, geotechnical investigation and additional operational analysis. The level of investigation required for each site will vary depending on the existing information available.