CITY OF AURORA

Proposed Excess Capacity Contracts
Fryingpan-Arkansas Project

Draft Hydrologic Model DOCUMENTATION

Prepared for:

Bureau of Reclamation
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PREFACE

This document was prepared to provide a description of the hydrologic model used to assess the effects of proposed contracts between Reclamation and City of Aurora for the use of excess capacity in the Fryingpan-Arkansas Project. As such, it was prepared to fulfill a portion of the reporting requirements of the Water Resources Studies Task of Professional Services Agreement No. 02PO783 (dated November 26, 2003) between the City of Aurora and MWH Americas, Inc. A companion document, the *Water Resources Technical Memorandum*, fulfills the reporting requirements of the Water Resources Task.

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ABBREVIATIONS AND ACRONYMS

CDSS	Colorado Decision Support System
CSU	Colorado Springs Utilities
DFLOW	Design Flow, EPA stream flow program
DLL	Dynamically Linked Libraries (MS Windows computer program files)
EA	Environmental Assessment
EIS	Environmental Impact Assessment
EPA	U.S. Environmental Protection Agency
FMP	Flow Management Plan
FVA	Fountain Valley Authority
GEI	GEI Consultants, Inc.
GRC	Grand River Consulting Corporation
GUI	Graphical User Interface
HRC	Hydrosphere Resource Consultants, Inc.
IGA	Intergovernmental agreement
IHA	Indicators of Hydrologic Alteration (software program)
MWH, MW	Montgomery Watson Harza
NEPA	National Environmental Policy Act
NWS	U.S. National Weather Service
PBWW	Pueblo Board of Water Works
RICD	Recreational In-Channel Diversion
ROY	Recovery of Yield (reservoir storage)
SECWCD	Southeastern Colorado Water Conservancy District
SDS	Southern Delivery System (pipeline
TMDL	Total Maximum Daily Load
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
VBA	Visual Basic for Applications (programming language)
WWSP	Winter Water Storage Program

EXECUTIVE SUMMARY

The United States Bureau of Reclamation is considering a request from the City of Aurora, Colorado, for a long-term excess capacity contract. The purpose of the proposed contract is to establish a long-term agreement between Reclamation and Aurora that allows Aurora to more efficiently manage and use its decreed Arkansas River Basin water rights.

This report provides documentation of Aurora's Quarter-Monthly Model. It includes information on the underlying network optimization modeling tool, overall modeling approach, data sources relied upon, major model assumptions, model limitations, model calibration and simulation of EA alternatives. Results of the model are presented in the Water Resource Technical Memorandum, a companion EA document presented under separate cover. As the EA lead agency, the Bureau of Reclamation (Reclamation) has provided technical oversight and has reviewed and approved the final model, including this documentation.

ES.1 Model Selection and Description

The purpose of the hydrologic model is to simulate the operations and effects of the Proposed Action and other reasonably foreseeable water projects in the Arkansas River Basin. The existing Quarter-Monthly Model developed by Hydrosphere Resource Consultants, Inc. (Quarter-Monthly Model) was refined to meet the modeling requirements of this project.

The Quarter-Monthly Model simulates conditions on a quarter-monthly time-step. A quarter-monthly time-step is similar to a weekly, except some weeks have eight days, which allows for calculation of monthly and annual statistics. The Quarter-Monthly Model simulates the operation of Aurora's existing supplies, including the Colorado Canal transfer, the Rocky Ford I, the Rocky Ford II transfer and the Highline Canal lease. The Quarter-Monthly Model also simulates other basin operations such as native water rights and diversions, the Fryingpan-Arkansas Project, the Winter Water Storage Program and other transmountain diversion and storage projects that affect water supplies and streamflow in the Arkansas River Basin. The model has been used by the City of Aurora for planning purposes in the Arkansas Basin for several years.

ES.2 Model Data

The Quarter-Monthly Model is based on decreed and conditional water rights, water rights applications, historical and projected operations of water users, historical and forecast water demands, and historical gage records. The study period selected depends on several criteria, including the purposes of the model, the extent of available data, and historical changes in river operating conditions. Reclamation's NEPA guidance suggests a minimum 20-year data set (Reclamation, 1997). A study period of water years 1982 through 2002 was selected because the diversion facilities for the Fryingpan-Arkansas Project were essentially complete and river basin operations have remained fairly consistent throughout this period.

The Proposed Action will primarily affect flows in the Arkansas River. Changes in flow were calculated from the confluence of Lake Fork and the Arkansas River at Leadville, through the Holbrook Reservoir outlet works. Because water quality impacts may extend further downstream, the hydrologic modeling was extended downstream to the La Junta gage. The Quarter-Monthly Model includes inflows from major tributaries, including Fountain Creek.

Data required for the Quarter-Monthly Model includes historical streamflow data, historical and future diversion data, historical storage data, water rights data, as well as other miscellaneous water operations and ownership data. No comprehensive database containing all required data existed at the onset of the project. The State of Colorado's Decision Support System (CDSS) contained a significant amount of hydrologic data required for the Quarter-Monthly Model. Other sources of data included the U.S. Geological Survey, Reclamation, Colorado Springs Utilities, and others. Ungaged gains and losses, which include transit losses for historical operations, were calculated and then imported into the model.

ES.3 Model Scenarios

As part of the EA, two separate analyses were performed that require simulated streamflows and reservoir contents from the Quarter-Monthly Model: the Effect Analysis and the Cumulative Effects Analysis. The Effects Analysis estimates the effects of the Proposed Action and No Action Alternatives due to these actions alone. The Cumulative Effects analysis estimates the effects of the Proposed Action and No Action Alternative when combined with other reasonably foreseeable actions in the basin.

For each of the analyses, both the Proposed Action and No-Action alternatives were simulated. In addition, for purposes of comparison by the resource studies, an Existing Conditions analysis was simulated. Quarter-Monthly Model assumptions and settings for each of the analyses and alternative are described in the following sub-sections. A summary of the Quarter-Monthly Model variable settings is presented in **Table ES-1**.

Historical water operations have varied over time. To prevent differences resulting from inconsistent operations, the Existing Conditions scenario assumes existing (circa 2004) operations on the river for the entire study period (1982-2002). The historical conditions, on the other hand, reflect varied river operations and demands on the river during the 1982 through 2002 study period.

Under the Proposed Action, Reclamation would execute a long-term (40-year) excess capacity contract(s) with Aurora for the use of up to 10,000 acre-feet of available excess storage capacity in Pueblo Reservoir. The storage space could be filled and emptied multiple times each year to accommodate water exchanges to Twin Lakes Reservoir, Turquoise Lake, and the Otero Pump Station. In addition, Reclamation would enter into a separate contract with Aurora that would allow annual contract exchanges of up to 10,000 acre-feet of Aurora's water rights stored in Pueblo Reservoir with Fry-Ark Project water stored in Twin Lakes Reservoir and Turquoise Lake. Contract exchanges could take place multiple times in one year, as long as the total amount exchanged in any year does not exceed 10,000 acre-feet. The Proposed Action does not require construction of new facilities to accommodate storage, conveyance, and exchange of this water. The proposed excess capacity contracts would use existing facilities to move Aurora's water from the Arkansas River basin to the South Platte River basin via pipelines and the Otero Pump Station north of Buena Vista.

Under the No Action Alternative, Reclamation would not enter into an excess capacity contract with Aurora or an agreement with Aurora for contract exchanges. In the absence of these contracts with Reclamation, Aurora would construct gravel pit storage to replace the storage in Pueblo Reservoir. The analysis performed by the model only determines the long-term effects of the No Action Alternative, and does not calculate effects for the alternative before the gravel pit storage is constructed.

Table ES-1. Summary of Simulation Model Variable Settings for Effects Analysis

Model Variable	Existing Condition	Effects		Cumulative Effects	
		No Action	Proposed Action	No Action	Proposed Action
General Settings					
Municipal Demands	2004	2004	2004	2045	2045
Additional Demand by Others(1)	No	No	No	Yes	Yes
Agricultural Demands(2)	Historical	Historical	Historical	Historical	Historical
Otero Pump Station Capacity	118.5 mgd	118.5 mgd	118.5 mgd	118.5 mgd	118.5 mgd
Aurora Settings					
Excess Capacity in Pueblo Reservoir	10,000 ac-ft	0 ac-ft	10,000 ac-ft	0 ac-ft	10,000 ac-ft
Gravel Pit Storage	0 ac-ft	10,000 ac-ft	0 ac-ft	10,000 ac-ft	0 ac-ft
USBR Contract Exchanges	0 ac-ft	0 ac-ft	10,000 ac-ft	0 ac-ft	10,000 ac-ft
Transmountain Diversions	Yes	Yes	Yes	Yes	Yes
Upper Arkansas Ranch Water Rights	Yes	Yes	Yes	Yes	Yes
Rocky Ford I Transfer	Yes	Yes (junior to RICD)	Yes	Yes (junior to RICD)	Yes
Colorado Canal	Yes	Yes	Yes	Yes	Yes
Rocky Ford II Transfer(3)(4)	Yes (50%)	Yes (100%)	Yes (100%)	Yes (100%)	Yes (100%)
Highline Lease	Yes	Yes	Yes	Yes	Yes
Pueblo FMP/RICD - Aurora	None	None	Full	None	Full
ROY Storage - Aurora	No	No	Yes	No	Yes
Other Municipal Settings					
Pueblo Board of Water Works Excess Capacity Storage in Pueblo Reservoir	3,000 ac-ft	3,000 ac-ft	3,000 ac-ft	15,000 ac-ft	15,000 ac-ft
Pueblo West Excess Capacity Storage in Pueblo Reservoir	1,000 ac-ft	1,000 ac-ft	1,000 ac-ft	1,000 ac-ft	1,000 ac-ft
Colorado Springs Utilities Excess Capacity in Pueblo Res.	10,000 ac-ft	10,000 ac-ft	10,000 ac-ft	1,000 ac-ft	1,000 ac-ft

Table ES-1. Summary of Simulation Model Variable Settings for Effects Analysis

Model Variable	Existing Condition	Effects		Cumulative Effects	
		No Action	Proposed Action	No Action	Proposed Action
Pueblo FMP/RICD - Others(5)	None	None	None	None	None
ROY Storage - Others	No	No	No	Yes	Yes
Colorado Springs' Future Operations(6)	No	No	No	Yes	Yes

Notes:

(1) Additional demand by municipal users for Fry-Ark Project water

(2) Agricultural demands are assumed to be the same as historical except for those systems that have been converted to municipal use, such as the Colorado Canal system, Rocky Ford Ditch and Highline Canal lease.

(3) The percentage value indicates the percent of the total decreed yield that is changed and diverted by Aurora. By decree, water cannot be changed from a tract of land until revegetation and "dry-up" is complete.

(4) During actual 2004 operations, because Aurora's Upper Basin exchange application (99CW170) was not finalized, Rocky Ford II water was diverted into the PBWW Excess Capacity account in Pueblo Reservoir, then moved to Twin Lakes by contract exchange with the PBWW (Simpson, 2005). The Upper Basin exchange was decreed in 2005. Therefore, the Quarter-Monthly Model operates per the decree. The differences in storage and streamflow between actual and simulated operations during 2004 are negligible.

(5) Due to limitations in the Quarter-Monthly Model, all Colorado Canal exchanges (including those by Colorado Springs Utilities, Pueblo West and the City of Fountain) are subject to the same Pueblo FMP conditions as other Aurora exchanges

(6) Colorado Springs Utilities increased ground water pumping and increased non-potable and potable reuse.

ES.4 Required Output and Deliverables

Because of the model's spatial and temporal extent, the Quarter-Monthly Model produces a tremendous amount of output data. Therefore, thoughtful selection of the required output is required. This section documents the location, type and format for model output. Output data includes streamflow gages for the Arkansas River from its headwaters downstream to the La Junta gage, Turquoise Reservoir, Pueblo Reservoir, Lake Meredith, Lake Henry and Holbrook Reservoir. Model output was in acre-feet per quarter-month for streamflow gages and end-of-quarter-month storage for reservoirs. This data was converted to appropriate units for use in the resource studies.

1.0 INTRODUCTION

The United States Bureau of Reclamation (Reclamation) is considering a request from the City of Aurora, Colorado, for long-term excess capacity contracts. The purpose of the proposed excess capacity contracts for use of storage space in Reclamation's Fryingpan-Arkansas (Fry-Ark) Project is to establish a long-term agreement that allows Aurora to efficiently manage and use its decreed Arkansas River water rights and leased Arkansas River water. Aurora's water rights and leased water from the Arkansas River provide about 25 percent to 40 percent of its water supply (depending on hydrologic conditions in a particular year) and are needed to meet the City's existing and projected municipal and industrial water demands. Use of excess capacity in the Fry-Ark Project would eliminate the need for construction of a new reservoir and other facilities to accommodate storage, conveyance, and exchange of this water.

The Fry-Ark Project is a Reclamation project that delivers water from the West Slope of Colorado to the upper Arkansas River Basin near Leadville. Turquoise Lake and Twin Lakes Reservoir are Reclamation facilities in the upper Arkansas River Basin that store Fry-Ark Project water before it is delivered to downstream users. From Turquoise Lake and Twin Lakes Reservoir, Fry-Ark Project waters are delivered via the Arkansas River to Pueblo Reservoir where this water is further distributed to Fry-Ark Project users.

Reclamation has the authority to decide whether to enter into a long-term (40-year) contract or contracts with Aurora to implement these storage and exchange agreements. Because this decision and the associated contracts require a federal action, the Project is subject to compliance with the National Environmental Policy Act (NEPA) of 1969, amendments, and other regulatory laws. Reclamation is preparing an Environmental Assessment to analyze and disclose the potential effects associated with the Proposed Action, as well as No Action if Reclamation denies the request for storage and exchange. To assist in the preparation of the EA, Reclamation has requested that a third-party consultant team prepare technical memoranda for resources of concern. The technical memoranda provide information on the affected environment and the environmental consequences of the Proposed Action and No Action Alternative. Information from the technical memoranda will be used in preparation of the EA. This document is a companion document to the Water Resources Technical Memorandum.

1.1 Hydrologic Model Documentation

This document describes the hydrologic model used as part of the effects analysis for the EA. The hydrologic model described in this document was developed by Hydrosphere Resource Consultants, Inc. (HRC). Included in the document is a framework for the modeling effort, a brief description of the model and the criteria by which the model was developed, including the model data, model construction and output formats. The Water Resources Technical Memorandum presents the model results and analysis of the results.

1.1.1 Purpose of the Model

The purpose of the model is to quantify the effects of proposed water development projects within the Arkansas River Basin. The Quarter-Monthly Model has the ability to:

- determine the operational feasibility of the Proposed Action and the potential alternatives;
- determine the spatial extent of the hydrological affected environment;
- develop simulated time-series hydrology at specific stream locations and reservoirs for each of the alternatives; and
- determine the yield of the Proposed Action and alternatives.

Output from the model was used to develop other physical properties of flows at selected points, including flow depth, velocity and wetted perimeter. In addition to the physical flow properties, the output data were used in the Indicators of Hydrologic Alteration (IHA) statistical hydrology package. This package develops a suite of statistics for various scenarios and alternatives that can be used by EA resource studies to compare flows between alternatives. The methods and development of these data are discussed in the Water Resources Technical Memorandum.

1.1.2 General Model Description

The Quarter-Monthly Model simulates conditions on a quarter-monthly time-step. A quarter-monthly time-step is similar to a weekly time-step, except some weeks have eight days, which allows for calculation of monthly and annual statistics. The model has been used by the City of Aurora for planning purposes in the Arkansas Basin for several years.

The Quarter-Monthly Model simulates the operation of Aurora's existing supplies, including the Colorado Canal transfer, the Rocky Ford I and II transfers, and the Highline Canal lease. Alternatives simulated by the Quarter-Monthly Model do not include any water supplies for Aurora not currently decreed or approved.

The model includes both existing and non-existent facilities required for the various scenarios. Non-existent facilities include a gravel pit fed by the Excelsior Ditch, which Aurora would use to hold exchangeable water in lieu of an account in Pueblo Reservoir under the No-Action alternative.

1.1.3 Previous Modeling Efforts

The Quarter-Monthly Model has been used by Aurora to quantify how changes in operations and facilities would affect Aurora's yields from the Arkansas River basin. Additionally, the model has been used to simulate the operation of Aurora's water rights in the basin in conjunction with their ownership of storage facilities in the Colorado Canal System, Twin Lakes Reservoir and Turquoise Reservoir.

1.2 Relationship to Other Resource Studies

Output from the Quarter-Monthly Model is summarized in the Water Resources Technical Memorandum and will be used by several other resource areas. The relationships with each of these resource areas are further described below.

The Water Resources Technical Memorandum is used to convey information on existing water resources conditions and results of the hydrologic analyses to the other resource teams. As part of the water resource analysis, streamflow was translated to stage using rating curves at existing streamflow gages and reservoir contents were translated to water surface elevation and surface area using reservoir rating curves. In addition, the water resources studies required model results to determine the geomorphic and water quality effects.

Aquatic habitat studies utilize hydrologic model results of various kinds (e.g., minimum flows, average flows, water levels, hydraulic properties, and water quality) in the analysis to determine impacts in channels and reservoirs. The Aquatic Resources Technical Memorandum used the IHA method for analysis of aquatic habitat effects. IHA relies on statistical analyses of daily streamflow data for native or Existing Conditions and any project alternatives.

Wetland and vegetation specialists required seasonal hydrologic model results in streams and reservoirs, and overbank flow conditions in floodplains.

Studies of aesthetics, socioeconomics, and land use required flow rates, water levels and erosion conditions for the Existing Conditions, Proposed Action Alternative and No Action alternatives.

Recreation studies required existing and simulated channel hydrology data and reservoir water levels.

The water resources team coordinated with other resource specialists to provide required information needed to address any issues raised during the EA study process.

1.3 Description of Alternatives

Aurora currently owns Arkansas River Basin water rights, and utilizes annually renewed "if-and-when" storage contracts with Reclamation to store Arkansas River Basin water in Pueblo Reservoir. An "if-and-when" contract permits Aurora to store non-Fry-Ark Project water in Pueblo Reservoir if-and-when Reclamation determines that conditions are appropriate. An exchange decree, issued by the State water court, allows entities to exchange water between locations by physically diverting and replacing water in priority. Contract exchanges allow willing entities to exchange water between storage accounts in different reservoirs.

The Existing Conditions discussed throughout this memorandum refer to the Arkansas River Basin operations as of 2004, and do not represent historical operations.

The future conditions action proposed by Aurora would provide a long-term and reliable contracting arrangement alternative to the current "if-and-when" contracting arrangement. The Proposed Action is to enter into a long-term contract with Aurora to allow the use of excess capacity in Pueblo Reservoir of the Fry-Ark Project for storage and conveyance of Aurora's non-Fry-Ark Project water and contract exchange of Aurora's water with Fry-Ark Project water. Under the No Action Alternative, Reclamation would no longer contract with Aurora for the storage and exchange of Aurora's water rights, and Aurora would develop other means of storage in the Arkansas River Basin. The No Action Alternative Proposed Action alternatives are described in more detail below.

1.3.1 Proposed Action

Under the Proposed Action, Reclamation would execute a long-term (40-year) excess capacity contract(s) with Aurora for the use of up to 10,000 acre-feet of available excess storage capacity in Pueblo Reservoir. The storage space could be filled and emptied multiple times each year to accommodate water exchanges to Twin Lakes Reservoir, Turquoise Lake, and the Otero Pump Station.

In addition, Reclamation would enter into a separate contract with Aurora that would allow annual contract exchanges of up to 10,000 acre-feet of Aurora's water rights stored in Pueblo Reservoir with Fry-Ark Project water stored in Twin Lakes Reservoir and Turquoise Lake. Contract exchanges could take place multiple times in one year, as long as the total amount exchanged in any year does not exceed 10,000 acre-feet.

The Proposed Action does not require construction of new facilities to accommodate storage, conveyance, and exchange of Aurora's water. Once native Arkansas River water is stored in Pueblo Reservoir, it may be exchanged upstream. The proposed excess capacity contracts would use existing facilities to move Aurora's water from the Arkansas River basin to the South Platte River basin via pipelines and the Otero Pump Station north of Buena Vista.

1.3.2 No Action Alternative

Under the No Action Alternative, Reclamation would not enter into an excess capacity contract with Aurora. Additionally, Reclamation would not enter into an agreement with Aurora for contract exchanges of up to 10,000 acre-feet of Aurora's Arkansas River water for Fry-Ark Project water in Twin Lakes Reservoir or Turquoise Lake. In the absence of these contracts with Reclamation, Aurora would look to other ways to use its decreed Arkansas River water rights. Aurora would pursue both short-term and long-term actions to secure and exchange existing Arkansas River water supplies. In the short-term, this would include filings with Colorado Water Court to modify existing decrees to allow additional alternate points of diversion to upstream locations for use of those water rights to upstream locations. In the long-term, new infrastructure, primarily gravel pit storage, would need to be constructed. The analysis contained within this document only considers the effects of the long-term No Action Alternative.

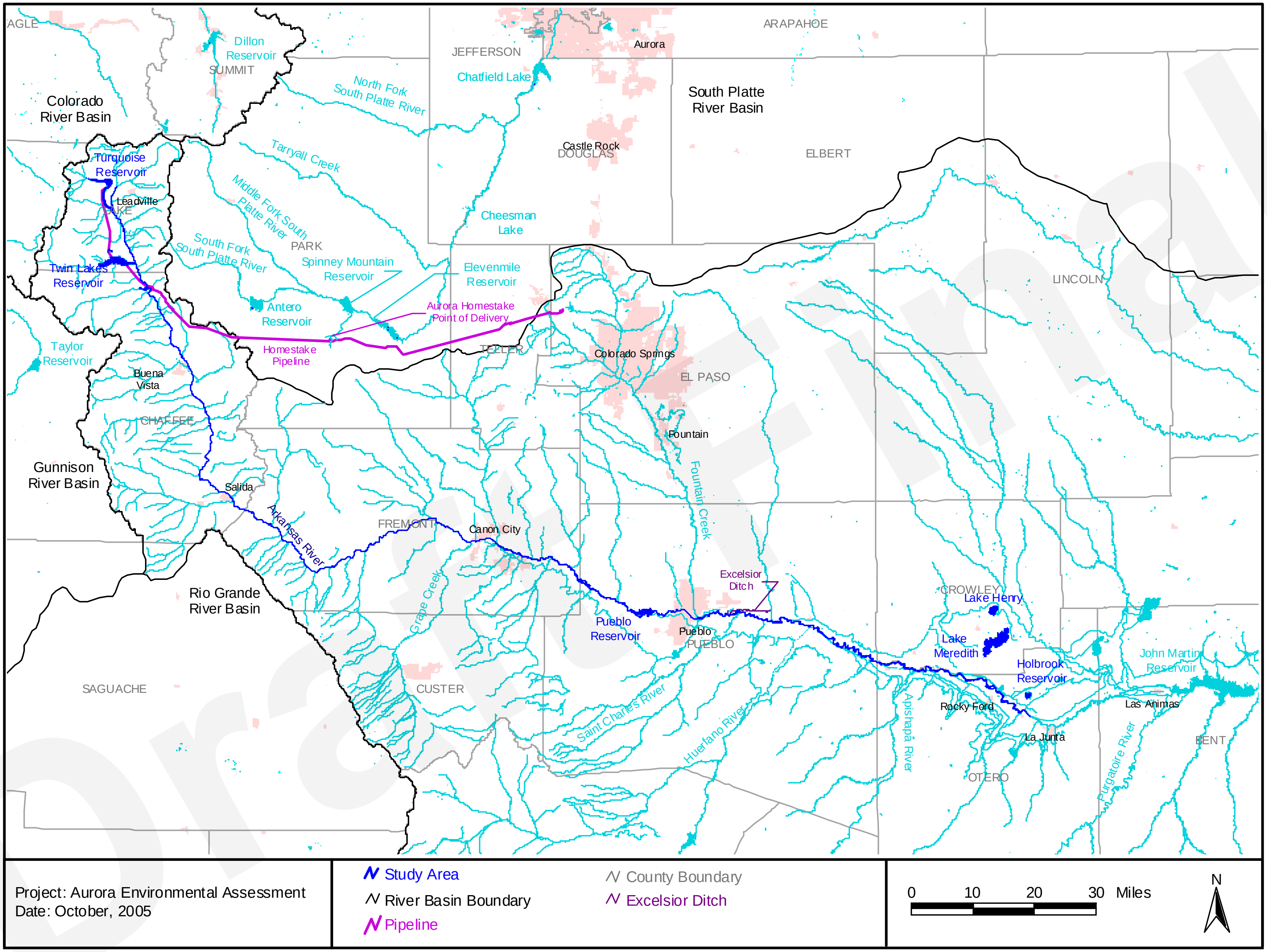
To provide for the long-term use of its water rights and to develop their full available yield, Aurora would develop a 10,000 acre-foot storage facility. Aurora currently has an option on the purchase of a gravel mining site that could provide water storage following gravel excavation. The gravel pit storage site is located adjacent to the Arkansas River about six miles downstream of the City of Pueblo. Depending on mining operations and final site development, it is anticipated that about 500 acres of land would be needed to provide sufficient storage for 10,000 acre-feet of water.

Water would be diverted to the gravel pit via the existing Excelsior Ditch located about two miles upstream of the gravel pit storage location (**Figure 1-1**). The Excelsior Ditch headgate on the Arkansas River is assumed to have adequate capacity, but some improvements to the Ditch may be necessary to convey Aurora's Arkansas River water rights. Water from gravel pit storage would be returned to the Arkansas River using a new outlet structure and pumping facilities as necessary. Development of the gravel pit site, including mining operations and the associated improvements that would be needed to make this site suitable for water storage, is expected to take about 10 years.

1.4 Study Area

The Quarter-Monthly Model study area encompasses Lake Fork below Turquoise Reservoir, Lake Creek below Twin Lakes Reservoir, and the Arkansas River from the Lake Fork confluence to the outlet of Holbrook Reservoir. Six existing reservoirs, including Twin Lakes, Turquoise Lake, Pueblo Reservoir, Lake Meredith, Lake Henry, and Holbrook Reservoir could potentially be affected by the proposed project. In addition, new gravel pit storage under the No Action Alternative would be located adjacent to the Arkansas River east of the City of Pueblo. These streams and reservoirs are collectively referred to as the study area and are shown in **Figure 1-1**.

Figure 1-1. Study Area Model Description



2.0 MODEL DESCRIPTION

Section 2 provides a general overview of the Quarter-Monthly Model. This section is meant to describe the model in sufficient detail so that necessary input data and model criteria can be defined.

2.1 General Solution Description

The Quarter-Monthly Model uses the ExcelCRAM model engine, which is a generalized network flow model. Generalized network flow models employ an optimization technique known as network flow programming to solve for an optimal set of flows in a network. The network flow programming algorithm simulates water allocation in river basins according to physical, hydrological and institutional parameters and other constraints. The Quarter-Monthly Model uses this optimization to allocate water to water rights in priority, and to simulate other operations that are driven by priorities, including exchanges.

The ExcelCRAM model engine embeds a network-flow-algorithm-based simulation system in Microsoft Excel. The network solver and simulation codes are provided in Dynamic Link Libraries (DLLs). Code that manages model simulation steps and most of the input and output is written in Visual Basic for Applications (VBA), the scripting language native to Excel. This provides for a simulation environment where the model inputs and outputs can be managed in a familiar spreadsheet program. Code to simulate special operations can be written in VBA.

In network flow programming, the model is created as a schematic constructed of a set of links connected by nodes. Like linear programming, pure network flow algorithms solve for a set of dependent variables so as to maximize the value of a system-wide objective function, subject to a set of constraints. The dependent variable is the flow through the links, which are limited with constraints representing the upper and lower bounds of flow. Links are "directed," which means they have a "from" node and a "to" node, though this does not necessarily limit flows to one direction, as negative lower bounds on flow are allowed. An additional constraint is that there is mass balance at each node, meaning that the flow in must equal the flow going out. Each link is assigned a unit cost coefficient that is applied to every unit of flow through the link. The objective function is the total, system-wide "cost" of all flows in the system. Networks amenable to solution by pure network formulations must be "circulating." This fundamental aspect of pure networks means that the solution algorithm guarantees mass balance.

Application of pure network algorithms to water resources problems requires that the real-world water resources system, its operating rules and its constraints be expressed in a form amenable to solution by the network. ExcelCRAM provides code that allows the user to use fairly high-level constructs (e.g., inflows, demands, reservoirs) to formulate a water resources problem, and additional code that translates that high-level formulation into a form that can be solved by the network algorithm. One purpose of these codes is to represent a river system, which is a tree-structured network, as a fully-circulating network amenable to solution by the network algorithm. The code also formulates high-level constructs as network components.

River systems are represented by a collection of links and nodes that contain physical information. System inflows, canals, rivers and demands and reservoirs are represented by links. Nodes are used to connect links. The model interface allows input of basic data requirements, as well as more complex network operating parameters such as water rights, including storage rights accounting, exchanges, instream flow requirements, augmentation plans and rule curves, all of which can vary with each time period. For operations that are too complex to represent through the standard model interface, the user also has the option to construct situation-specific VBA code. Code can be used to check and modify system operations.

There are eight types of links: regular conveyance links, inflows, demands, decrees, reservoirs, in-stream flows, and return flows. Regular conveyance links are used to connect other components, and can be opened, closed or constrained for each time-step. Inflow links provide water for the model to operate on. Demand links contain demands on the system, such as municipal and agricultural demands, water transfers, and reach losses. Demands also contain information such as consumptive use, demand patterns and water rights. Decrees are conveyance links that can be volumetrically limited over time. Reservoir links contain information regarding reservoirs, such as capacities, evaporation rates, target storage curves, and storage rights. Reservoir evaporation is calculated dynamically as a function of evaporation rate and surface area Return flows are inflows that account for water based on the flow in another link. These flows can either be positive to simulate a return flow, or negative, to simulate a transit loss.

Constructs of various links are used to represent complex systems. Link capacities are used to represent facility or reach capacities, or diversion, demand or storage targets. Link costs are mapped to water rights or system operation priorities. The model uses the priority on each link to allocate water, maximizing the value of the water distribution.

A fundamental assumption of the network approach is that flows within a single network and, thus, a single time-step in the application, are in equilibrium. A practical consequence of this is that routing is not simulated in the network, and therefore all flows within a single time-step are available at all points in the network. Accordingly, if the length of the time-step used to solve a system is less than the longest travel time between any two points in the system, some errors will be introduced in the solution. In real-world systems, the presence of reservoirs often serves to minimize the significance of these errors. The quarter-monthly time-step of Aurora's Quarter-Monthly Model is longer than the two to three day travel time from the top of the basin to the La Junta gage, so neglecting travel time is assumed to have no significant effect on the results.

ExcelCRAM uses a single, discrete network to simulate conditions in a single time-step. The system state variables (i.e., reservoir storage, return flows from previous time-steps) are used at the beginning of each time-step to initialize the network. This means that decisions in a time-step are based on information available at that point in the model run, so no foreknowledge of future conditions is utilized in simulating operations.

ExcelCRAM contains built in capabilities to perform simple ground water return flow routing. The timing and percentage of ground water return flows is specified in ExcelCRAM. Complex ground water modeling must be done outside of the ExcelCRAM model using a program such as MODFLOW.

2.1.1 General Model Use

ExcelCRAM has a graphical user interface (GUI) for model construction and operation. Because Aurora's Quarter-Monthly Model is constructed in ExcelCRAM which is based in the Excel environment, all model data is stored, operated on and displayed within the model.

Because ExcelCRAM is based on a GUI, links and nodes can be added in a topology similar to the actual system, which aids in understanding model operation. Data sheets containing time series data are stored as individual worksheets in ExcelCRAM, and allow the user to enter and modify data for individual model features. Because ExcelCRAM is based in Excel, all standard spreadsheet operations are available to the user to add, modify, summarize and graph model data.

ExcelCRAM is run using a toolbar entry added to Excel. Up to 253 links or data objects can be selected for inclusion on each output sheet, so the output table can become quite large. Output consists of columns of time series data, one column for each link or data object. Output can be viewed in tabular form on the output sheet, or in graphical forms constructed by the user. Output can include river and pipeline flows; reservoir account contents and evaporation; reach gains and losses; and river and contract exchanges by entity and water right.

ExcelCRAM has the ability to repeatedly solve the same time-step using operation steps (op-steps). Op-steps provide the modeler with a means to solve complex water rights administration and water operations problems. For example, in the Quarter-Monthly Model, the first op-step represents the allocation of native water rights, where all the links representing direct flow diversions are open. The second represents the allocation of transmountain water, where only a limited number of demand links would be open. Op-steps allow the modeler to track the water moving through the system by ownership, source or type. ExcelCRAM uses op-steps to simulate river exchanges, and can accurately account for junior decrees or stipulations that are dependent on the amount of water moved under senior decrees. This is particularly important to Aurora, which typically does not hold senior decrees.

2.2 Process Representations

ExcelCRAM can represent processes in three different ways:

- Explicit representation
- Implicit representation
- Data representation

Explicit representation of a process involves a simulation that dynamically responds to variables. An example of an explicit representation is a demand that is met according to its water right priorities, or a reservoir system that simulates the operations of the reservoir. Explicit representations can be predominantly mechanistic, process-oriented simulations or predominantly statistical, lumped-parameter simulations. Either process-oriented or statistical representations can be deterministic or stochastic. Explicit representations are implemented with both model codes and data. ExcelCRAM can support mechanistic or statistical representations, but does not support stochastic representations.

An implicit representation of a process is a static representation, often based on historical conditions, that is implicitly captured in the input data to the model. Implicit representations are not separately quantified, but are left embedded in other data. An example of an implicit representation is the operation of small water rights that are subsumed in the reach gain/loss data. It is often said of implicit representations that they are "left in the gage." Implicit representations are implemented in data and are not dependent on model codes.

Data representations, similar to implicit representations, are static, but they are quantified separately. An example of a static representation is the water "demand" associated with an agricultural water right. While the delivery to this water right could be explicitly represented according to its priority, the demand itself might be a static data set representing water demand under historical conditions, such as cropping and weather. Data representations are implemented in data and are not dependent on model codes.

2.3 Model Verification and Calibration

For purposes of this work, the terms "model verification" and "model calibration" have the following definitions:

- **Verification -** Establishing that the model realistically represents the real-world processes it is intended to represent, and that water moves from its source to its point of diversion under the proper water rights. Criteria for verification are both conceptual and quantitative.
- **Calibration -** Adjusting the parameters used by the model, within realistic bounds, so that the model provides results that represent observed conditions with acceptable accuracy. The criteria for calibration are quantitative. Note that the term "parameter" as used here is not the strict mathematical definition and can include data representing processes, such as various system gains and losses.

The verification process involves a detailed evaluation of the model calculations. For the Quarter-Monthly Model, spreadsheets were utilized to verify the relevant and significant processes in the model. The spreadsheets were used to independently calculate conditions both over single time-steps and on an annual basis. The model was verified by comparing its results with spreadsheets for the same time period.

The calibration process involved comparing results from the simulation model with actual historical data. In the calibration process, the model was initialized with observed conditions at the start of the calibration period and driven by observed data over the calibration period. The values of important model independent variables (e.g., reservoir contents and streamflows) were compared with observed values of those variables. Model parameters were adjusted to improve agreement between the model and observed data. The calibration process involved adjustments in gain-losses, return flows, and reservoir rule curve calculations, among other things.

The calibration period did not coincide with the study period, as conditions have changed sufficiently over the study period to confound any calibration effort. Rather, the calibration period was for water years 1992-2002, during which river operations have been close to those represented as current conditions in the Quarter-Monthly Model.

2.4 Aurora's Quarter-Monthly System Model

As part of its raw water planning and management program, Aurora contracted with Hydrosphere to construct a model to evaluate the City's operations in the Arkansas basin. This model was originally constructed in 2000 under separate contract with Aurora. The original model was modified under the direction of Reclamation for use in the EA to include detailed operations of other water users. Standard operating system used at the City, modeling in the Windows environment also allows the greatest number of people access to the model.

2.4.1 General Model Solution Method

The Quarter-Monthly Model simulates the river system hydrologic processes on a quarter-monthly basis. The model simulates the diversion of natural streamflows based on a water rights priority and reservoir storage based upon storage ownership. The model also makes exchanges based upon water right priority and can limit exchanges based upon stipulations and other agreements.

2.4.2 General Model Description

The Quarter-Monthly Model contains both explicitly and implicitly modeled parameters. In general, major diversions are modeled explicitly while minor diversions are modeled implicitly. Major reservoirs and their associated reservoir accounts are explicitly modeled while minor reservoirs are implicitly modeled. Ungaged gains and losses include all implicitly modeled inflows, diversions and return flows. Ungaged gains include not only tributary inflows, but also surface water accretions due to stormwater runoff and ground water accretions of implicitly modeled diversions. Ungaged losses include implicitly modeled diversions, natural channel losses, evaporative losses from implicitly modeled reservoirs, depletions due to ground water pumping and other minor losses.

Table 2-1 lists explicit model parameters and **Table 2-2** lists implicit model parameters in the Quarter-Monthly Model.

Table 2-1. Explicit Model Parameters

Major Municipal Demands	

▪ Colorado Springs Utilities
  • Homestake Pipeline
  • Direct Reuse System
▪ Fountain Valley Authority Pipeline
▪ Pueblo Board of Water Works
▪ Pueblo West
	▪ Minor municipal Fry-Ark demands:
	  • Buena Vista
	  • Salida
	  • Cañon City
	  • St. Charles Mesa
	  • La Junta

Aurora's Agricultural/Transmountain Supplies	
▪ Colorado Canal ▪ Rocky Ford ▪ Highline lease ▪ Homestake ▪ Twin Lakes ▪ Busk-Ivanhoe ▪ Aurora's Lake County water rights	
Reservoir Accounts	

▪ Homestake Reservoir
  • Aurora
  • Colorado Springs
▪ Turquoise Reservoir
  • Fry-Ark
  • CF&I
  • Homestake
  • Busk-Ivanhoe
▪ Twin Lakes Reservoir
  • Fry-Ark
  • Twin Lakes Reservoir and Canal Company
▪ Clear Creek Reservoir
	▪ Pueblo Reservoir
	  • Fry-Ark
	  • Excess Capacity Contracts
	▪ Lake Meredith, Lake Henry
	  • Colorado Springs
	  • Aurora
	  • Pueblo West
	  • Ag
	▪ Aurora Gravel Pit Below Fountain Creek
	▪ Holbrook Reservoir
	  • Aurora
	  • Colorado Springs

River Exchanges on the Arkansas River	
▪ SECWCD Municipal ▪ Pueblo Board of Water Works ▪ Colorado Canal ▪ Colorado Springs	▪ Rocky Ford ▪ Highline Lease ▪ Holbrook Reservoir Lease
Decreed, Stipulated and Other Minimum Flows	
▪ Lake Fork Creek ▪ Lake Creek ▪ Wastewater flows at Salida ▪ Rafting Flows at Wellsville	▪ Wastewater flows at Florence ▪ Minimum Flows Below Pueblo Res ▪ Recreational In Channel Diversion (RICD)
Winter Water Storage Program - Direct Flow Participants	

▪ Tributary Inflows
  • Lake Fork Creek
  • Lake Creek
  • Clear Creek
  • Fountain Creek	

▪ Reusable Return Flows
  • Colorado Springs Utilities
  • Pueblo Board of Water Works
  • Fountain Valley Authority Entities
  • Pueblo West	

Table 2-2. Implicit Model Parameters

Minor Municipal Demands (native)	
▪ Leadville ▪ Buena Vista ▪ Salida ▪ Cañon City ▪ Avondale	
All Other Agricultural/Transmountain	
▪ Native Ag Supplies ▪ Historical Fry-Ark ▪ Fort Lyon Canal ▪ Fort Lyon Storage Canal ▪ Holbrook Canal ▪ Catlin Canal	▪ Otero Canal ▪ Bessemer Ditch ▪ Columbine ▪ Ewing ▪ Wurtz ▪ Others
Basin Hydrology	
▪ Reach Gains/Losses ▪ Travel Time	
Well Depletions and Augmentation	
Winter Water Storage Program - Off-Channel Participants	
All Other Tributary Inflows	
▪ Cottonwood Creek ▪ South Fork of the Arkansas ▪ Grape Creek	▪ St. Charles River ▪ Huerfano River ▪ Apishapa River
All Other Reusable Return Flows	

2.4.3 General Model Settings

ExcelCRAM was designed specifically to model complex river systems in states using the prior appropriation doctrine of water rights. Of particular importance for the Quarter-Monthly Model are operational steps, and the operations of others. These and other settings, and their applicability to the Quarter-Monthly Model, are described in the following sub-sections.

2.4.3.1 Model Engine

ExcelCRAM optimizes flow by maximizing the value of the allocation of water through the system. In Aurora's Quarter-Monthly Model, priority numbers range from -2,00,000 to +2,000,000, with priorities assigned to individual links. Generally speaking, the Quarter-Monthly Model was constructed with the following priorities:

1. River gains and losses - highest priority,
2. Diversions of native water in order of decreasing seniority - second highest priority,
3. River exchanges - third highest priority, and
4. Reservoir rule curves and other priorities used to modify basin operations have the fourth and lowest priorities.

2.4.3.2 Time-step

The Quarter-Monthly Model uses time-steps that are one quarter month in duration. This means that each time-step is either 7 or 8 days long, and there are 48 time-steps per year. While perhaps seeming unorthodox, a quarter month time-step has advantages over either a daily or monthly time-step, because it retains more precision than a monthly model without the data required for a daily model. Results can also easily be summarized to a monthly or annual basis. Daily time-step models that use network programming solutions may overestimate system capabilities because they optimize operations that are frequently unattainable in practice. Additionally, the data requirements for daily time-step models are often prohibitive, and issues such as routing, which are problematic in a network optimization setting, may become significant. While a monthly time-step does not provide the resolution needed to administer water rights precisely, it is sufficient to predict general operations.

As stated above, Quarter-months have either eight or seven days, starting with 8-day "weeks" at the beginning of the month, and finishing the month with the number of 7-day weeks so the month has the correct number of days. For example, the numbers of days in various quarter-months are:

28-day month (Feb in a normal year) ....:	7 days, 7 days, 7 days, 7 days
29 day month (Feb in leap year) ....:	7 days, 7 days, 7 days, 8 days
30 day months (Apr, Jun, Sep, Nov).......................................:	8 days, 8 days, 7 days, 7 days
31 day months (Jan, Mar, May, Jul, Aug, Oct, and Dec) ....:	8 days, 8 days, 8 days, 7 days

2.4.3.3 Operation Steps

Operations steps (op-steps) allow the model to repeatedly solve the same time-step, and in conjunction with settings on links and the use of VBA code, allow the user to model complex water operations.

The Quarter-Monthly Model uses eight op-steps in its simulation. The op-steps are as follows:

1. Allocate native water to direct flow and storage rights in the Arkansas basin.
2. Simulates the movement of transmountain water, including that from the Homestake, Busk-Ivanhoe, Twin Lakes and Fry-Ark systems.
3. Operate decreed exchanges on the river between the outlet of Holbrook Reservoir and Turquoise Reservoir.
4. Same as Op-Step 3.
5. Same as Op-Step 3.
6. Same as Op-Step 3.
7. Same as Op-Step 3.
8. Move Aurora's water from Pueblo Reservoir to Twin Lakes/Turquoise Reservoir via contract exchange.

River exchanges are curtailed by decrees, stipulations or other agreements, and include the minimum stream flows on Lake Fork and Lake Creek, the minimum flow stipulations for the Salida and Fremont County wastewater treatment plants, Aurora's stipulated rafting flow limits at Wellsville, and the Recreational In Channel Diversion (RICD) filing below Pueblo Reservoir. More information on these decrees, stipulations and agreements are contained in Section 4.

2.4.3.4 Operations of Others

Aurora depends on exchanges to move water from the originally decreed location in the lower basin to its diversion in the upper basin. Aurora's alternate point and exchange rights are junior to some of the other decreed exchanges. Aurora's operations are influenced by the operations of other water users in the basin.

2.4.3.5 Routing

Travel time from the upper end of the basin to the bottom of the study area is approximately three days. The Quarter-Monthly Model simulates a minimum of seven days per time-step. Routing is not explicitly modeled in the Quarter-Monthly Model.

2.4.3.6 Evaporative and Transit Losses

Evaporation losses in the Quarter-Monthly Model are calculated by the model. Reservoir contents are correlated to a reservoir-specific area-capacity-elevation curve, and the surface area is multiplied against a monthly evaporation factor. Where site-specific evaporation rates have not been developed, annual rates were obtained from the National Weather Service (NWS, 1982) and distributed to monthly amounts using the State Engineer's evaporation criteria for augmentation plans. Evaporation losses are pro-rated among the reservoir accounts by actual account contents for each quarter-month. This differs slightly from methodology used by Reclamation to allocate evaporation to accounts in Twin Lakes and Turquoise Reservoirs. Because these reservoirs were enlarged from existing reservoirs, evaporation is pro-rated differently to those accounts that were in place before expansion. However, for purposes of this analysis, a pro-ration based on storage accounts was deemed adequate.

Transit losses for historical flows were calculated using historical gage data. This was done by subtracting flows between pairs of adjacent gages, after accounting for the historical inflows and diversions being explicitly modeled. Because transit losses are primarily driven by native hydrology, transit losses in the model are assumed to equal what occurred historically. The consequence of this assumption is that transit losses on the Arkansas River are the same as they were historically, even though flows in the river may change with system operations. Transit losses for explicitly modeled flows are calculated and deducted from releases, spills or transfers. For example, transit losses for the delivery of Fry-Ark Project water delivered from Twin Lakes to Pueblo Reservoir are calculated as 9.6 percent (Abbott, 1985).

2.4.3.7 Ground Water Accounting

The Lower Arkansas River Basin has a complex ground water system that is hydrologically tributary to the Arkansas River. However, modeling of this ground water system is outside of the scope of work for the EA. Therefore, surface water depletions and accretions from ground water influences were assumed to be equal to historical and are implicitly modeled.

3.0 MODEL DATA

Accurate and comprehensive data are very important to the overall success of the Quarter-Monthly Model. This section describes the model study period, spatial extent of the data required, the sources of data and supplemental data calculations required for the model.

3.1 Study Period

The Quarter-Monthly Model combines existing and future conditions on historical hydrology. Therefore, selection of the study period is an important decision. The selected study period would ideally be the entire period-of-record for the basin, which is approximately 110 years in the Arkansas River basin. However, data are only available at a few sites for this entire period. Therefore, alternatives were run using a representative data set that has approximately the same statistical makeup of the entire data set population.

The selection of the study period for the Quarter-Monthly Model was dependent upon several items, including the purposes of the model, the extent of available data, and historical changes in river operating conditions. Reclamation’s NEPA guidance suggests a minimum 20-year data set (Reclamation, 1997). In selection of a study period for NEPA purposes, the following considerations were given:

- The primary purpose of the NEPA analysis is to determine effects of the Proposed Action and EA alternatives, and assist in making a selection between alternatives. Because high and low extreme events are important events to include in the study period, the data set should include extreme events that are representative of the overall hydrologic record;
- Construction of East Slope Fryingpan-Arkansas Project facilities began in 1965 with Turquoise Reservoir and continued through the 1980s. Fry-Ark operations have significant effects on river operations within the basin. The following milestones have had an effect on operations within the Arkansas River, including (Reclamation, 2001):
  - May 1972 - Initial diversions through Boustead Tunnel;
  - January 1974 - Began storing in Pueblo Reservoir;
  - May 1981 - Substantial completion of the West Slope diversion facilities;
  - June 1981 - Reclamation assumes operations of Twin Lakes Dam;
  - October 1981 - Completion of Mount Elbert Powerplant Unit #1;
  - June 1982 - Turquoise Reservoir filled for first time;
  - July 1985 - Initial diversion through Fountain Valley Conduit;
  - November 1985 - Began operations of Twin Lakes pipeline;
  - July 1990 - Initial releases from Twin Lakes for recreational flows on Arkansas River;
  - September 1990 - Completion of Pueblo Fish Hatchery.
- The Winter Water Storage Program (WWSP) was developed to allow direct flow agricultural water rights to be stored in Pueblo reservoir from November

15 through March 15. This program began in 1977 and had a significant effect on winter river operations.

- Colorado Canal transfers to municipal uses were completed during the late 1980s.

Based on the information above, a study period of water years 1982 through 2002 was selected. A statistical summary of the study period as compared to the long-range statistics for the Arkansas River at Cañon City gage is presented in **Table 3-1**, while the annual flows as compared with the mean flows are shown in **Figure 3-1**. As shown, the mean of the study period is approximately 9 percent higher than the overall mean, while, the median is one percent higher. This indicates that the mean of the study period is being exaggerated by a few extremely high flows. In addition, the study period contains operations of the Fry-Ark Project, which from 1972 through 1995 diverted an average of approximately 50,000 ac-ft through the Boustead Tunnel (MW, 2000), and therefore accounts for a large majority of the difference between the period-of-record and the study period. The inclusion of both the absolute minimum and absolute maximum flow years within the study period is important for many of the environmental resource analyses.

Table 3-1. Statistical Comparison of Annual Flow, Arkansas River at Cañon City Gage (07096000)

Statistic	Value (ac-ft)	
	Overall	Study Period
	1900-2002	1982-2002
Absolute Minimum	202,440	202,440
80% Exceedance	411,564	430,362
Median	516,678	523,109
Mean	524,134	570,699
20% Exceedance	639,922	712,204
Absolute Maximum	940,328	940,328

The Quarter-Monthly Model would ideally be able to simulate any time-period, and for the most part, is constructed to do so. However, a few of the assumptions made in the model construction, primarily constant flow routing, are dependent upon the flow regimes in the river being somewhat consistent with the historical hydrology. Consequently, the shorter study period produces more reliable model results.

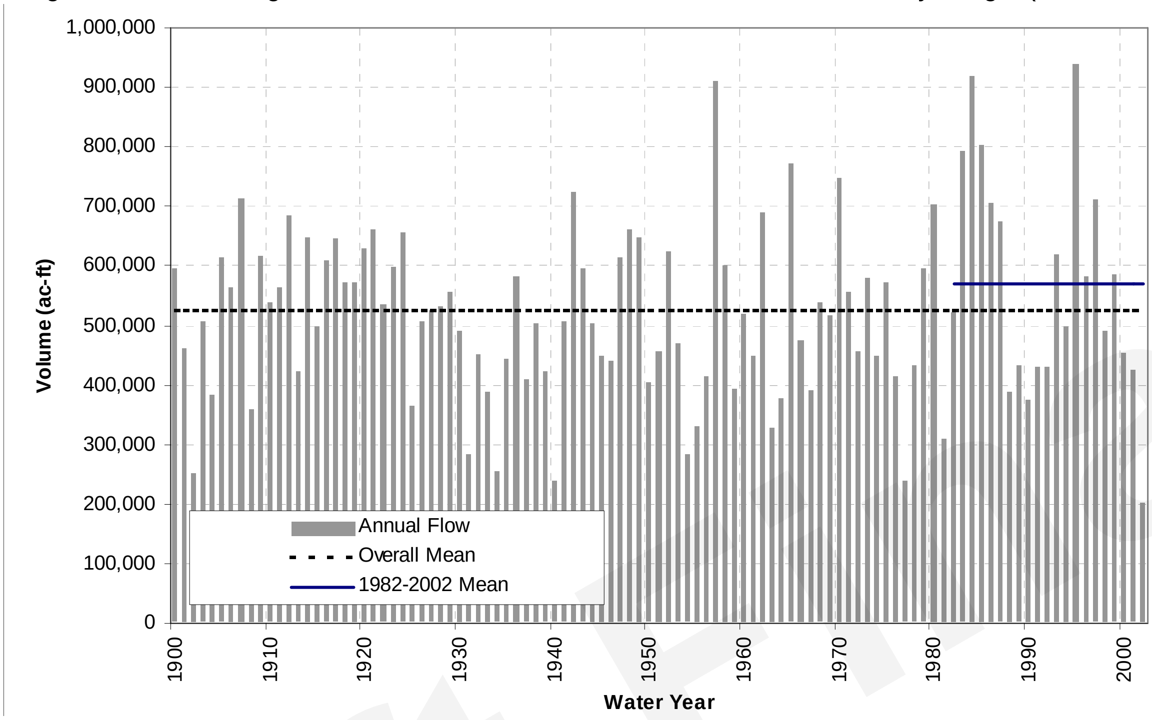
3.2 Developing Quarter-Monthly Data

The Quarter-Monthly Model runs on a quarter-monthly time-step and calculates flow in acre-feet. This time-step is adequate for water rights planning purposes and should provide an adequate level of streamflow definition for use in the Aurora EA.

Quarter-monthly data sets were typically constructed by taking historical daily values and summing to quarter-monthly totals. The exception to this is where there are monthly limitations, such as Aurora's Rocky Ford Decree (1983CW18), where the monthly total was pro-rated by the number of days in the quarter-month. For data sets that are not available in a daily format, monthly data was converted to quarter-monthly format using linear interpolation.

The quarter-monthly results were transformed into daily results by dividing the quarter-monthly results by the number of days in the quarter-month. Mean daily values in acre-feet are converted to flow in cfs by dividing by 1.9835, the number of acre-feet equivalent to one cubic-foot per second flowing for one day.

Figure 3-1. Average Annual Flow, Arkansas River at Cañon City Gage (07096000)



3.3 Spatial Extent of Data Set

As proposed, operation of Aurora's Proposed Action would primarily affect flows in the Arkansas River between Lake Creek and the Holbrook Reservoir outlet and Lake Creek below Twin Lakes. Changes on the Arkansas River will be assessed from Lake Fork Creek below Turquoise Reservoir, down the Arkansas River to the La Junta gage. The Quarter-Monthly Model includes inflows from major tributaries including Lake Fork Creek, Lake Creek, Clear Creek and Fountain Creek.

The Quarter-Monthly Model includes nodes at each gage location to calculate flow at those locations and exchange potential along the river. Because the exchange potential is dependent upon the minimum flow in the river between the location of the source water inflow and the exchange diversion, detailed accounting within the low flow reaches is critical for the model.

3.4 Data Sources

The Quarter-Monthly Model is data driven, meaning that the model results are highly dependent on the amount and quality of the data used as input. These data include historical streamflow data, historical and future diversion data, historical storage data, water rights data and other miscellaneous data. No comprehensive database containing all required data existed at the time the model was constructed. The State of Colorado's Decision Support System contains a significant amount of data and was used to supply as much of the data as possible (CDSS, 2003). Because this database was incomplete at the time, supplemental data sources were required for a portion of the data requirements. Supplemental data were available from other sources, such as Reclamation, Colorado Springs Utilities, the U.S. Geological Survey (USGS) and others.

3.4.1 Streamflow Data

Streamflow data was required for the Quarter-Monthly Model, which uses gage data to calculate both gaged and ungaged gains and losses. Historical gage data was used as inflows to the model for both the mainstem of the Arkansas and the explicitly simulated tributaries. Daily gage data was aggregated into quarter-monthly format for use in the model, following the monthly time-step patterns shown in Section **4.0**.

Streamflow data were typically available from the USGS, Colorado Decision Support System and Reclamation. Many of the CDSS data are a direct duplication of the USGS data because the gaging stations are administered cooperatively. However, there are occasionally minor differences in data between the two data sets. The USGS was used as the preferred source of data, followed by CDSS, and where available, Reclamation. All streamflow data were available on a daily basis.

3.4.2 Diversion Data

Demand nodes within the Quarter-Monthly Model were populated with either historical diversion data or estimated future diversion data. For calibration, the Quarter-Monthly Model used historical diversion data for all diversions. For the Existing Conditions, No Action and Proposed Action, scenarios, the model used historical diversion data for most agricultural diversions and smaller municipal diversions, and current diversions for the larger municipal diversions. For the Cumulative Effects scenarios, the municipal diversions were increased to the demand projected in 2045. The Pueblo, Pueblo West and Colorado Springs demands were supplied from their existing supplies, while small municipalities, including Buena Vista, Salida, St. Charles Mesa and La Junta were supplied additional water from the Fry-Ark Project. In all scenarios, calculation of historical ungaged gains and losses used historical demands.

The primary source of diversion data was the Division 2 State Engineer's Office (Division Engineer). The Division Engineer maintains a database of all recorded diversions within the Arkansas River Basin. The database sorts diversions based upon state structure number and water source (direct flow right, storage, transmountain) and is available as average daily diversion. Some data were also available through the CDSS database. Diversion data is primarily limited to 2000-2002, which is also covered by the Division Engineer's database. Therefore, the CDSS diversion database generally was not used.

A limited amount of diversion data was obtained from Reclamation, either directly from the Great Plains Regions' Hydromet data system (Reclamation, 2003) or the Pueblo Field office. These data were primarily limited to those facilities in which Reclamation has direct influence on operation of the structure, such as the Mt. Elbert Pipeline and the Fountain Valley Conduit.

In addition to physical diversions on the river, historical exchange accounting was also required for the model. Colorado Springs Utilities and the City of Aurora made the majority of historical exchanges, for which they provided historical data. Exchange data for other historical exchanges on the river were obtained from the Division Engineer's office, when available.

Projected future municipal diversion data were obtained from the larger municipal diverters in the basin. This included data for Colorado Springs Utilities, the Pueblo Board of Water Works (PBWW), the City of Fountain and Pueblo West. **Appendix A** contains more description than this data was provided by Colorado Springs. Future diversions for selected smaller municipalities were obtained from the Water and Storage Needs Assessment (GEI, 1998).

3.4.3 Historical Storage Data

Historical storage data were required for historical gain/loss calculations, model calibration, and to develop rule curves for target storage levels. For purposes of the NEPA analysis, five existing reservoirs and their associated accounts were explicitly modeled. Three of these reservoirs, Turquoise Reservoir, Twin Lakes and Pueblo Reservoir, are owned by Reclamation. Historical daily contents for these reservoirs were available through the Hydromet website (Reclamation, 2003). Where necessary, detailed historical reservoir account information was supplied by Reclamation's Pueblo Field office.

Clear Creek Reservoir is owned and operated by the Pueblo Board of Water Works. Because gaging data were available immediately upstream and downstream of the reservoir, historical Clear Creek contents were not needed for model calibration or operation.

Historical storage data for Lakes Henry and Meredith was available from the Colorado Canal Company. Because the reservoir is an off-stream facility, the data were not needed for historical gain/loss calculations.

3.4.4 Water Rights Data

Water rights data are an integral part of the Quarter-Monthly Model. Water rights priorities and limitations are used to allocate water for explicitly modeled diversions and exchanges. Priorities associated with decreed water rights are used to allocate native flows for direct flow and storage rights in the Arkansas Basin, such as those owned by Twin Lakes Company, Pueblo Board of Water Works, the Colorado Canal Companies, and the Rocky Ford Ditch. This is done by assigning senior water rights higher priorities, and having the model supply water to that demand until it reaches its decreed rate or capacity. Explicitly modeling water rights diversions allow the model to calculate how changes in operations of others or native supply affects native water rights.

Decreed priorities are also used to allocate the available exchange potential between the competing exchanges of the Southeastern Colorado Water Conservancy District (SECWCD), Pueblo Board of Water Works, Colorado Canal Companies, Colorado Springs Utilities, and Aurora. The limitations of the exchange decrees, including both instantaneous rates and volumetric limitations, are included in the Quarter-Monthly Model. The model was also constructed to accurately simulate shared exchanges, as stipulated in the Colorado Canal Companies exchange decrees (84CW62, -63, -64).

Detailed water rights data are available from the CDSS website. These water rights identify all water rights for each structure within the database, including those water rights that have been transferred to and from each structure. The database also lists conditional and exchange water rights. For water rights with complex limitations, copies of the decrees were obtained from either the water right holder or the Colorado State Engineer's office, so no limitations would be overlooked.

3.5 Filling Missing Data and Data Extension

Previous experience with the data sets in the Arkansas Basin has found that most data sets are incomplete. There are two possible cases of gaps for these data: periodic short-term data gaps due to malfunctioning equipment or ice, and long-term data gaps due to discontinuation of the measuring site or long-term malfunctioning of equipment. Because the Quarter-Monthly Model is based on daily data, the nature of data filling and extension for these two situations were handled slightly different.

For longer term gaps in data and data extension, the most common method to use is regression of measured streamflow at the dependent gage (the gage where data filling is required) to measured streamflow at an independent gage (the gage where data exists for the missing period). Once this mathematical relationship is established, measured data from the independent gage can be used to estimate the streamflow for the dependent gage. Typical regression relationships can be based on linear, polynomial, power or logarithmic relationships. The measure of the degree to which the two gages correlate is typically called the coefficient of determination (R-squared value). A coefficient of determination of 1.0 indicates perfect correlation. Therefore, the relationships with coefficients of determination closest to 1.0 have the best correlation. Typically coefficients of determination greater than 0.7 are presumed adequate. When coefficients of determination are less than this value, then relationships are considered weak, and attempts to find gages with better relationships should be made. In addition to single-station correlations, multiple station correlations can also be used, such as the method referred to as the Maintenance of Variance Extension, Type 1. In cases where single station correlations provide unacceptable results, these more advanced methods can be used to perform the data extension.

For short-term data gaps, a correlation similar to those for the long-term gaps can be used. However, it is important to maintain temporal consistency within the data set. Therefore, for the short-term data sets, nearby data sets or directly related data sets were investigated to determine whether temporal consistency is maintained during the data gap. If so, then a linear (or other) relationship was used between the bounding data points to estimate the data gap. If there is a spike in the data, then a regression analysis as described in the previous paragraph was performed.

3.6 Ungaged Gains and Losses

As discussed in Section 2, ungaged gains and losses were calculated outside of the Quarter-Monthly Model and then input as a constant value through the reach for each quarter-month.

Gage data from the Arkansas River was used to calculate the ungaged gains and losses between gages. Diversions and inflows not explicitly modeled in the Quarter-Monthly Model were aggregated into a single reach gain or loss that is applied to each gage. Reach gains are calculated by taking the difference between two successive gages, adding or subtracting any historical data from diversions or inflows that occur in the reach that are explicitly modeled, aggregating the results to quarter-monthly values and converting values to acre-feet.

Under the assumption that low flows are the most critical for exchange-modeling scenarios, the most conservative method for allocating gains and losses would be to subtract gains from the upstream gage in a reach, and add gains at the lower gage. However, previous model calibration found that this was overly conservative, and that historical flows could be more closely replicated if both the gains and losses were applied to the lower gage in the reach. Because of the improvement to calibration, the Quarter-Monthly Model applies both the gains and losses to the lower gage.

4.0 MODEL PARAMETERS

This section describes the modeling methodology and the assumptions used in the Quarter-Monthly Model.

4.1 Modeled Systems

The Quarter-Monthly Model explicitly simulates the large municipal users in the Arkansas basin and agricultural users whose use has changed or is anticipated to change in the near future. The model implicitly simulates the smaller municipal users, and the agricultural users whose operations are not anticipated to change in the foreseeable future. A schematic of the model is shown **Figure 4-1**.

4.1.1 Explicitly Modeled Systems

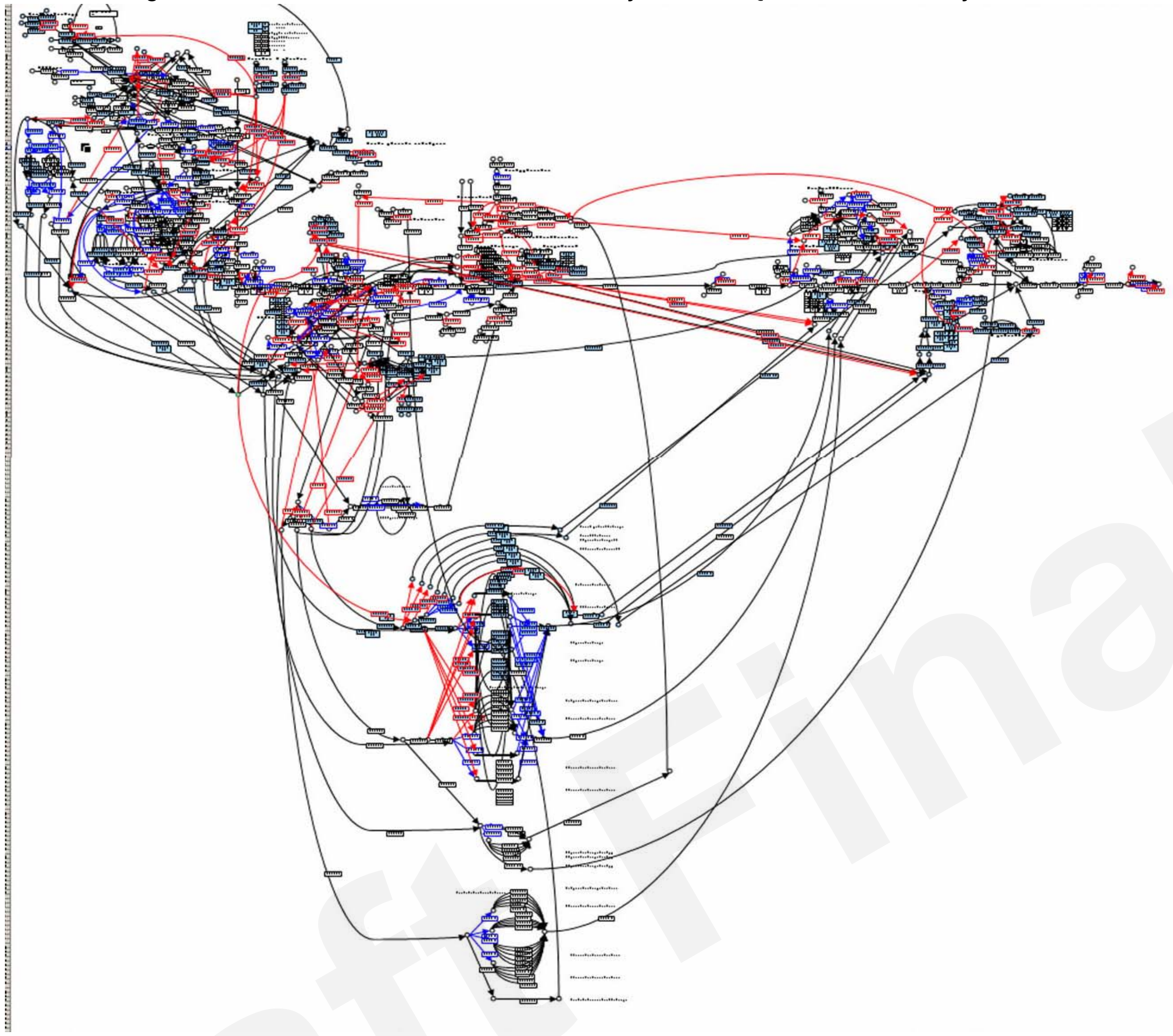
Explicitly modeled systems are represented by nodes and links in the Quarter-Monthly Model. Values for supply(ies), demands and storage (if any) can be included in the output for use in calibration, verification and analysis. The operations of explicitly modeled systems can also be modified through the model's user interface and/or through model code, to represent past of future changes in operations, including the timing and amount of supply, timing and amount of demand, the location of the diversion, the priority of the water right(s), and the amount of storage available. Each of the explicitly modeled systems is discussed in the following sub-sections.

4.1.1.1 Homestake Project

The Homestake Project is a municipal transmountain diversion project owned jointly by the City of Aurora and Colorado Springs Utilities. The West Slope collection system diverts water from the Homestake Creek watershed, a tributary of the Eagle River, into Homestake Reservoir. From Homestake Reservoir, this water is delivered to Turquoise Reservoir through the Homestake Tunnel. From Turquoise Reservoir, water is conveyed to Twin Lakes Reservoir via contract exchange. From Twin Lakes, water is diverted through the Twin Lakes pipeline to the Otero Pump Station, where it is pumped into the Homestake pipeline and delivered to Spinney Reservoir in the South Platte Basin for Aurora, and to the Catamount Reservoir system for Colorado Springs Utilities.

Aurora and Colorado Springs Utilities share ownership in the Project. Both Colorado Springs Utilities and Aurora have 15,000 acre-foot long-term storage contracts in Turquoise Reservoir for storage of Homestake water. Pursuant to contract, this storage space can only be used for storage of Homestake water and cannot be used to store water from any other source.

Figure 4-1. ExcelCRAM Interface Layout for Quarter-Monthly Model



The Homestake Tunnel was completed in 1965 and Homestake Reservoir in 1967. The Homestake Project has been in full operation throughout the study period. However, diversions by the Project have been affected slightly by construction of key facilities during the study period in the Arkansas Basin, and by increases in demand for the water over time. Potential diversions through the Homestake tunnel are typically near historical levels especially during the latter years. However, as with other transmountain diversion projects, modeling estimates of potential diversions have been made by Grand River Consulting Corporation (Grand River, GRC 2004). The values estimated by GRC are based on an independent model developed and maintained by GRC, containing hydrology and water rights data in the Colorado River basin. GRC's model is a comprehensive development of available flows in the Colorado River Basin. Data provided from this model was used in the analysis.

Water from the Homestake project can only be delivered to Aurora via the Otero pump station, therefore it does not flow down the Arkansas River. Aurora does not plan to store Homestake water in Pueblo Reservoir, and the Quarter-Monthly Model is not capable of simulating such a delivery or storage. Homestake yields that cannot be delivered directly to the Otero Pump Station or stored in Homestake, Turquoise or Twin Lakes reservoirs are spilled on the west slope.

4.1.1.2 Twin Lakes Project

The Twin Lakes Project is a transmountain diversion and storage system constructed in the early 1930's to provide supplemental agricultural water to lands under the Colorado Canal system (USGS, 1985). The Independence Pass Transmountain Diversion System diverts water from several streams located in Pitkin County on the West Slope into Grizzly Reservoir. From Grizzly Reservoir, this water is diverted into the Twin Lakes (a.k.a. Independence Pass) tunnel under the Continental Divide, and into Lake Creek above Twin Lakes. The Twin Lakes Tunnel first delivered water in 1935. In addition, the Twin Lakes Company also possesses east-slope water rights with 1896 and 1897 priority dates. The average annual total Twin Lakes Project yield is about 48,200 acre-feet, with about 36,500 acre-feet coming from West Slope water rights and 11,700 acre-feet from East Slope water rights (Ringle, 2004).

Table 4-1 presents a summary of the current Twin Lakes Project ownership. As shown, a majority of the water is used for municipal purposes. Both Colorado Springs Utilities and the City of Aurora convey their yield from the Twin Lakes project to the Otero Pump Station and Homestake Pipeline via the Twin Lakes Pipeline.

Table 4-1. Twin Lakes Project Ownership Distribution

Entity	Shares	Percent (%)	Storage (ac-ft)
Colorado Springs Utilities	27,103.693	54.66	29,761.7
Aurora	2,478.475	5.00	2,721.5
Pueblo Board of Water Works	11,476.157	23.14	12,601.6
Pueblo West(2)	5,766.410	11.63	6,331.9
Augmentation(2)	472.822	0.95	519.2
Other M&I(2)	1,697.341	3.42	1,863.8
Other Ag and Inactive(2)	594.070	1.20	652.3
Sub-Total	49,588.968	100.00	54,452

Notes:

(1) From Ringle (2004)
(2) Grouped into one shareholder for purposes of the Quarter-Monthly Model

The Twin Lakes Project has been in full operation throughout the study period, potential diversions through the Twin Lakes tunnel are very near historical diversions. However, to be consistent with the use of estimated diversions for other transmountain projects, projections made by Grand River Consulting Corporation were used for the Twin Lakes Project.

For purposes of the model, it is expected that future operations of the Twin Lakes Project will closely mirror those of most recent operations. It is assumed that Colorado Springs Utilities and Aurora will continue to take delivery of their portion of Twin Lakes Project yields through the Twin Lakes tunnel, the Otero pump station and the Homestake pipeline.

The model assumes that the remaining shareholders will take delivery of Twin Lakes water down the Arkansas River. Because return flows from the West Slope imports are reusable, entities receiving Twin Lakes water can reuse their return flows directly through exchanges, indirectly for well augmentation, or by some other capture and reuse method. The Quarter-Monthly Model explicitly models the exchange and reuse of Twin Lakes West Slope water by the Pueblo Board of Water Works and Colorado Springs. Reuse of Twin Lakes water was implicitly modeled for all other minority owners of Twin Lakes shares, including agricultural users under the Colorado Canal, who can exchange water from the Meredith Outlet to the Colorado Canal headgate.

Water from the Twin Lakes project can only be delivered to Aurora via the Otero pump station, therefore Aurora does not anticipate that any of its Twin Lakes water will flow down the Arkansas River. Consequently, the Quarter-Monthly Model is not capable of simulating delivery or storage of Aurora's or Colorado Springs' Twin Lakes water to Pueblo Reservoir. The model assumes Aurora's Twin Lakes yields that can not be stored in Twin Lakes Reservoir or delivered directly to the Otero Pump Station are spilled on the west slope.

4.1.1.3 Busk-Ivanhoe System

The Busk-Ivanhoe System is a transmountain project that diverts water from the upper reaches of Ivanhoe Creek in the Colorado River Basin, under the Continental Divide, into Turquoise Reservoir. Deliveries to the east slope are made through the Carlton Tunnel.

Aurora and the PBWW each own 5,000 acre-feet of Busk-Ivanhoe agricultural storage space in Turquoise Reservoir. The 10,000 acre-feet of Busk-Ivanhoe storage space in Turquoise Reservoir is firm storage space with agricultural type and place of use requirements and thus, cannot be used by Aurora or PBWW. In addition, both Aurora and PBWW each own 5,000 acre-feet of storage space in Turquoise Reservoir through their purchase of CF&I shares, which can be used to store Busk-Ivanhoe water. The City of Aurora takes delivery of their water through the Homestake pipeline via the Mount Elbert Conduit, Twin Lakes and the Otero Pump Station. The PBWW typically leases most of their Busk-Ivanhoe yield to Aurora (2,500 acre-feet per year). The Quarter-Monthly Model assumes this lease will continue, and has links that deliver the PBWW Busk-Ivanhoe water to Aurora. Any remaining yield is either stored in CF&I storage space or leased to other entities in the Arkansas Basin.

Because Busk-Ivanhoe water can only be delivered to Aurora via the Otero pump station, none of Aurora's share of Busk-Ivanhoe water flows down the Arkansas River. Consequently, Aurora's Busk-Ivanhoe water will never be stored in Pueblo Reservoir as a result of Aurora's application for if-and-when space, and the model is not capable of simulating such a delivery and storage.

Potential yield data for the Busk-Ivanhoe was provided by Grand River Consulting Corporation (GRC, 2004).

4.1.1.4 Fryingpan-Arkansas Project

The Fryingpan-Arkansas Project is a multipurpose transbasin water diversion and delivery project located in southern Colorado. It diverts an average of 69,200 acre-feet of water annually from the Fryingpan River and other tributaries of the Roaring Fork River, on the western slope of the Rocky Mountains, to the Arkansas River basin on the eastern slope.

Water diverted from the western slope, together with water supplies in the Arkansas River Basin, provides an average annual supply of 80,400 acre-feet of water for both municipal and domestic uses, including the supplemental supply of irrigation water for 280,600 acres in the Arkansas Valley. Project water may be reused to extinction.

The Project includes reservoir storage in Turquoise, Twin Lakes and Pueblo reservoirs. Through various contracting arrangements, these reservoirs can store both Project and non-Project waters.

The use of reservoir storage space through Excess Capacity contracts is inversely proportional to the volume of Fry-Ark water in storage in Fry-Ark Project reservoirs. Therefore, prediction of future Fry-Ark Project water use is an important factor when simulating the proposed NEPA actions.

Fryingpan-Arkansas Project Water Sources

The Fry-Ark Project holds water rights on both the east and the west slopes of the Continental Divide, and the SECWCD manages these water rights. The west slope water rights are imported through the Boustead Tunnel, and subsequently referred to as Boustead Tunnel Imports. The decree for the west slope rights is dated August 3, 1959, with a date of appropriation of July 29, 1957 The native east slope Arkansas Basin water rights in Chaffee County have an appropriation date of 1942 - July 14 for irrigation and December 15 for non-irrigation - and adjudication date of July 9, 1969. The Pueblo Reservoir decree has an appropriation date of February 10, 1939, and an adjudication date of June 24, 1962. All the east slope rights are comparatively junior to the other rights in the basin and are therefore rarely in priority.

Because model scenarios anticipate full use of the Fry-Ark Project, maximum potential Fry-Ark Project inflows are required. Therefore, both maximum potential Boustead Tunnel Imports and maximum potential native Arkansas River water rights are calculated. The model was then used to determine the actual amount of these inflows stored or used by Project demands. The following describes the calculation methods used to determine the volume of water available on a monthly basis during the study period for both east and west slope water rights.

- **Boustead Tunnel Imports -** Historically, diversions through the Boustead tunnel have been less than the potential diversion for a variety of reasons, including the development of the west slope diversion system, available east slope storage, and demand for supplemental water on the east slope. Consequently, historical imports for the Boustead Tunnel do not provide an accurate picture of how much water was actually available for diversion during any given year. Therefore, potential Boustead Tunnel imports were used in the model to simulate Fry-Ark operations.

Previous estimates of potential Boustead Tunnel imports have relied on two primary sources of information: Reclamation regression equations, and modeling estimates made by Grand River. The Reclamation equations were developed during Fry-Ark Project planning, and correlate potential Boustead Tunnel imports to the native flow at the Roaring Fork gage near Aspen. The Grand River estimates are based on an independent model that contains hydrology and water rights data in the Colorado River basin. Because the Grand River model is a more comprehensive development of available flows, data provided from his model were used in the analysis. The City of Aurora contracted with and received these data from Grand River, and has approved of their use following review and approval of the data by staff at Aurora.

In addition to the water diverted through the Boustead Tunnel under Fry-Ark Project water rights, the Fry-Ark Project diverts up to 3,000 acre-feet per year foregone by the Twin Lakes project for fish and recreational water supplies in the Roaring Fork basin. The Quarter-Monthly Model does not simulate the 3,000 acre-foot exchange between the Fry-Ark Project and the Twin Lakes Project.

- **East-Slope Water Rights -** Periods when Reclamation could store native water were determined by the historical call record, which was obtained from the Division 2 Engineer's Office.

Fryingpan-Arkansas Project Water Demands

Municipal Fry-Ark Project water demands include all municipal entities that participate in the Fry-Ark Project, including those entities that participate through the Fountain Valley Authority. Through their allocation principals, the SECWCD has categorized municipal Fry-Ark Project users into four groupings: municipal entities west of Pueblo, the Pueblo Board of Water Works, FVA entities, and municipal entities east of Pueblo. Each entity is allocated a certain percentage of the Fry-Ark Project yield and the Fry-Ark Project storage. Original estimates of Fry-Ark Project yield were approximately 80,400 acre-feet (Reclamation, 1990) which were verified in the original PSOP modeling (MW, 2000). A total of 159,000 acre-feet of Fry-Ark Project storage is set aside for municipal storage and municipal carryover storage (Reclamation, 1990). A summary of Fry-Ark Project yield and storage allocations for each of the entities is presented in **Table 4-2**. It should be noted that the entities are not guaranteed the yield as shown in **Table 4-2**, rather the actual yield available to an entity for any given year is their percentage of the Fry-Ark Project yield for the year.

Table 4-2. Summary of Fry-Ark Municipal Yield and Storage Allocations

Entity	Allocation Percentage	Average Annual Yield Allocation(1) (ac-ft)	Storage Space Allocation(2) (ac-ft)
Municipal West of Pueblo	4%	3,216	12,400
Pueblo Board of Water Works	10%	8,040	31,200
Municipal East of Pueblo	12%	9,648	37,400
Fountain Valley Authority	25%	20,100	78,000
Total	**51%**	**41,004**	**159,000**

Notes:

(1) Based on average annual Fry-Ark Project yield of 80,400 ac-ft.

(2) Based on (Reclamation, 1990) and original District allocation policies. However, the 1998 amended SECWCD Allocation Policies indicate 163,100 acre-feet of municipal carryover storage. This value will be verified with SECWCD.

Historically, Fry-Ark Project water use by non-FVA entities has been low, primarily because the full population planning horizon has not yet been reached. In addition, based upon Fry-Ark Project diversion records, the non-FVA municipal entities have primarily used Fry-Ark water as supplemental supplies and not as primary supplies. However, during the drought years in the early 2000s, several entities requested their full allocation. For Cumulative Effects scenarios it was assumed that all municipal entities, except for the Pueblo Board of Water Works, will use their full contract amount. The Board of Water Works is assumed to continue taking Fry-Ark Project water only on an as-needed basis. The following methods were used for each of the four municipal groupings:

- **Entities West of Pueblo -** The Quarter-Monthly Model does not explicitly model all of the entities' demands that can take delivery of Fry-Ark Project allocations for "Entities West of Pueblo." Deliveries of Fry-Ark Project water to this group is simulated at three points on the Arkansas: Buena Vista, Salida and Cañon City. Spatial and monthly distributions of deliveries to the three delivery points were made by utilizing estimates of future demands contained in the Arkansas Basin Future Water and Storage Needs Assessment (GEI, 1998). In addition, demand projections for these entities in the GEI report far exceed annual Fry-Ark allocations. Therefore, it was assumed that these entities use all of the average annual allocation shown in **Table 4-2** each year in the model.
- **Pueblo Board of Water Works -** The Quarter-Monthly Model contains a single demand node for the PBWW and all of its associated direct flow and storage rights. Fry-Ark Project water was used as an additional supply source only if the PBWW's direct flow and storage rights do not meet its demands. Any excess PBWW water that is not used by Pueblo is reallocated to other Fry-Ark users.
- **Entities East of Pueblo -** As with the "Entities West of Pueblo," the Quarter-Monthly Model does not explicitly model all of the possible users that can take delivery of Fry-Ark Project allocations for "Entities East of Pueblo." Deliveries of Fry-Ark Project water to this group is simulated at three locations on the Arkansas: St. Charles Mesa Water District, La Junta and Las Animas. Spatial and monthly distributions of these deliveries to the three delivery points were made by utilizing estimates of future demands contained

in the Arkansas Basin Future Water and Storage Needs Assessment (GEI, 1998). It was assumed that these entities use all of their average annual allocation each year in the model.

- **Fountain Valley Authority -** Based upon historical water use during recent years, overall planning by the FVA participants and the contract between the FVA and Reclamation, the model assumes that the FVA will divert its full contractual volume of 20,100 acre-feet each year (Reclamation, 1979).

Unallocated water is that portion of the Fry-Ark Project yield that is available to agricultural water users. Typically, this is the 49 percent of Fry-Ark Project yield not allocated to municipal entities plus any unused allocations from previous years. Agricultural water users draw from Fry-Ark Project storage in Turquoise, Twin Lakes and Pueblo reservoirs to meet their demands. Because agricultural demands are assumed to be the same as their historical demands, any historical demands not met by their native or storage rights are met by Fry-Ark Project water.

4.1.1.5 Direct Flow Water Rights

There are numerous direct flow water rights in the study area. Direct flow rights for native water explicitly included in the model in the upper basin include Colorado Springs Utilities CF&I water rights on Lake Fork Creek, the Twin Lakes Company on Lake Creek, the Fry-Ark Project on both Lake Fork and Lake Creek, and Aurora's Lake County ranches on the Arkansas River. Aurora's Lake County ranches include: Buffalo Park, Burrows, Hayden, and Spurlin-Shaw ranches. The ranches consisted of irrigated pasture land from which Aurora has transferred the consumptive use portion to municipal use.

Direct flow rights in the lower basin include the Fry-Ark storage right at Pueblo Reservoir, and direct flow diversion rights by the Pueblo Board of Water Works, the Highline Canal, the Colorado Canal, and the Rocky Ford Canal. **Appendix A** includes a more detailed description of how Colorado Springs demands and operations were estimated.

All diversions not explicitly simulated are implicitly simulated, and because ungaged gains/losses are given the highest priority in the model, their historical demand is fully satisfied.

Demands for direct flow agricultural water rights will generally be equal to their historical demand. Future demands for municipal direct flow diversions that are explicitly modeled have been calculated. The primary source of information for estimating demands for smaller entities was the Water and Storage Needs Assessment (GEI, 1998). For the larger entities of Colorado Springs and Pueblo Board of Water Works, more detailed planning estimates were available and were obtained directly from each entity.

4.1.1.6 Municipal Return Flows

Municipal return flows occur both as sewered return flows, which are released from wastewater treatment plants to the river, and non-sewered return flows, which accrue to streams as a result of lawn watering, system leakage, reservoir seepage, and other unmeasured accruals to the stream.

Return flows originating from reusable sources such as transmountain diversions, transferred consumptive use, and non-tributary ground water, can be captured and reused to extinction by the water's owner. Colorado Springs, the PBWW, Pueblo West and the Fountain Valley entities all use, track, exchange and reuse their reusable water.

Data for Colorado Springs' and PBWW reusable return flows were provide by the utilities. Reusable return flows for Pueblo West and Fountain Valley are calculated by the model off their reusable consumption, and were assumed to be 50 percent of the reusable supply diverted.

4.1.2 Implicitly Modeled Systems

Implicitly modeled systems are represented in the model as part of the gain/loss for each stream reach. These systems are assumed to operate the same in the future as they have in the past. Implicitly modeled systems have the highest priority in the model, so their demands are satisfied first in each model time-step.

Data from implicitly modeled systems can not be retrieved individually, but only as part of the reach gain or loss, which can be examined to verify that the demand was met.

4.1.2.1 Direct Flow Water Rights

Implicitly modeled systems include:

- Native rights for the smaller municipalities west of Pueblo - Leadville, Buena Vista, Salida, Cañon City
- Native rights for the smaller municipalities east of Pueblo - Avondale, Rocky Ford, La Junta
- Agricultural users - all non-explicitly modeled agricultural users

4.1.2.2 Ground Water Use and Well Augmentation

For purposes of the model, it is assumed that ground water pumping and associated well augmentation requirements are accounted for in the gage records and that no changes will be made from historical uses for both pumping and the associated well augmentation.

4.1.2.3 Columbine, Ewing and Wurtz Ditches

Columbine, Ewing and Wurtz Ditches are transmountain diversion ditches that divert water from the Colorado River Basin to the Arkansas River Basin near Tennessee and Fremont passes north of Leadville. The Pueblo Board of Water Works owns the diversion facilities, water rights, and the associated yields. Because yields from these systems are included in the

Leadville gage record, diversions through these ditches was assumed the same as historical and the ditches were implicitly modeled.

4.1.2.4 Blue River Project

The Blue River Project is a transmountain project that diverts water from the upper reaches of the Blue River into Colorado Springs Utilities' local system. Water is diverted out of several tributary streams to the Blue River and the Blue River headwaters through a series of pipelines and tunnels to the Hoosier Tunnel. The Hoosier Tunnel conveys water beneath the Continental Divide to Montgomery Reservoir in the South Platte Basin. From Montgomery Reservoir, water flows by gravity through the Montgomery Pipeline to North Catamount Reservoir on the north slope of Pike's Peak.

By decree, water diverted through the Blue River system must be reused to extinction by Colorado Springs. Therefore, although this import does not directly affect flows in the study area, the reusable return flows resulting from its use do impact flows in Fountain Creek. Historical Blue River diversions have averaged 8,900 acre-feet per year. The recent Blue River Substitution Agreement will change operations of the Blue River system, and Colorado Springs Utilities estimates project yield to be approximately 8,100 acre-feet per year (MWH, 2005). Return flows from this system are included in Colorado Springs Utilities' reusable return flows (**Appendix A**).

4.2 Water Rights Yields and Demands

This section discusses the source of the system yield and demand data used in the model.

4.2.1 System Yields

Collection system and water rights yields used in the Quarter-Monthly Model were developed from one of two primary sources, either from historical records or from calculated potential yields. Historical yields were used for systems where the owner, use and supply have not changed over the study period, nor are they anticipated to change in the foreseeable future. These primarily include water rights that obtain their supplies from the Arkansas River, such as the Pueblo Board of Water Works and the Highline Canal. For these systems, the yields are based on river call and the historical gage record, which are used to develop some of the model inputs.

For systems where a water right's use has changed over time, potential system yields were developed to reflect diversions unconstrained by a lack of demand or facilities. This is particularly applicable for transmountain supplies, which were commonly developed to meet future municipal demand. Unconstrained yields were developed for the Homestake, Busk-Ivanhoe, Fryingpan-Arkansas, Twin Lakes, Colorado Canal and Rocky Ford systems. These yields reflect water legally available at the headgates of these projects, which are then constrained by the model to limitations in diversion or delivery capacity as the model uses supplies to meet demands.

Calculated yields from transferred agricultural rights were calculated for both the consumptive use portion and the delayed return flow portion of the historical diversion. The consumptive use portion is the part of historical diversion that was consumed through evaporation and transpiration. The delayed return flow is the portion of the historical diversion that eventually made its way back to the Arkansas River must be returned to the river outside of the diversion season.

4.2.1.1 Rocky Ford Ditch

System yields for the Rocky Ford ditch were developed by Ross Bethel, LLC. Under the Rocky Ford I transfer decree (a.k.a. RIG decree, 1983CW018), Aurora is allowed to divert both the consumptive use and the delayed return flow portion of the water right, but is bound by the decree to store 1000 acre-feet of delayed return flows and release them back to the river from November through February. These delayed return flows are stored in Pueblo Reservoir.

Each year, Aurora consults with the Board of Trustees for the Winter Water Program, which decides if the delayed return flow obligation water should be released to the river or if the water should be transferred from Aurora's account to the WWSP account. Historically, the Board has recommended that the water be transferred to the WWSP account and made part of the water allocated to WWSP participants on March 15 each year. The Quarter-Monthly Model diverts the first 1000 acre-feet of Rocky Ford water into a reusable return flow account, which is debited in November of each year. The requirement for the 618 acre-feet of delayed return flows under the Rocky Ford II transfer (1998-CW-169) is handled in the same manner.

Rocky Ford yields are diverted as an alternate point of diversion at either Pueblo Reservoir (Proposed Action) or the gravel pit (No-Action). Diversions of Rocky Ford I water at Pueblo are made in accordance with the Rocky Ford transfer decree, 1983CW18. Diversions into the gravel pit are made assuming that the decree to the alternate point is junior to all intervening diversions and decrees.

4.2.1.2 Winter Water Storage Program

Prior to completion of Pueblo Dam, water users would divert their water rights in-priority throughout the winter to maintain soil moisture levels. However, problems associated with wintertime operations were frequently experienced. In 1975, the Winter Water Storage Program (WWSP) was developed to allow these entities to store water for use during the following irrigation season. Water from the WWSP is stored in several reservoirs throughout the basin from November 15 through March 15 of each year, when it is made available to winter water participants.

4.2.1.3 Colorado Canal

Yields for the Colorado Canal were calculated by Grand River Consulting, Inc. Under the Colorado Canal transfer (1984CW62, -63, -64), the delayed return flows are apportioned within the Colorado Canal system, and releases are made to the river from the Lake Meredith outlet. Because the delayed return flows for the Colorado Canal are calculated on a four-year cycle, the Quarter-Monthly Model diverts the consumptive use portion of the water transferred from the Colorado Canal into storage in Lakes Henry and Meredith, and leaves the operation of the delayed return flows as an implicitly modeled component of the model within the ditch. The result of this simplification is that the contents of Lakes Henry and Meredith will likely be higher than what is shown in the modeling results, because the lakes commonly contain return flows owed in future years.

Municipal yields from the Colorado Canal are diverted at the Colorado Canal headgate and stored in Lakes Henry or Meredith. Water is released from the reservoir when there is exchange potential to move it upstream. Under the Existing Conditions, Colorado Canal water can be exchanged either into Pueblo Reservoir or the upper basin reservoirs. Under the No-Action, Colorado Canal water can only be exchanged from the Meredith outlet to the upper basin or into the gravel pit.

4.2.1.4 Highline Canal Lease

The City of Aurora has entered into a intergovernmental agreement (IGA) with SECWCD and the UAWCD to limit Aurora's ability to lease water from the Arkansas basin, to 10,000 acre-feet of water in up to 3 of every 10 years. Aurora developed a contract for lease of water from Rocky Ford Highline Canal shareholders and received approval of terms and conditions to operate the lease in 2004 and 2005 from the State Engineers office.

The consumable portion of the Highline lease was developed by Aurora's city staff and provided to Hydrosphere. The model diverts those yields as an alternate point of diversion in either Pueblo Reservoir (Proposed Action) or the gravel pit (No-Action), with the right to divert at the alternate point being junior to all existing exchanges. Based on the historical hydrology, the lease is activated in the model for water years 1990, 1991, 1992, 2000, 2001 and 2002, for 10,000 acre-feet each year.

4.2.2 System Demands

By definition, implicitly modeled systems use historical demands. Using historical diversions in the calculation of system gains and losses assumes that the supply and demand for water by these systems will be the same for a given hydrology in the future as it was in the past.

Current and future demands for Colorado Springs (**Appendix A**), and the Pueblo Board of Water Works were obtained from those entities. The Fountain Valley Authority pipeline was assumed to run at capacity for all scenarios. Demands at the Otero pump station were obtained from Colorado Springs Utilities and from the Aurora Water Resources Department.

4.3 Reservoir Accounting

The Quarter-Monthly Model dynamically simulates total reservoir contents and individual reservoir accounts for all of the major reservoirs used by Aurora in the Arkansas River basin. This section describes how each of these reservoirs is represented in the model.

The Fryingpan-Arkansas Project includes one West Slope reservoir, three East Slope reservoirs and one East Slope forebay. The storage volumes for each of these reservoirs are shown in **Table 4-3**. The three major East Slope reservoirs, Turquoise, Twin Lakes and Pueblo reservoirs, are explicitly included in the model. Because West Slope operations are not explicitly simulated in the Quarter-Monthly Model, storage in Ruedi Reservoir is not simulated. In addition, because storage in the Mount Elbert Forebay is primarily used for storage associated with pump-storage power generation at the Mount Elbert Powerplant, storage in this facility is not included in the model.

Table 4-3. Fryingpan-Arkansas Project Reservoir Storage Volumes

Reservoir	Reservoir Storage (ac-ft)					
	Dead	Inactive(1)	Active Conservation	Joint Use	Flood Control	Total Capacity
Ruedi	63	1,095	101,278	0	0	102,373
Turquoise	2,810	8,920	120,478	0	0	129,398
Pueblo	2,329	28,121	228,828	66,000	26,991	349,940
Twin Lakes	63,324	72,938	67,917	0	0	140,855
Mount Elbert Forebay	561	3,825	7,318	0	0	11,431

Notes:
(1) Inactive includes dead storage
(2) From: http://www.usbr.gov/gp/aop/fa/97/table_10.htm

4.3.1 Turquoise Reservoir

Turquoise Reservoir was originally owned by the CF&I Steel Corporation, and had a capacity of 17,416 acre-feet. The reservoir was expanded as part of the construction of the Fry-Ark Project in 1968 to its present capacity of 129,398 acre-feet. Turquoise Reservoir is modeled using six distinct accounts:

- Fry-Ark Project
- Aurora's Homestake
- Colorado Springs' Homestake
- Aurora's CF&I
- Colorado Springs' CF&I
- Pueblo BOWW CF&I

The total reservoir space is allocated as shown in **Table 4-4**.

Table 4-4. Turquoise Reservoir Accounts

Account(1)	Storage (ac-ft)
Active	
CF&I	
Colorado Springs Utilities	17,416
Aurora	5,000
Pueblo Board of Water Works	5,000
Sub-Total	**27,416**
Homestake	
Aurora	15,000
Colorado Springs Utilities	15,000
Sub-Total	**30,000**
USBR Fry-Ark Project	**63,062**
Sub-Total	**120,478**
Dead/Inactive	8,920
TOTAL	**129,398**

Notes:

(1) The Busk-Ivanhoe account can only be used to store agricultural water, so the operation of this account is not simulated in the model.

Routine operations by Reclamation at Turquoise Reservoir are to divert as much water as possible down the Mount Elbert Conduit, to maximize power generation at Twin Lakes. With an adjudication date of 1977, the Colorado Water Conservation Board (CWCB) in-stream flow rights on Lake Fork are junior to all of the water rights on Lake Fork except for river exchanges, which were decreed in 1983. Consequently, Reclamation is not required to bypass water through Turquoise Reservoir to meet minimum stream flows. Reclamation does, however, voluntarily release 3 cfs below Turquoise Reservoir from October 1 through April 30, and 15 cfs from May 1 through September 30. These voluntary releases have been incorporated into the modeling as the minimum flows below the reservoir, with water being released from the Fry-Ark Project account if native inflows are less than these rates.

Reclamation's account in Turquoise is used primarily for the storage of Fry-Ark Project water imported through the Boustead Tunnel. The rule curve for Bureau space in Turquoise Reservoir has the highest priority of the three east slope project reservoirs in the Quarter-Monthly Model. Water can be pulled from Reclamation's account in Turquoise to meet the minimum flow requirements in Lake Fork Creek and Lake Creek, to meet the voluntary rafting flow program at Wellsville, and to meet demands for Fry-Ark Project water below Pueblo Reservoir.

Evaporation is calculated by the model using an area-capacity curve obtained from Reclamation, and monthly evaporation rate data obtained from the National Weather Service. Evaporation losses are calculated for the entire reservoir, and then pro-rated to the individual account owners based on account contents.

Modeling of Turquoise operations is done on a strict accounting basis, and water may only be stored in the space allocated to an entity. Because storage accounts in Turquoise Reservoir are for a fixed amount of firm space, and because the model is programmed not to allow water from one entity into the space of another, there can be no impact by Aurora on Reclamation's project operations.

4.3.2 Twin Lakes Reservoir

Twin Lakes was a natural lake that was dammed by the Twin Lakes Reservoir and Canal Company in the 1930's, with an active capacity of 54,452 acre-feet. The reservoir was expanded again with the construction of the Fry-Ark Project, for a total reservoir capacity of 140,855 acre-feet. Because of its earlier decree, the Twin Lakes Company retains control over 54,452 acre-feet of space in the reservoir.

Due to their status as shareholders of the Twin Lakes Company, the Quarter-Monthly Model includes accounts in Twin Lakes Reservoir for Aurora, Colorado Springs, Pueblo West, Pueblo Board of Water Works, and a general account for smaller shareholders of the canal company. Demand for the minority shareholders account is modeled at the headgate of the Colorado Canal, and is assumed to have the timing of an agricultural demand. These accounts are dedicated storage, which, unlike excess capacity (if-and-when) accounts in Pueblo Reservoir, are not subject to spill by Project water. Storage space allocations in Twin Lakes are shown in **Table 4-5**.

Table 4-5. Twin Lakes Reservoir Accounts

Account	Storage (ac-ft)
Active	
Twin Lakes Project(1)	
Colorado Springs Utilities	29,762
Aurora	2,722
Pueblo Board of Water Works	12,602
Others	9,366
Sub-Total	**54,452**
Fry-Ark Project	**13,465**
Sub-Total	**67,917**
Dead/Inactive	**72,938**
TOTAL	**140,855**

Notes:

(1) Twin Lakes Project storage accounts based on share information provided by the Twin Lakes Company (Ringle, 2004).

Reclamation's account in Twin Lakes is used primarily for the storage of Fry-Ark Project water imported through the Boustead Tunnel, and for reregulating water associated with power generation at the Mt. Elbert hydroelectric plant. The rule curve in Twin Lakes for project water is second in priority to the rule curve in Turquoise Reservoir. Water can be pulled from the Reclamation account to meet the minimum flow requirements in Lake Creek below Twin Lakes, to meet the voluntary rafting flow program at Wellsville, and to meet agricultural demands in the lower basin below Pueblo Reservoir. Reclamation retains the ability to use up to 8000 acre-feet, the top 2.75 feet, of the reservoir for operation of the Mount Elbert Pump-Storage Plant (Hopkins, 2005).

Evaporation is calculated by the model using an area-capacity curve obtained from Reclamation, and monthly evaporation rate data obtained from the National Weather Service. Evaporation losses are calculated for the entire reservoir, and then pro-rated to the individual account owners based on account contents.

4.3.3 Clear Creek Reservoir

Clear Creek Reservoir is owned and operated by the Pueblo Board of Water Works, and has an active capacity of 11,180 acre-feet. The reservoir is included in the model to meet the PBWW municipal demands.

Evaporation is modeled dynamically by the model using an area-capacity curve obtained from the Colorado Division of Water Resources, and evaporation data obtained from the National Weather Service.

4.3.4 Pueblo Reservoir

Pueblo Reservoir was constructed as part of the Fry-Ark Project, and was completed in 1975. Pueblo Reservoir is used to re-regulate Fry-Ark Project water delivered from the upper Arkansas basin, and when space is available, to store non-Project water owned by other entities including the Winter Water Storage Program.

In the 1979 Allocation Principals, the SECWCD allocated a minimum of 159,000 acre-feet of Project storage to municipal entities. For FVA entities, this value was further subdivided in the FVA contract between the participants and Reclamation. For entities west of Pueblo and east of Pueblo these values were determined from documents contained at the SECWCD offices. A summary of this distribution is shown in **Table 4-6**.

Table 4-6. Summary of Fry-Ark Municipal Storage Allocations

Entity	Municipal Allocated Storage Space(1)		Distribution of Storage Space	
	(percent)	(ac-ft)	(percent)	(ac-ft)
Municipal West of Pueblo	7.80%	12,400		
Florence			4.5%	558
Cañon City			2.8%	347
Others			92.7%	11,495
Pueblo Board of Water Works	19.62%	31,200	100.0%	31,200
Municipal East of Pueblo	23.52%	37,400		
St. Charles Mesa			15.2%	5,686
Others East of Pueblo			84.8%	31,714
Fountain Valley Authority	49.06%	78,000		
Colorado Springs Utilities (71.41%)			71.4%	55,700
Other FVA Entities (28.59%)			28.6%	22,300
Total		**159,000**		**159,000**

Notes:

(1) From SECWCD "Allocation Principles, Findings, Determinations, and Resolutions," November 29, 1979 as shown in Reclamation "Review of Operations Fryingpan-Arkansas Project Colorado," September 1990. It should be noted that in the SECWCD "Water Allocation Policy Amended August 1988," contained in the same document, the municipal carryover storage space was stated to be 163,100 acre-feet.

For the Quarter-Monthly Model, all municipal project accounts are represented as a single account, and municipalities withdraw water from that account to meet their demands for project water.

In addition to firm account space, Reclamation has historically allowed storage of non-Project water in Project storage space through programs such as the WWSP and if-and-when accounts. The spill priority of this non-Project water is important in simulating storage in Project reservoirs because when Project water is available, it has the first right to use Project space. The spill priorities shown in **Table 4-7** have been established by Reclamation (Reclamation, 1990). These spill priorities are followed in the model.

Table 4-7. Fryingpan-Arkansas Project Reservoir Spill Priorities

Spill Order(1)	Storage Account
1	Entities Outside of District
2	If & When Storage
3	WWSP water in Excess of 70,000 ac-ft
4	Municipal non-Fry-Ark Project water
5	WWSP water less than 70,000 ac-ft
6	Native Arkansas River Basin Fry-Ark Project water

Notes:
(1) First to spill is the first account in the list.

Reclamation has historically contracted with entities to allow storage of non-Project water in Project storage space. The municipal users Aurora, PBWW, Colorado Springs, Pueblo West and Fountain, as well as some of the agricultural users in the lower basin, have leased if-and-when space in the reservoir. Historically, if-and-when contracts were signed on an annual basis. The largest users of these contracts have been Colorado Springs Utilities and the City of Aurora, with contracts for up to 10,000 acre-feet of storage space.

Long-term Excess Capacity Contracts (long-term contracts) are similar to those being requested by Colorado Springs Utilities and Aurora. Currently, the only long-term contract in Project facilities is a 40-year contract with the Pueblo Board of Water Works for 15,000 acre-feet. Because of the contract length, Reclamation has determined that it should be modeled for the future conditions. In the model, it is assumed that the Pueblo Board of Water Works will exchange reusable return flows into its contracted storage space and use them to meet future demands.

Modeling the Existing Conditions scenario includes If-and-When storage in Pueblo Reservoir. Because the contracts for storage have changed over time, only the most regular users of If-and-When contracts are included in the model. These include Aurora, Colorado Springs, Pueblo Board of Water Works, and Pueblo West. The sizes of the storage accounts used in the model are shown in **Table 4-8**.

Table 4-8. Pueblo Reservoir Modeled If-and-When Storage Volumes

Entity	Existing Conditions (ac-ft)	Effects (ac-ft)	Cumulative Effects (ac-ft)
Aurora	10,000	0/10,000 (1)	10,000
Colorado Springs	10,000	10,000	1,000
Pueblo Board of Water Works	3,000	3,000	15,000
Pueblo West	1,000	1,000	1,000
Total	**24,000**	**24,000**	**27,000**

Notes:
(1) Proposed Action = 10,000 ac-ft
No Action = 1,000 ac-ft

For the purpose of the NEPA analysis, it was assumed that Colorado Springs Utilities will pursue its No Action alternative, which would presumably result in a smaller year-to-year if-and-when contract. The Pueblo Board of Water Works recently obtained a long-term contract for if-and-when space, so the size of its account reflects its historical usage and potential future use. The account sizes for the other entities are assumed to be the same as past contracts.

For the No-Action scenario, Aurora has no space in Pueblo Reservoir, and Aurora is not allowed to use the reservoir as a terminal point for any of its exchanges. Under the Proposed Action scenarios, Aurora is allocated 10,000 acre-feet of space in the reservoir, though Aurora's account spills according to the spill priority if the reservoir fills with project water.

Fry-Ark Project storage in Pueblo Reservoir is determined by the historical call record, which was obtained from the Division 2 Engineer's Office. The Quarter-Monthly Model allows Arkansas basin water to be stored in Bureau space in project reservoirs only when a free river historically occurred on the Arkansas mainstem when the reservoir is in priority, when there is water available at Pueblo Reservoir, and when reservoir space is available. The model allows water to be stored in both the 228,828 acre-foot conservation pool, but not in the 66,000 acre-foot joint use pool. When Pueblo Reservoir fills in the model, all the if-and-when accounts are spilled to the Arkansas River. Accounts can begin refilling when the level of Pueblo Reservoir drops below the top of the Conservation Pool.

WWSP water is stored in available space and distributed to users downstream during the summer months. Because this model focuses on Aurora's operations and not on the ownership of particular drops of water in the stream, water stored during the WWSP period is not tracked separately, but is co-mingled with other Bureau water in the three project reservoirs.

Evaporation losses are calculated for Pueblo Reservoir using an area-capacity curve obtained from the State Engineer's Office (Colorado Division of Water Resources, 2004), and evaporation rates obtained from the NOAA evaporation Atlas. Evaporation losses are calculated for the entire reservoir, and then pro-rated to the individual account owners based on account contents. This is different than Reclamation's actual operations, which is to allocate the total evaporation from Pueblo, Twin Lakes and Turquoise reservoirs to the water users storing water in the reservoirs, regardless of which reservoir the water is stored in.

4.3.5 Colorado Canal System

The model includes the Colorado Canal system reservoirs, Lakes Henry and Meredith. Historically, the Colorado Canal system has operated Lakes Henry and Meredith to maximize the benefits to the Colorado Canal system, and not in accordance to a particular management or operations plan. Creating modeling rules that reproduce historical allocations between Henry and Meredith has proved difficult at best. Consequently Lakes Henry and Meredith are represented in the model as a single reservoir. **Table 4-9** shows the reservoir accounts used in modeling. Evaporation for the reservoirs was calculated from a composite area-capacity curve.

Table 4-9. Ownership of Colorado Canal System Companies

Entity	Company Shares(1)			Percent Ownership		
	Colorado Canal (3)	Lake Meredith	Lake Henry	Colorado Canal	Lake Meredith	Lake Henry
Colorado Springs Utilities	28,012.760	21,084.750	6,923.150	56.4%	51.9%	77.2%
City of Aurora	14,225.380	13,061.800	1,163.580	28.7%	32.2%	13.0%
City of Fountain(4)	512.500	512.500	0.000	1.0%	1.3%	0.0%
Pueblo West	360.330	360.330	0.000	0.7%	0.9%	0.0%
Woodland Park(4)	583.250	336.000	247.250	1.2%	0.8%	2.8%
Other Uses(2)(4)	1,108.584	946.184	123.000	2.2%	2.3%	1.4%
Agricultural(4)	4,836.171	4,319.821	510.600	9.7%	10.6%	5.7%
Total	**49,638.975**	**40,621.385**	**8,967.580**	**100.0%**	**100.0%**	**100.0%**

Notes:

(1) Source: Ringle (2004).
(2) Includes municipal and industrial use and uses for augmentation.
(3) Total Colorado Canal shares are typically the sum of Lake Meredith and Lake Henry shares, but this is not always true. Data reported is the most current available.
(4) Entities are grouped into a single shareholder for purposes of the Quarter-Monthly Model.

To calculate the effects of the different scenarios on operations at Lakes Henry and Meredith, output from the single reservoir in the model was disaggregated into likely operations at the two reservoirs. This was done by subtracting the historical contents of Lake Henry from the model output, effectively placing all the change due to changes in Aurora's operations in Lake Meredith. If the total change in contents could not be contained in the available storage in Meredith, the remaining change was made in Lake Henry. For example, if the model stored 500 acre-feet in the combined reservoir but there was only 475 acre-feet of space in Lake Meredith, the remaining 25 acre-feet was put into Lake Henry.

4.4 Exchanges

Water can be exchanged from the lower basin to the upper basin by either river exchange or contract exchange. River exchanges take place when a water user diverts water at an upstream point and replaces that diversion with water at a downstream point, with no injury to senior water rights holders. A contract exchange occurs when two water users agree to trade water that is in storage, typically when one user has water in a lower reservoir and storage space in an upper reservoir, and a second with space in the lower reservoir and water in the upper. The users agree to trade water between accounts, with the party initiating the exchange typically providing extra water or paying cash to the other party participating in the trade.

4.4.1 River Exchanges

To be a recognized water right, river exchanges must be decreed in water court and have a priority dates assigned to them. To obtain a decree, the applicant for a river exchange must demonstrate that the exchange will not injure any senior water rights. The Quarter-Monthly Model includes all exchanges that are either filed or decreed, though some of the exchange amounts have been reduced from their historical operation to reflect recent historical operations.

4.4.1.1 Modeling Adjustments for Historical Exchanges

River Exchanges

River exchanges reduce the flow that would otherwise occur in the river between the point of diversion and the point of replacement. To make the model as accurate as possible, historical river exchanges by Colorado Springs and Aurora were added back into the historical gage record, using data provided by the two municipalities. Gage records were not corrected for river exchanges by the Pueblo Board of Water Works because it has traditionally made comparatively low rates of exchanges. River exchanges for agricultural users, were not added back into the historical gage record. This is a conservative assumption for modeling exchange potential.

There have been times when Colorado Springs discharged more reusable return flows into Fountain Creek than they were able to exchange or for which they had a demand. Under these circumstances, this water flowed into the Arkansas River. Some of this water was sold to other entities for augmentation purposes, and some was relinquished to the river to the benefit of downstream users. Because the release of this type of water has been sporadic over time, because the users of this water have not been constant, and because records of the fate of unexchanged water are not kept, no attempt was made to back this water out of the historical gage record. The result of not backing out these flows is that gaged flows in the Arkansas below Fountain Creek are occasionally higher than what they would have been without Colorado Springs' operations.

The higher flows resulting from this assumption are mitigated in two ways. First, return flows from Colorado Springs are not added to the stream until the third op-step, after native and transmountain demands have been satisfied, so downstream demands do not rely on this water as part of their supply. Second, at least some water users needing augmentation water would have acquired water from other sources, and that water would likely have been delivered in a similar quantity and pattern as that provided by Colorado Springs.

Contract Exchanges

Contract exchanges are made by moving water from one account to another within a reservoir, and moving a similar amount of water the opposite direction between the same account holders in a different reservoir. During the execution of a contract exchange, there is no physical movement of water in or out of either reservoir. Reach gains and losses are calculated using the change in total historical reservoir contents, but no calculations are based on historical reservoir contents at the account level. Consequently, no adjustments were made for historical contract exchanges.

4.4.1.2 *Modeling of Exchanges*

The first exchanges in the Arkansas basin were decreed to move agricultural water from a downstream point of return to an upstream headgate for reuse. Today, the majority of the river exchanges in the Arkansas basin move reusable water into Pueblo Reservoir, and from Pueblo Reservoir to upstream storage and conveyance facilities at Twin Lakes and Turquoise reservoirs. The decree allowing Pueblo Reservoir as an alternate point of diversion for Rocky Ford Ditch water is operated in the same priority system and in a manner similar to a river exchange.

While water run from the upper basin to the lower basin is charged a transit loss, river exchanges do not receive a credit for a reverse loss, and the loss left in the stream becomes a benefit to the other users in the system. Consequently, water moved by exchange in the model is not inflated by the transit loss, and is consistent with administration of exchanges by the Division Engineer's Office.

End-Points of Exchanges

Because Aurora's decrees for alternate points of diversion and exchange are junior to other river exchanges, the model includes senior exchanges that compete with Aurora's operations in the basin. These include exchanges by the SECWCD, the Pueblo Board of Water Works, the Colorado Canal Companies, and the City of Colorado Springs.

While it is common to include every conceivable alternate point of diversion when obtaining an exchange decree, in practice water is typically exchanged to only a few locations. **Table 4-10** shows the exchanges included in the model.

Table 4-10. Modeled Exchange Entities, Reaches and Rates

Entity	From (lower end)	To (upper end)	Max Rate (cfs)	Annual Limit (ac-ft)
SECWCD	Fountain Creek	Pueblo Reservoir	15 cfs	none
PBWW	WWTP effluent	Pueblo Reservoir	27 cfs	none
	Pueblo Reservoir	Clear Creek Reservoir	native inflow	none
	Pueblo Reservoir	Twin Lakes Reservoir	native inflow	none
	Pueblo Reservoir	Turquoise Reservoir	native inflow	none
Colorado Canal Companies	Meredith Outlet	Pueblo Reservoir	100 cfs	none
	Pueblo Reservoir	Twin Lakes Reservoir	756 cfs	none
	Pueblo Reservoir	Turquoise Reservoir	756 cfs	none
Colorado Springs Utilities	Fountain Creek	Pueblo Reservoir	100 cfs	none
	Pueblo Reservoir	Twin Lakes Reservoir	native inflow	none
	Pueblo Reservoir	Turquoise Reservoir	native inflow	none
Aurora	Rocky Ford Headgate (RF I)	Pueblo Reservoir	0 to 32 cfs	9,270 ac-ft
	Rocky Ford Headgate (RF II)	Pueblo Reservoir	0 to 18 cfs	56,379 ac-ft
	Pueblo Reservoir	Twin Lakes Reservoir	500 cfs	none
	Pueblo Reservoir	Turquoise Reservoir	350 cfs	none

Exchange Priorities

There are no less than ten water users with decreed and pending applications for exchanges on the mainstem of the Arkansas River. A summary of the decreed, pending and potential future exchanges is presented in **Table 4-11**, which has its origins in the exchange order stipulated in 1984CW62, -63 and -64. As shown, the decreed exchanges in the table (priorities 1-11) are administered in a rather complex priority system and often have monthly and annual limitations. Each of these exchanges is simulated in the model according to the relative decrees and stipulations. However, several exchanges are dependent upon using Project storage space to facilitate the exchanges. Consequently, Colorado Springs and Pueblo West, entities which have historically used if-and-when space, are assumed to have access to at least a minimal amount of such space in Pueblo Reservoir in the cumulative effects scenarios.

In addition to the decreed exchanges, there are several other pending exchanges (priorities 12-13) that are also modeled, as a portion of these exchanges are directly tied to operations of the Southern Delivery System (SDS). These exchanges include the City of Aurora Rocky Ford II application, City of Fountain exchange application, the SECWCD exchange application for non-sewered municipal and agricultural Project return flows, and the Pueblo West exchange application. Future Exchanges (Priority No. 14 in the table) will not be modeled.

The WWSP, which operates from November 15 through March 15 of each year, sets the call on the Arkansas River to March 1, 1910, which effectively calls out the decreed river exchanges on the mainstem of the Arkansas River. A condition of the WWSP decree allows Colorado Springs to store up to half of the native inflow to Pueblo Reservoir in Pueblo Reservoir, with a maximum annual limitation of 17,000 acre-feet, during the winter water storage season. The Pueblo Board of Water Works is also allowed to exchange to its river intakes during the winter water season, up to its decreed rate. For modeling purposes, no river exchanges were allowed during the WWSP storage season for the PBWW, because the Board has changed its normal diversion point from its river intakes to Pueblo Reservoir. The model does allow Colorado Springs to exchange up to 17,000 acre-feet of water during the winter water season. The consequence of this assumption is that water from the PBWW that returns to the river during the WWSP season will flow unused down the Arkansas River.

Table 4-11. Arkansas River Priorities for Exchanges into Pueblo Reservoir

Priority	Beneficiary	Amount	Case	Priority Date
1	SECWCD	(1)	B42135, 88CW143, 84CW56	2/10/1939
2	PBWW	27 cfs	83CW18, 84CW62, 84CW63, 84CW64, 84CW35, 84CW202, 84CW203, 84CW177, 84CW178	4/14/81, 5/31/84
3	Colorado Canal Company Agricultural Entities	100 cfs		
4	PBWW	50 cfs		
	Colorado Canal Companies	50 cfs		
5	Colorado Canal Companies	50 cfs		
6	Colorado Springs	77 cfs minus PBWW Exchange under #2 and #4		
7	City of Aurora	Applicable Maximum Rate of Flow Allowed by Decree in 83CW18		
8	Colorado Springs	100 cfs minus CSU Exchange under #6		
	Colorado Canal Companies	1/2 or remaining exchange potential up to 756 cfs		
9	Colorado Springs	1/2 of remaining exchange potential minus Rocky Ford I under #9		
	City of Aurora	Up to 40 cfs of 1/2, but not to exceed 500 ac-ft annually; thereafter 25% of 1/2 up to an additional 500 ac-ft annually.		
10	Colorado Springs	164 cfs/1000 acre-feet	86CW118	3/20/1985
11	Public Service Company	14 cfs		
12	City of Aurora	Applicable Maximum Rate of Flow Allowed by Decree in 99CW169	99CW169	12/28/1999
13	City of Fountain	60 cfs	01CW108, 01CW146	(3)
	SECWCD	(2)	01CW151	(3)
	Pueblo West	100 cfs	01CW152	(3)
	City of Pueblo	(4)	01CW160	(3)

Notes:

(1) Measured Municipal Fry-Ark Project Return Flows generated and re-purchased by the same entity.
(2) Non-measured Municipal and Agricultural Fry-Ark Project Return Flows.
(3) Priority yet to be determined.
(4) See discussion on Pueblo Flow Management Program

Exchange Modeling Methodology

After the Quarter-Monthly Model has allocated the native and transmountain water to the users in the basin in the first two op-steps, it exchanges water upstream in op-steps three through seven. Multiple op-steps are required because of the interrelated nature of the exchange decrees.

The amount of water that can be moved by river exchanges is a function of multiple factors. Links routing the exchanged water are constrained by the demand or available reservoir storage space available at the upper end of the exchange, the minimum of the replacement supply available at the lower end of the exchange, the rate and volume granted by the exchange decree, and by the water physically available for exchange.

To determine the amount of water available for exchange, the model calculates the streamflow for each reach in the model, and then determines the reach with the least amount of unallocated flow. The model then allocates water to exchanges, up to the amount of the remaining flow, based on the priority and rates of the exchange decrees.

4.4.2 Contract Exchanges

In the Arkansas basin, Aurora and Colorado Springs have initiated contract exchanges to move reusable water from Pueblo Reservoir to Twin Lakes, where it can be diverted to the Otero pump station. The accommodating parties have typically been the Pueblo Board of Water Works and Reclamation, who import transmountain water in the upper basin and want to move it to the Pueblo Reservoir and points below. Contract exchanges are not decreed by the water court, because the exchange occurs between two willing parties who have legally diverted water, which is under their control, and when doing so would not injure other water rights holders

A typical contract exchange under the Proposed Action would consist of Aurora trading Reclamation 1,000 acre-feet of water in Pueblo Reservoir for 1,000 acre-feet of Reclamation’s water in Twin Lakes. If the water was moved by river exchange instead of a contract exchange, and if the release and the river exchange were planned for the same rate over the same length of time, there would also be no change in stream flows. If the release and the contract exchange were not scheduled to coincide, then the effect would be to increase flows in the river at one time and decrease them at another.

In addition to the benefit that Aurora’s contract exchanges are typically accompanied by a cash payment to the other entity participating in the trade, the accommodating party also benefits from the exchange by eliminating the transit loss that would have otherwise been charged them if they had conveyed the water down the stream channel. The State Engineer assesses a 0.7 percent transit loss per mile between Twin Lakes and Pueblo Reservoir, for a total transit loss is 9.6 percent, so a contract exchange, which moves water without physically running it down the stream, saves the accommodating entity almost 10 percent of the water moved. This additional water is then available for the end user, typically irrigated agriculture. Historically, the initiating parties have not received credit for the saved transit loss.

Contract exchanges are modeled between Aurora the Pueblo Board of Water Works, and/or Reclamation. Exchanges are carried out in 1,000 acre-foot blocks, first with the Board of Water Works and second with Reclamation. Exchanges are made preferentially to Twin Lakes and then to Turquoise Reservoir. For a contract exchange to occur, there must be at least 1,000 acre-feet of Aurora’s water and 1,000 acre-feet of Pueblo or Fry-Ark space in Pueblo Reservoir, at least 1,000 acre-feet of Pueblo or Fry-Ark water in Twin or Turquoise, and at least 1,000 acre-feet of Aurora’s space, also in Twin or Turquoise. Contract exchanges are restricted to occur in the months of June through March, when river exchanges are most likely to be partially or completely called out by other factors.

4.4.3 Flow Management Programs

There are several legally binding flow programs and decreed minimum flow requirements within the study area, several of which are on the Arkansas River. **Table 4-12** presents a summary of these programs, including who is a party to the program, the location of flow measurement, a brief description of the program, whether the program is mandatory or voluntary, and whether it applies only to exchanges or to reservoir releases as well. Many of the minimum flows are tied to decreed change cases and exchanges.

4.4.3.1 Simulation Methods

All currently legally binding flow programs are included in the Quarter-Monthly Model. If operations have historically been made to meet a voluntary program, then the program was included as a mandatory program in the model. For instance, the Upper Arkansas Flow Management Program is a voluntary flow program, but because all entities have historically operated their systems to meet these flows. This flow program is modeled as a mandatory program. This assumption is conservative for calculating exchange potential.

4.4.3.2 Flow Management and Recovery of Yield Programs

Aurora's ability to execute river exchanges is constrained by decrees, stipulations, in-stream flow filings, IGAs and voluntary subordination of water rights. **Table 4-12** lists the various locations where Aurora's exchanges are limited by streamflows.

Table 4-12. Flow Management Programs and Minimum Flow Requirements on the Arkansas River

Program	Binding Parties	Type	Location	Description
Lake Fork CWCB Instream Flow Right	Reclamation	Mandatory Storage Bypass/Release	Lake Fork D/S of Turquoise Reservoir	Decreed minimum flow of 15 cfs from Sugarloaf Dam outlet to Willow Creek, 20 cfs from Willow Creek to Arkansas.
Lake Creek CWCB Instream Flow Right	Aurora	Mandatory Exchange/APOD Curtailments	Lake Creek D/S of Twin Lakes	Decreed instream flow right of 15 cfs.
Salida Q710	Exchangers	Mandatory Exchange/APOD Curtailments	Salida WWTP Effluent Discharge	Nov-Jan, 189 cfs; Feb-Apr, 180 cfs; May-Jul, 239 cfs; Aug-Oct, 229 cfs.
Salida Q710	Aurora	Mandatory Exchange/APOD Curtailments	Salida WWTP Effluent Discharge	Sep-Jun, 240 cfs; Jul-Aug, 260 cfs
Upper Arkansas Flow Management Program	Reclamation, Colorado Springs, Aurora, PBWW	Voluntary Exchange /APOD Curtailments and Storage Releases	Arkansas River at Wellsville Gage	Aug 16-Jun 30, target 250 cfs; Jul 1-Aug 15, target 700 cfs
Arkansas River Outfitters Association Stipulation	Aurora (Rocky Ford I and II and leased Ag)	Mandatory Exchange/APOD Curtailments	Arkansas River at Wellsville Gage	Gage/Maximum exchange 0-249/0, 250-499/50, 500-999/75, 1000-1499/125, 1500-1999/175, 2000-2999/250, 3000+/500
Fremont County Q710	Exchangers	Mandatory Exchange/APOD Curtailments	Fremont County WWTP Effluent Discharge	190 cfs minimum flow

Table 4-12. Flow Management Programs and Minimum Flow Requirements on the Arkansas River

Program	Binding Parties	Type	Location	Description
Pueblo Reservoir Inflows	Aurora	Mandatory Exchange/APOD Curtailments	Arkansas River at Portland gage	155 cfs native flow when all senior water rights diverting.
Pueblo Flow Management Program(1)	Colorado Springs Utilities, PBWW	Mandatory Exchange/APOD Curtailments	Arkansas River at Above Pueblo Gage	Exchanges curtailed when flow is less than target flow. Target flow varies based on hydrologic state.
Stipulation	Aurora (Rocky Ford I and II and leased Ag)	Mandatory Exchange/APOD Curtailments	Arkansas River at Moffat Street gage	57 cfs minimum flow
Pueblo Flow Management Program (1)	Colorado Springs Utilities, PBWW	Mandatory Exchange/APOD Curtailments	Arkansas River at Combined Flow location	85 cfs target flow
St. Charles Mesa Pumping Plant Minimum Flows	Colorado Springs Utilities and Aurora	Mandatory Exchange/APOD Curtailments	Arkansas River at Moffat Street gage	Exchanges curtailed if SCMWD is pumping, flow is < 50 cfs and specific conductance is >850 uS/cm.
Avondale Flow Requirements (2)	Aurora (Rocky Ford II from Lake Meredith)	Mandatory Exchange/APOD Curtailments	Arkansas River at Avondale Gage	500 cfs minimum flow
La Junta Flow Requirements	Aurora (Rocky Ford I and II during recoup.)	Mandatory Exchange/APOD Curtailments	Arkansas River at La Junta gage	35 cfs minimum flow
Dry-Streambed	Aurora	Mandatory Exchange/APOD Curtailments	Between diversion point and Rocky Ford ditch	10 cfs (excluding reservoir releases and transmountain)

Notes:

(1) The Pueblo Flow Management Program has several components, restrictions, and conditions. See text for full explanation (March IGA 2004, May IGA 2004).

(2) For Colorado Canal exchanges, Arkansas Valley Ditch Association must be notified when flow reaches 500 cfs.

Upper Arkansas Flow Management Program

The Upper Arkansas Voluntary Flow Management Program is designed to provide water for fisheries and rafting in the Upper Arkansas River. The program is primarily aimed at providing target flows for releases of Fry-Ark Project water from Twin Lakes and Turquoise Reservoir to Pueblo Reservoir. However, many other entities have voluntarily agreed to the program as well, including Colorado Springs Utilities, the PBWW and the City of Aurora. The flow recommendations are "intended to provide an annual flow regime that helps the state maintain the brown trout fishery, meet the demand for boating recreation, support the region's tourism industry, and allow managers of the Arkansas Headwaters Recreation Area (AHRA) to meet their obligation to manage recreation and natural resources within the area's boundaries" (Walcher, 2003).

Recommended flows for the program are defined at the Wellsville gage. Components of the recommended flows include (Walcher, 2003):

1. The highest priority is the maintenance of a minimum year-round flow of at least 250 cfs to protect the fishery.
2. Winter incubation flows (mid November through April) should be maintained at a level of not more than 5 inches below river height during the spawning

period (October 15 to November 15). The optimum flow range is from 250 to 400 cfs, depending on spawning flows:

Minimum Incubation Flow		*Spawning Flow*
Nov. 16 - Apr. 30		*Oct. 15 - Nov. 15*
250 cfs	*IF*	*300-500 cfs*
325 cfs	*IF*	*500-600 cfs*
400 cfs	*IF*	*600-700 cfs*

3. To the extent possible, between April 1 and May 15, Reclamation should maintain flows within the range of 250 cfs to 400 cfs in order to provide conditions favorable to egg hatching and fry emergence.
4. Deliveries in excess of 10,000 acre-feet should be subject to review and consideration, prior to such deliveries, by Reclamation and the SECWCD.
5. Subject to water and storage availability, Reclamation should augment flows during the July 1 to August 15 period at 700 cfs through releases from the Fry-Ark Project. The 700 cfs is a target; when augmentation occurs, every effort should be made to ensure that flows are as little above, or as little below, 700 cfs as possible. The Division of Parks and Outdoor Recreation, using funds collected from commercial outfitters, shall be responsible for replacing evaporative losses caused by summer augmentation.
6. Reclamation should avoid dramatic fluctuations on the river as much as possible throughout the year. When it is necessary to alter flow rates, Reclamation should limit the daily change to 10 to 15 percent.
7. It may be possible to improve feeding conditions for brown trout by reducing flows between Labor Day and October 15 in years when flows would otherwise be higher than those recommended by the Division of Wildlife. If potential benefits warrant the effort, AHRA managers, the Division of Wildlife, Reclamation and the Division 2 Engineer should work with water users to seek opportunities for reducing flows after Labor Day.

City of Pueblo RICD

In 2001, the City of Pueblo filed an RICD water right application in Division 2 water court (2001CW160). Shortly after this application, Colorado Springs Utilities, PBWW, City of Aurora, SECWCD, and other entities began negotiating with the City of Pueblo regarding potential subordination of existing decreed exchanges to meet all or a portion of the RICD flows. The result of these negotiations is an intergovernmental agreements between these parties for a target flow program on the Arkansas River through the City of Pueblo. A schematic of this reach is shown in **Figure 4-2**. The components of the program that are directly related to the model include (May IGA, 2004):

- **Year-round Flows (currently in effect) -** Exchanges (or diversions at alternate points) will be reduced or curtailed as necessary so that average daily flows do not fall below 100 cfs at the Above Pueblo gage (including Pueblo Fish Hatchery return flows and an amount equal to any below dam diversions by or for the benefit of the parties to the agreement). Likewise, exchanges will be reduced or curtailed so that exchanges do not reduce the minimum average daily flow below 85 cfs at the combined flow location (downstream of the inflow from Runyon Lake, and above the confluence with Fountain Creek).

- **Recreational Flows -** During the period of March 16 through November 14 of each year, exchanges (or changes of water rights) will be reduced or curtailed as necessary so exchanges do not reduce the average flows below those specified in **Figure 4-3**. The "Above Average" flows shown on the graph shall apply when the NRCS "most probable" forecast for the Arkansas River at Salida (Forecast) is 100 percent or more, and the "Below Average" flow shall apply when the Forecast is less than 100 percent.
- **Dry-Year Exception -** In accordance with the RICD, there is reduction or curtailment of exchanges when the "Most Probable Flow" forecast by the NRCS is below 70 percent. This was included in the model by incorporating the historical NRCS forecast, and eliminating the minimum flows during periods when the forecast was less than 70 percent.
- **Cooperative Flow Management Program -** The CFMP is for the development of a program to manage storage in and release storage from Pueblo Reservoir to meet a recreation flow target of 600 cfs to 1,000 cfs during an unspecified number of weekend periods during the summer. Because of the uncertainty of the timing of this program, it was not included in the model.
- **Storage Restoration -** The IGA contains a provision for storage restoration following excessively dry years. During the year following a year where the Forecast is less than 70 percent, the Flow Management Committee will decide how the program will operate with regards to both the intent of the agreement and the need to restore storage levels. Because of the uncertainty of this program, it was not included in the model. Section **4.4.3.3** provides more information regarding Recovery of Yield storage.
- **Equitable Allocation of Operational Hours -** The original IGA contained a clause "to generally achieve on a monthly basis a 50/50 balance of time between periods of reduction of the Subject Exchanges and periods of no reduction of the Subject Exchanges." The recreational target flows "shall be in effect during the day, and reduction requirements [associated with recreational target flows] shall not be required during the night" (March IGA, 2004). The Pueblo Flow Management Committee modified the clause in 2005, with the concurrence of Reclamation and the Colorado Division of Wildlife, by recommending that the recreational flow targets be operated on a weekly basis instead of the diurnal basis in the original IGA. The committee agreed that "the exchanges would be curtailed to the extent necessary to meet flow targets on Thursdays at 3:00 p.m. to accommodate recreational uses over the weekend period. The exchanges would cease to be curtailed at 12:00 p.m. on Mondays" to allow entities party to the IGA to realize their exchange potential (Gracely, 2005). Due to the uncertainty about diurnal exchanges being allowed, and if so, how they would be administered, no provision was made for night-time exchanges.

There are several provisions within the IGA regarding termination of the agreement and other matters. Two of the more important provisions are as follows:

- **Section II.A Stipulated Decree (March IGA, 2004) -** Colorado Springs and the Board (Pueblo Board of Water Works) shall stipulate to entry of a decree in Case No. 01CW160 (Water Division 2) that provides for the same flows and restrictions specified in paragraphs I.B, C., E. and H., except that the Stipulated Decree shall provide for the decreed flows to be measured at the Moffat Street Gage.
- **Section VIII.D Colorado Springs' Support for Flow Management (March IGA, 2004) -** If, at any time, Colorado Springs is unable to reasonably construct the SDS from Pueblo Dam due to terms, conditions or requirements contained in any federal, state or local permit, permission, or license including Reclamation's Record of Decision or Pueblo County's 1041 permit, then Colorado Springs may terminate this Agreement by providing written notice of such termination to the other Parties.

From the language contained in the above sub-sections of the IGAs, it is evident that there are two distinct parts of the flow program: (1) the agreed-to flow targets that could curtail exchanges by any participant and (2) the RICD water right that, if decreed and depending on adjudication date, could be senior to any new water rights on the Arkansas River. Colorado Springs Utilities may terminate its part of the agreement if the SDS Project is abandoned or is constructed without the diversion point located at Pueblo Dam.

Aurora may terminate its part of the agreement if the city's current application for a long-term excess capacity contract in Pueblo Reservoir is not approved (March IGA; May IGA). However, as part of its negotiations with other water users in the basin, if Aurora obtains its long-term excess capacity contract with Reclamation, Aurora is obligated to honor the flows specified above, even if the other entities terminate their portions of the agreement.

Figure 4-2. Schematic of Arkansas River Through the City of Pueblo

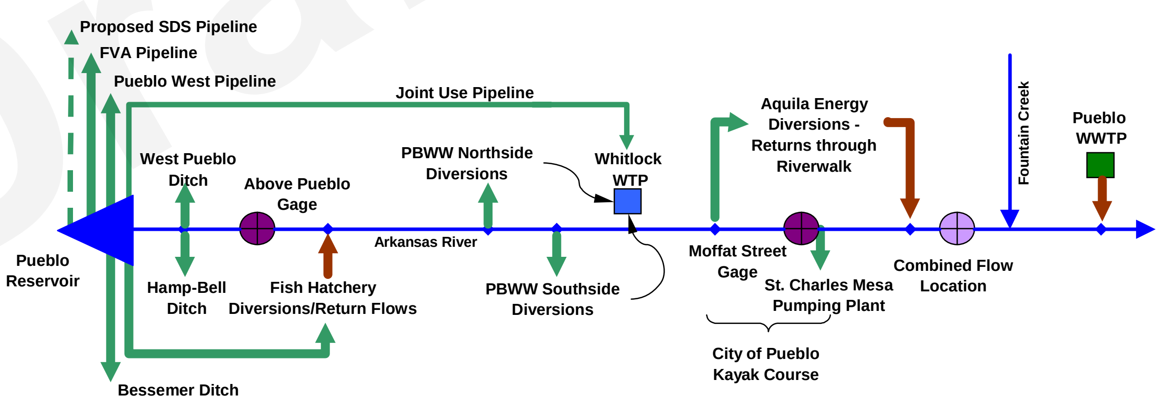
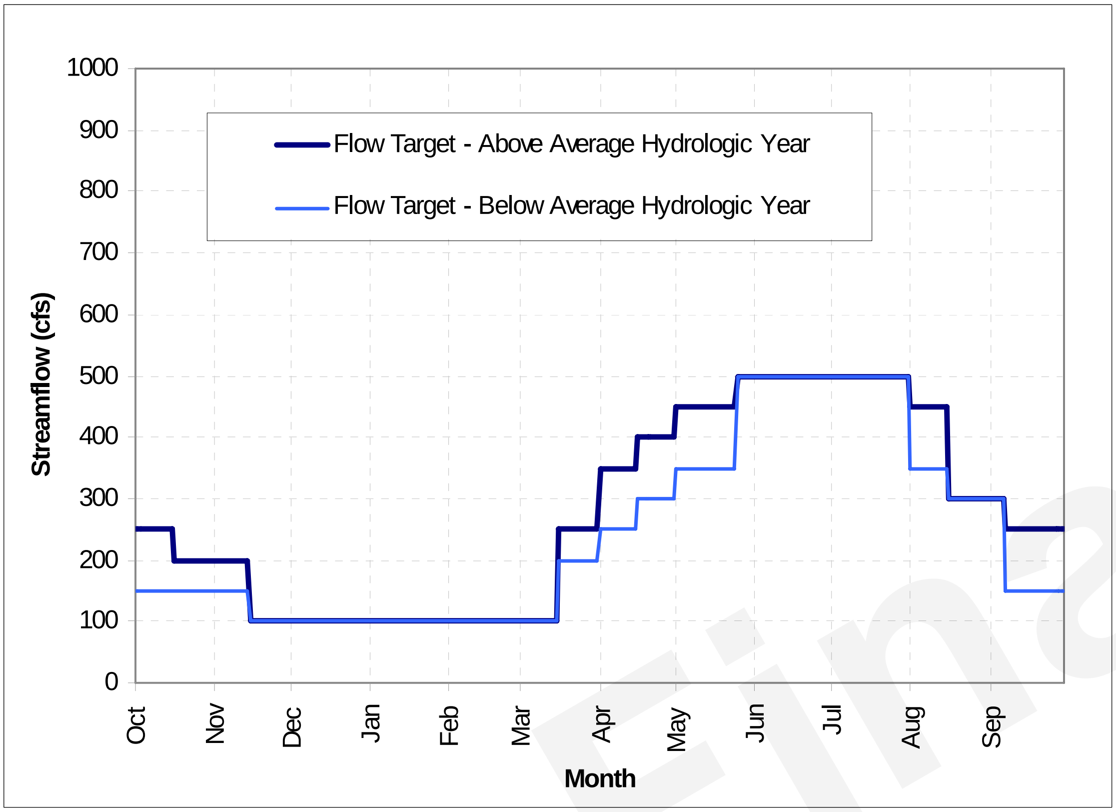


Figure 4-3. Proposed Recreational Flow Targets at Above Pueblo Gage for Pueblo Flow Management Program



City of Pueblo Flow Management Program

In February 2004, the Pueblo Board of Water Works and Colorado Springs Utilities signed an Intergovernmental Agreement (IGA) with the City of Pueblo regarding a recreational flow program in the Arkansas River through the City of Pueblo.

The February 2004 IGA states that the Flow Management Program can be terminated if Colorado Springs Utilities is unsuccessful in developing the Southern Delivery System. Because the Aurora Proposed Action assumes the Colorado Springs Utilities' No-Action alternative, which does not contain a Southern Delivery System diverting from Pueblo Dam, the Flow Management Program was incorporated into the Quarter-Monthly Model with a 2001 priority date, which is junior to all of Colorado Springs Utilities and the PBWW exchange decrees. Consequently, Aurora's modeling assumes the Flow Management Plan does not limit Colorado Springs Utilities, the PBWW, the City of Fountain, or the Pueblo West exchanges into Pueblo Reservoir. Rather, exchanges by these entities are limited by the winter water storage program, a minimum flow of 10 cfs at the Above Pueblo gage, and a minimum flow of 68 cfs below the Above Pueblo gage (18 cfs for the Comanche power plant, plus 50 cfs pursuant to agreements with St. Charles Mesa Water District) for all scenarios.

The priorities for Aurora's exchanges vary, depending on the alternative being simulated. For the Existing Conditions and No Action alternatives, Aurora's decreed exchanges are senior to the Flow Management Program, while the exchanges from the gravel pit, and alternate points of diversion from the Highline canal headgate and Holbrook Reservoir are all junior to the Flow Management Program.

In May 2004, the City of Aurora signed an Intergovernmental Agreement whereby Aurora agreed to curtail its exchanges to the levels specified in the flow management plan, regardless of the final decision regarding development of the Southern Delivery System. Consequently, for the Proposed Action, all of Aurora's exchanges and alternate points of diversion are junior to the Flow Management Program. The model was modified to subordinate Aurora's exchanges to the flow rates in Exhibit 2 of the February 2004 IGA for Aurora's Proposed Action alternative. There is one exception to Aurora's subordination. Because of the shared nature of Aurora's Colorado Canal rights, the Colorado Canal exchange priority was left senior to the Flow Management Program for all Colorado Canal shareholders, including Aurora, for all alternatives.

4.4.3.3 Recovery of Yield (ROY) Storage

Restoration of Yield (ROY) was developed in principle as part of the Pueblo Flow Management Program (FMP) Intergovernmental Agreements (May IGA, 2004). The intent of ROY is to develop operations and facilities that would allow the signatory parties to recover a portion of the yield lost as part of their participation in the FMP. Colorado Springs Utilities anticipates continued use of ROY storage independent of the proposed SDS. Recently, the City of Aurora has signed a temporary agreement with the Holbrook Irrigating Company to use excess capacity in the Holbrook system as part of the ROY program (Holbrook and Aurora, 2005). The City of Aurora then signed agreements with other ROY participants to divide the available excess capacity between the participants (Aurora, et al., 2005).

The agreement between Aurora and Holbrook allows use of the entire Holbrook system by Aurora, including both Holbrook Reservoir and Dye Reservoir. The Temporary Substitute Water Supply Plan (TSWSP) that was obtained by Aurora to administer the program includes the ability to divert unexchanged reusable return flows in the Colorado Canal system as well (Wolfe, 2005).

The active storage capacity for Holbrook Reservoir is approximately 6,200 acre-feet (Simpson, 2005). The agreements state the ROY participants may use "Excess Capacity" in the reservoirs. Thus, the ROY participants can only store water in Holbrook Reservoir when space is available beyond Holbrook's normal operations.

Water used to fill Holbrook Reservoir is diverted by several means: from the Holbrook Reservoir native flow storage rights (priority dates of 3/2/1892 and 9/15/1909), by exchange from lower portions of the system, and through the Winter Water Storage Program (Division 2 diversion and water rights records). Because the native water rights' priority dates are relatively junior, the reservoirs are only able to divert water during times of high flow on the river and do not always fill under their native flow right. The reservoirs sometimes fill during the Winter Water season. However, as part of the agreements, Holbrook will operate so that winter water does not spill ROY participant water from the Holbrook system if storage space is available in Pueblo Reservoir (Holbrook and Aurora, 2005).

4.5 Model Calibration and Verification

The Quarter-Monthly Model underwent a calibration and verification procedure that included reviews by persons familiar with the basin and its water operations.

During the initial construction of the Quarter-Monthly Model, model features were tested as they were added, to ensure that the model was moving water in accordance with decrees and historical gage records. Each decree was tested individually and in concert with others to verify it was taking only the water it was entitled to, and that water was moving between the proper accounts. Modeled exchanges were examined to see if the model was producing results consistent with operational experience.

Modeled operations of others were also reviewed to ensure that the model was reasonably simulating other water users in the basin. This included operations of the Fry-Ark Project, Colorado Canal, Colorado Springs, the Pueblo Board of Water Works and Pueblo West.

Basin-wide calibration was performed using historical municipal and agricultural demands for municipal and agricultural users, and historical exchanges for municipal users. The Quarter-Monthly Model has rule curves for Twin, Turquoise and Pueblo reservoirs, with Pueblo Reservoir having the lowest priority. Calibration compared model output to historical records for stream flows and reservoir contents for the period 1982 through 2002, with a focus on 1996-2002 because operations in this period were fairly consistent. Actual model calibration was carried out by adjusting river reach gains, system losses, and reservoir rule curves to maximize the r-square between the simulated and historical gage and reservoir operations.

Table 4-13 and **Table 4-14** show the calibration results for select points in the basin. The table shows that the model simulates mainstem streamflows and reservoir operations to a reasonable degree. The model does not replicate historical streamflows on Lake Creek and Lake Fork Creek well because the model follows a single set of annual operations, whereas actual operations have changed over time as management objectives have been revised.

Table 4-13. Calibration Results for Select Locations - 1996-2002 Calibration Period

Model Variable	R-Squared	Standard Error	Average Difference	Average Difference %	Historical Average
Turquoise Reservoir ac-ft	0.48	16116	-5336	-5%	102390
Lake Fork, cfs	0.02	53	-9	-49%	18
Lake Creek, cfs	0.54	172	0	0%	185
Granite, cfs	0.91	135	11	3%	384
Wellsville cfs	0.95	137	14	2%	675
Portland, cfs	0.96	135	14	2%	712
Pueblo Reservoir, ac-ft	0.96	10493	6737	3%	203585
Above Pueblo, cfs	0.89	246	-7	-1%	638
Avondale, cfs	0.91	302	-68	-7%	932
Catlin, cfs	0.89	313	20	3%	624
La Junta, cfs	0.94	141	57	21%	265

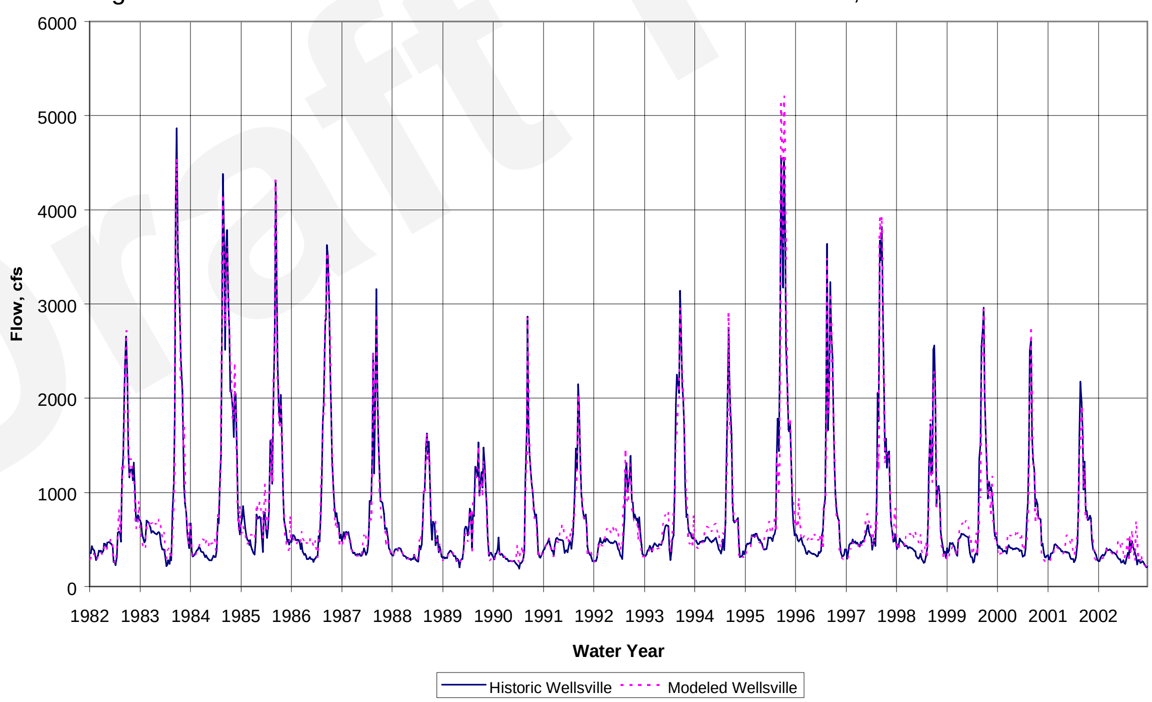
Table 4-14. Calibration Results for Select Locations - All Available Data

Model Variable	R-Squared	Standard Error	Average Difference	Average Difference %	Historical Average
Turquoise Reservoir ac-ft	0.23	20567	-9584	-9%	105413
Lake Fork, cfs	0.15	60	-8	-40%	20
Lake Creek, cfs	0.49	201	-2	-1%	195
Granite, cfs	0.93	129	8	2%	433
Wellsville cfs	0.96	136	14	2%	752
Portland, cfs	0.98	135	14	2%	844
Pueblo Reservoir, ac-ft	0.94	16071	1312	1%	189290
Above Pueblo, cfs	0.94	216	-19	-2%	763
Avondale, cfs	0.95	307	-72	-7%	1039
Catlin, cfs	0.93	304	-7	-1%	746
La Junta, cfs	0.94	156	54	17%	317

Figure 4-4 shows the results of the calibration run verses the historical gage at Wellsville. The results from the calibration run were created by converting quarter-monthly volumes in acre-feet into mean daily flows in cubic feet per second. This graph shows that the model typically has greater winter flows than what occurred historically. The contents of Pueblo Reservoir and streamflows below Pueblo show similar levels of correlation.

Reservoir contents in Turquoise Reservoir do not track historical operations as well as other model nodes, in part because water was released to meet instream flow targets that were not in place over the 1982-2002 period, and in part due to changing operational criteria over time. Contents in Twin Lakes were not included in the analysis of the calibration because of the heavy impact of pump-storage operations on reservoir storage levels.

Figure 4-4. Modeled vs. Historical Flows at Wellsville, Calibration Run



5.0 MODEL SCENARIOS

This section describes the alternatives analyzed, and details the underlying assumptions made in the model for simulating the proposed and alternative actions. As part of the EA, two separate analyses were performed that require simulated streamflows and reservoir contents from the Quarter-Monthly Model: the Effects Analysis and the Cumulative Effects Analysis. The Effects Analysis estimates the effects of the Proposed Action and No Action Alternatives due to these actions alone. The Cumulative Effects analysis estimates the effects of the Proposed Action and No Action Alternative when combined with other reasonably foreseeable actions in the basin.

For each of the analyses, both the Proposed Action and the No-Action alternatives were simulated. In addition, for purposes of comparison by the resource studies, an Existing Conditions analysis was simulated. Quarter-Monthly Model assumptions and settings for each of the analyses and alternatives are described in the following sub-sections. A summary of the Quarter-Monthly Model variable settings is presented in **Table 5-1**.

5.1 Existing Conditions Scenario

The primary goal of the Existing Conditions scenario was to simulate 2004 operational conditions in the river for the modeled period. Existing Conditions differ from historical conditions in that Existing Conditions assume existing (2004) operations on the river for the entire study period (1982-2002). The historical conditions, on the other hand, reflect varied river operations and demands on the river during the 1982 through 2002 study period. The Existing Conditions provide a basis of comparison to the No Action and Proposed Action alternatives. The model follows strict operational criteria that have not been carried out consistently in historical operations. To eliminate inconsistencies between modeled and actual operations, modeled existing conditions are used rather than actual historical data for comparisons between scenarios.

Existing Conditions assume 2004 demands (unconstrained by drought-related conservation programs that were in effect), current levels of excess storage capacity contracts (if-and-when contracts) in Pueblo Reservoir, and facilities and decreed water rights as of the beginning of the year. The Aurora Rocky Ford I transfer, Rocky Ford II transfer, and Highline Canal lease are included in this condition. Fifty percent of the total decreed yield of the Rocky Ford II transfer was modeled for this condition, because by decree, water cannot be changed from a tract of land until revegetation is complete. And this revegetation was not complete in 2004. Although the conditions of the Pueblo FMP are currently being administered in 2005, the Pueblo FMP is not included in this condition, because Aurora’s future participation in the Pueblo FMP is dependent on the adoption of the Proposed Action and No Action scenarios. The City of Aurora’s existing “if-and-when” excess capacity contract with Reclamation is assumed to be the same as was granted in 2004 under the Existing Conditions simulation.

Table 5-1. Summary of Simulation Model Variable Settings for Effects Analysis

Model Variable	Existing Condition	Effects		Cumulative Effects	
		No Action	Proposed Action	No Action	Proposed Action
General Settings					
Municipal Demands	2004	2004	2004	2045	2045
Additional Demand by Others(1)	No	No	No	Yes	Yes
Agricultural Demands(2)	Historical	Historical	Historical	Historical	Historical
Otero Pump Station Capacity	118.5 mgd	118.5 mgd	118.5 mgd	118.5 mgd	118.5 mgd
Aurora Settings					
Excess Capacity in Pueblo Reservoir	10,000 ac-ft	0 ac-ft	10,000 ac-ft	0 ac-ft	10,000 ac-ft
Gravel Pit Storage	0 ac-ft	10,000 ac-ft	0 ac-ft	10,000 ac-ft	0 ac-ft
USBR Contract Exchanges	0 ac-ft	0 ac-ft	10,000 ac-ft	0 ac-ft	10,000 ac-ft
Transmountain Diversions	Yes	Yes	Yes	Yes	Yes
Upper Arkansas Ranch Water Rights	Yes	Yes	Yes	Yes	Yes
Rocky Ford I Transfer	Yes	Yes (junior to RICD)	Yes	Yes (junior to RICD)	Yes
Colorado Canal	Yes	Yes	Yes	Yes	Yes
Rocky Ford II Transfer(3)(4)	Yes (50%)	Yes (100%)	Yes (100%)	Yes (100%)	Yes (100%)
Highline Lease	Yes	Yes	Yes	Yes	Yes
Pueblo FMP/RICD - Aurora	None	None	Full	None	Full
ROY Storage - Aurora	No	No	Yes	No	Yes
Other Municipal Settings					
Pueblo Board of Water Works Excess Capacity Storage in Pueblo Reservoir	3,000 ac-ft	3,000 ac-ft	3,000 ac-ft	15,000 ac-ft	15,000 ac-ft
Pueblo West Excess Capacity Storage in Pueblo Reservoir	1,000 ac-ft	1,000 ac-ft	1,000 ac-ft	1,000 ac-ft	1,000 ac-ft
Colorado Springs Utilities Excess Capacity in Pueblo Res.	10,000 ac-ft	10,000 ac-ft	10,000 ac-ft	1,000 ac-ft	1,000 ac-ft
Pueblo FMP/RICD - Others(5)	None	None	None	None	None
ROY Storage - Others	No	No	No	Yes	Yes
Colorado Springs' Future Operations(6)	No	No	No	Yes	Yes

Notes:

(1) Additional demand by municipal users for Fry-Ark Project water

(2) Agricultural demands are assumed to be the same as historical except for those systems that have been converted to municipal use, such as the Colorado Canal system, Rocky Ford Ditch and Highline Canal lease.

(3) The percentage value indicates the percent of the total decreed yield that is changed and diverted by Aurora. By decree, water cannot be changed from a tract of land until revegetation and "dry-up" is complete.

(4) During actual 2004 operations, because Aurora's Upper Basin exchange application (99CW170) was not finalized, Rocky Ford II water was diverted into the PBWW Excess Capacity account in Pueblo Reservoir, then moved to Twin Lakes by contract exchange with the PBWW (Simpson, 2005). The Upper Basin exchange was decreed in 2005. Therefore, the Quarter-Monthly Model operates per the decree. The differences in storage and streamflow between actual and simulated operations during 2004 are negligible.

(5) Due to limitations in the Quarter-Monthly Model, all Colorado Canal exchanges (including those by Colorado Springs Utilities, Pueblo West and the City of Fountain) are subject to the same Pueblo FMP conditions as other Aurora exchanges

(6) Colorado Springs Utilities increased ground water pumping and increased non-potable and potable reuse.

5.2 Effects Scenarios

The Effects Analysis estimates the effects of the Proposed Action and No Action Alternatives due to these actions alone. The purpose of this analysis is to "isolate" the effects of the actions.

The Quarter-Monthly Model assumes that future physical hydrology in both the Colorado and Arkansas river basins will be similar in the future as it was in the past. This predicates that there will be no significant effects in the amount, timing or form of precipitation due to climate change or other factors. As stated earlier, the Quarter-Monthly Model uses potential yields for transmountain projects. These yields are used to satisfy demands by the model, and the model tries to minimize the lost yield on the west slope for all scenarios. Future diversions of west slope water should approximate historical, except in instances where there was a physical failure of the system, or where there was historically not the demand for the water. The legal availability of water to users in both the Arkansas and Colorado River basins is assumed to be the same as the historical call record. This assumes no significant changes in river administration, either from changes internal to the state by the State Engineer's Office, or external to the state system, such as from the endangered species act or a call from the Colorado River Compact.

In general, future agricultural diversions are assumed to be the same as historical. If significant changes in operations or ownership took place for an agricultural entity during the study period, then the historical diversions were adjusted to reflect current operations based on current data. For example, Colorado Canal and Rocky Ford operations were modified for the historical period prior to their change in use from agricultural to municipal purposes. For municipal entities, demands for 2004 were calculated based on projected populations. Future demands for each entity were obtained from the entities or other planning documents, such as the Water and Storage Needs Assessment (GEI, 1998).

Simulation of Colorado Springs Utilities existing operations in the Quarter-Monthly Model assumed the following:

- Annual reusable return flows from Colorado Springs Utilities in 2004 = 26,200 acre-feet
- Annual diversions for Colorado Springs Utilities in 2004
  - Fountain Valley Conduit diversions = 20,100 acre-feet
  - Otero Pump Station diversion = 65,600 acre-feet

More details on Colorado Springs Utilities operations and development of this data is presented in **Appendix A**.

5.2.1 Proposed Action

The Proposed Action model run simulates the operations of the Arkansas River assuming that the Proposed Action is implemented under existing conditions. In-basin municipal demands were set to equal demands in the year 2004. As in-basin municipal demands increase, Aurora's Effects on the Arkansas River Basin hydrology become relatively smaller. That is to say later in the contract period (closer to 2045), Aurora's Effects would be dampened due to the exercise of senior exchanges made by other entities in the basin. The following operational differences are unique to the Proposed Action alternative when compared with the Existing Conditions run.

- The City of Aurora would be permitted to exchange up to 10,000 ac-ft via contract exchanges from Pueblo Reservoir with Reclamation's Fry-Ark Project water in Twin Lakes and Turquoise Reservoir.
- The percent of the total decreed yield of the Rocky Ford II transfer that is simulated increases from 50 to 100 percent.
- The Pueblo FMP is simulated.
- Recovery of Yield (ROY) Storage is simulated.

Under the Proposed Action, the City of Aurora's current annual "if-and-when" excess capacity contracts for 10,000 acre-feet of storage in Pueblo Reservoir would become a long-term (40-year) excess capacity contract. In the Quarter-Monthly Model, however, the excess capacity contracts are simulated in the same manner for the Existing Conditions and Proposed Action. Settings for all other operations in the Arkansas River Basin are assumed to be the same as for the Existing Conditions scenario.

Exchanges into Pueblo Reservoir were modeled in accordance with the current decrees, stipulations and agreements. Aurora's exchanges would be subject to the Pueblo FMP target flows and other conditions of the IGA signed by Aurora in May of 2004. The model requires that Rocky Ford Ditch and Highline Canal water must be diverted at Pueblo Reservoir and held for a minimum of one time-step before being exchanged upstream. Colorado Canal water can be exchanged to Pueblo or all the way to the upper basin in a single time-step.

Rocky Ford and Highline Canal diversions into Pueblo Reservoir are assumed to be junior to the RICD. Exchange priorities out of Pueblo Reservoir are the same as for Existing Conditions.

Contract exchanges are subject to water and storage availability for Reclamation and Aurora in Pueblo, Twin Lakes, and Turquoise reservoirs. Contract exchanges between Aurora and Reclamation are limited to 10,000 acre-feet per calendar year. Under the Proposed Action, Aurora's contract exchanges with Reclamation are modeled to occur in 1,000 acre-foot blocks, with a maximum of 1,000 acre-feet into each of the upper basin reservoirs, or 2,000 acre-feet per quarter-month.

5.2.2 No Action

The No Action model run simulates the future operations of the Arkansas River assuming that the No Action Alternative is implemented. For the purposes of this simulation an annual excess capacity contract with Reclamation was not assumed. Municipal demands were set to equal demands in the year 2004 for the same reasons discussed for the Proposed Action. The following operational differences are unique to the No Action Alternative when compared with the Existing Conditions run.

- 10,000 acre-feet of gravel pit storage by the City of Aurora is generally located adjacent to the Arkansas River east of the Fountain Creek confluence.
- The Rocky Ford I transfer is assumed to be junior to the City of Pueblo RICD, because its current decree does not allow an alternate point of diversion at any location other than Pueblo Reservoir.
- The percent of the total decreed yield of the Rocky Ford II transfer that is simulated increases from 50 to 100 percent.

Because Aurora's Rocky Ford and Colorado Canal decrees do not list a gravel pit in this vicinity as an alternate point of diversion and exchange, Aurora would have to add this diversion point to its decrees in water court. This action would make the priority of Aurora's exchanges junior to all other filed exchanges and the City of Pueblo's application for a Recreational In-Channel Diversion.

Aurora anticipates that if it had to go back to water court to change its decrees, the court would likely impose additional restrictions to its decrees, effectively reducing the yield of its existing system. Because the exact nature of these restrictions is unknown, the No-Action scenario uses the same restrictions that were placed on Aurora in the Rocky Ford II decree. This is conservative from an impacts analysis, because it is likely that there would be less water exchanged if additional restrictions were imposed, though it likely overstates the amount of lower basin water Aurora could expect to divert at the Otero pump station.

The gravel pit was modeled as a single 10,000 acre-foot reservoir. The size was selected to match the volume of storage space that Aurora has applied for in Pueblo Reservoir. It is anticipated that the gravel pit would be located such that it could be filled by gravity using the Excelsior Ditch. The Quarter-Monthly Model assumes that the ability of the Excelsior ditch to fill the gravel pit would have a capacity of 100 cfs. Releases from the gravel pit would have to be pumped to the river, so the modeled outlet capacity from the gravel pit was set to 50 cfs. Evaporation was calculated assuming the gravel pit was 20 feet deep and would have a surface area of 500 acres.

Exchanges into and out of the gravel pit are modeled as junior to all decreed exchanges into Pueblo Reservoir and the RICD filing. Because there are no cooperating agencies with space in the gravel pit, no contract exchanges are possible under this scenario. To be consistent with existing decrees and contracts, the Rocky Ford Ditch and Highline Canal water must be diverted into the gravel pit before being exchanged upstream. Under the existing 1982CW62,

-63 and -64 decrees, Colorado Canal water can be exchanged directly from the Meredith outlet to Twin Lakes and/or Turquoise Reservoir, when the exchange potential exists.

Settings for all other operations in the Arkansas River Basin are the same as for the Existing Conditions scenario.

5.3 Cumulative Effects Scenarios

Cumulative Effects are the potential effects of the Proposed Action or No Action alternatives in combination with past, present, and future actions. NEPA regulations define Cumulative Effects "as the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor, but collectively significant actions taking place over time" (40 CFS 1508.7).

The Cumulative Effects analysis for this project is based on reasonably foreseeable future actions that, if implemented, would contribute to the effects of the Proposed Action or No Action. The year 2045 was used as the time period for the assessment of Cumulative Effects because this is the approximate end of the proposed 40-year contract period for the storage and exchange contracts between Aurora and Reclamation under the Proposed Action.

Reclamation has defined reasonably foreseeable projects involving federal action as those for which NEPA permitting has been successfully completed and are awaiting completion of implementation (i.e., construction or operational implementation). Consequently, there are no reasonably foreseeable projects at this time. Never the less, Reclamation has determined for purposes of this analysis that the reasonably foreseeable actions for the Cumulative Effects analysis are to be based on anticipated changes in water demand, use, and storage in the year 2045. Anticipated reasonably foreseeable actions include:

- Municipal entities would increase use of Fry-Ark and native water.
- Consistent with the PBWW Excess Capacity Contract, storage in Pueblo Reservoir would increase from 3,000 acre-feet to 15,000 acre-feet.
- Colorado Springs Utilities' Excess Capacity Contract for storage in Pueblo Reservoir would be reduced from 10,000 acre-feet to 1,000 acre-feet.
- Colorado Springs Utilities would increase ground water pumping and potable reuse to meet future demands.
- Colorado Springs Utilities would construct a 25,000 acre-foot reservoir in the Fountain Creek Basin as part of the reuse plan.
- All entities currently participating in recovery of yield (ROY) storage (Aurora, Colorado Springs, Fountain, SECWCD, and PBWW) would continue their participation.
- Because the No Action Alternative includes the development of gravel pit water storage, reasonably foreseeable actions in the vicinity of the gravel pit storage site were assessed. No reasonably foreseeable actions or activities were identified near the potential area of gravel pit storage.

To be consistent with the definition of reasonably foreseeable projects, the Cumulative Effects analysis must assume actions by Colorado Springs Utilities to meet their future demands without needing federal action requiring NEPA permitting. Based on review of previous planning documents by Colorado Springs Utilities (B&V, 1996) and discussions with Colorado Springs Utilities staff, it was assumed that a combination of increased ground water pumping and potable reuse (via the Jimmy Camp Creek Water Treatment Plant) to meet demands. It was assumed that the proposed Williams Creek Reservoir in the Fountain Creek basin would be constructed for raw water storage. Simulation of Colorado Springs Utilities future operations in the Quarter-Monthly Model by assuming the following:

- Annual reusable return flows from Colorado Springs Utilities in 2045 = 75,500 acre-feet
- Annual diversions for Colorado Springs Utilities in 2045
    - JCC WTP demands = 35,400 acre-feet
    - Fountain Valley Conduit diversions = 20,100 acre-feet
    - Otero Pump Station diversion = 71,900 acre-feet

More details on Colorado Springs Utilities operations and development of data is presented in **Appendix A**.

5.3.1 Proposed Action

Simulation of Aurora's Proposed Action in the Cumulative Effects analysis is identical to its simulation in the Effects analysis.

5.3.2 No Action

Simulation of Aurora's No Action in the Cumulative Effects analysis is identical to its simulation in the Effects analysis.

6.0 REQUIRED OUTPUT AND DELIVERABLES

Because of the model's spatial and temporal extent, the Quarter-Monthly Model produces a tremendous amount of output data. Therefore, thoughtful selection of the required output is required. This section documents the location, type and format for model output.

6.1 Output Locations

Reclamation provided a list of the locations for evaluating cumulative effects. The direct effects model results will use the same set of nodes. A map showing these locations is presented in **Figure 6-1**, while a table that corresponds to each of the number nodes and other information regarding the types of output required is presented in **Table 6-1**. As shown, the nodes range from the Arkansas headwaters downstream to the La Junta gage. All of these nodes are included in the Quarter-Monthly Model.

In addition to the nodes requested in the map by Reclamation, reservoir contents, elevations and surface areas were calculated for Turquoise Reservoir, Pueblo Reservoir, and Lakes Henry and Meredith. An analysis of Twin Lakes was not required because, given the size of Aurora's Twin Lakes account, the operation of the Mount Elbert Pump-Storage Facility produces much greater effects than those by Aurora.

6.2 Output Measurements

The Quarter-Monthly Model performs all calculations in acre-feet. Therefore, all of the standard output from the model is in acre-feet, including streamflow in acre-feet per quarter-month and storage in acre-feet. Conversions from acre-feet units to mean daily flow in cubic feet per second (cfs) and mean monthly flow in cfs are made to simplify the comparison of results at each of the primary hydrologic nodes.

All of the model results, summaries for other resource areas, hydraulic calculations and water resource analysis are presented in the Water Resources Technical Memorandum.

6.3 Deliverables

Deliverable products to Reclamation and Aurora under the Environmental Assessment (EA) contract with MWH will include the following items:

- Quarter-Monthly Model documentation;
- An electronic version of the model input and output files

The documentation report will provide Aurora and Reclamation with adequate information to fully understand the model construction, associated data sets and output. The documents will also contain electronic copies of the models and adequate instruction through both the written material and training sessions to fully execute the models if needed.

The Hydrologic Modeling Report contains specific results from the models for the Existing Condition, No-Action, Proposed Action and Cumulative Effects scenarios. All data in the Water Resources Technical Memorandum were taken directly from the modeling described in this document, and is the sole repository for model results.

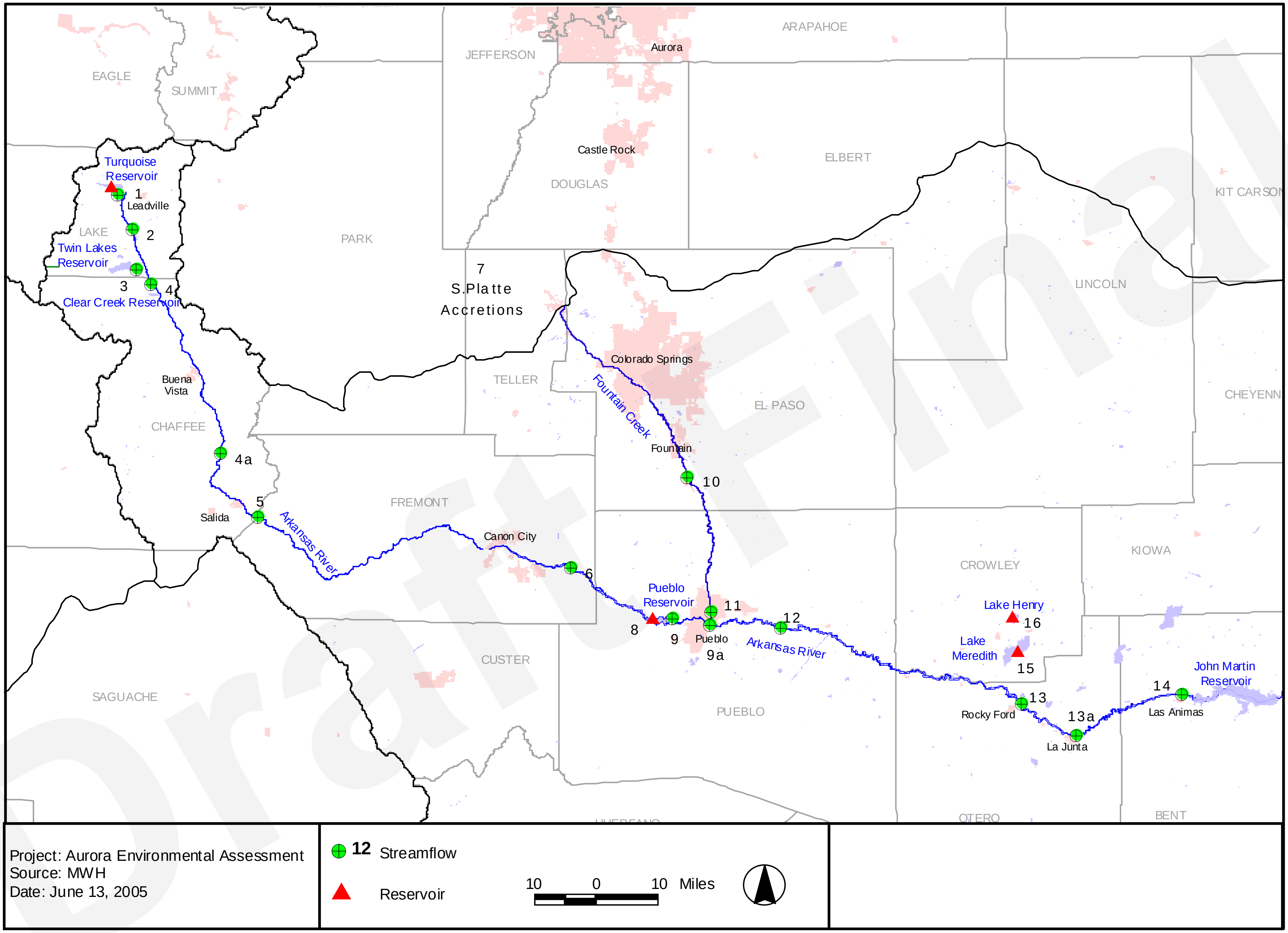
Table 6-1. Description of Hydrologic Nodes for Cumulative Effects Analysis

Node Number	River/ Stream	Location	Measurement	Supports
1	Lake Fork	Lake Fork outflow from Turquoise Reservoir	cfs daily avg.	Determination of exchange effects on Lake Fork from Turquoise to the Arkansas River
2	Arkansas	Arkansas River upstream of Lake Creek	cfs daily avg.	Determination of exchange effects on Arkansas River flows from Lake Fork to Lake Creek (Hayden Ranch)
3	Lake Creek	Lake Creek outflow from Twin Lakes Reservoir	cfs daily avg.	Determination of exchange effects on Lake Creek from Twin Lakes to the Arkansas River
4	Arkansas	Arkansas River at Granite	cfs monthly avg.	Determination of depletions to flows on the Arkansas River from delivery of water through the Otero Pipeline to Colorado Spring Utilities and Aurora
5	Arkansas	Arkansas River at Wellsville	cfs monthly avg.	Determination of exchange effects to flows on the Arkansas River and incidentally the fishery, rafting, and the Salida waste water treatment plant (the flows at this node will be a constraint for Aurora per their Rocky Ford I decree, see Sheet 3 for details restrictions)
6	Arkansas	Arkansas River at Portland	cfs monthly avg.	Determination of exchange effects at the Fremont wastewater treatment plant (the flows at this node will also be a constraint on Aurora's exchanges per their decree, see Sheet 3 for detailed restrictions)
7	South Platte	Total daily accretions to the South Platte River at Aurora's discharge points	cfs monthly avg.	Determination of Aurora's increased transmountain diversion accretions to the South Platte-This will not be necessary if Aurora can describe how they will use/reuse their water in a way that will not contribute to accretions
8	Pueblo Reservoir	Total daily elevation flux on Pueblo Reservoir	ft/day	Effects of exchange on Pueblo Reservoir elevation
9	Arkansas	Arkansas River at Pueblo Dam	cfs daily avg.	Effects of exchange on Arkansas River flows below Pueblo Dam
10(1)	Fountain Creek	Fountain Creek at Fountain	cfs daily avg.	Not used in Aurora analysis.
11	Arkansas	Fountain Creek at the mouth	cfs monthly avg.	Not used in Aurora analysis.
12	Arkansas	Arkansas River at Avondale	cfs monthly avg.	Assess cumulative effects of exchanges by both Aurora and Colorado Springs Utilities, and input of Colorado Springs Utilities return flows from Fountain Creek, to the Arkansas River downstream of Pueblo
13	Arkansas	Arkansas River at Rocky Ford	cfs monthly avg.	Assess flow impacts of Rocky Ford ditch water diverted at an upstream location (Pueblo Reservoir)
13a	Arkansas	Arkansas River at La Junta	cfs monthly avg.	Asses flow impacts of Aurora's and Colorado Springs Utilities' operations on the Lower Arkansas River downstream of Rocky Ford
14	Arkansas	Arkansas River at Las Animas	cfs monthly avg.	Not used in Aurora analysis.

Notes:

(1) Applies only to impacts from Colorado Springs Utilities.

Figure 6-1. Location Map of Hydrologic Nodes from U.S. Bureau of Reclamation



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