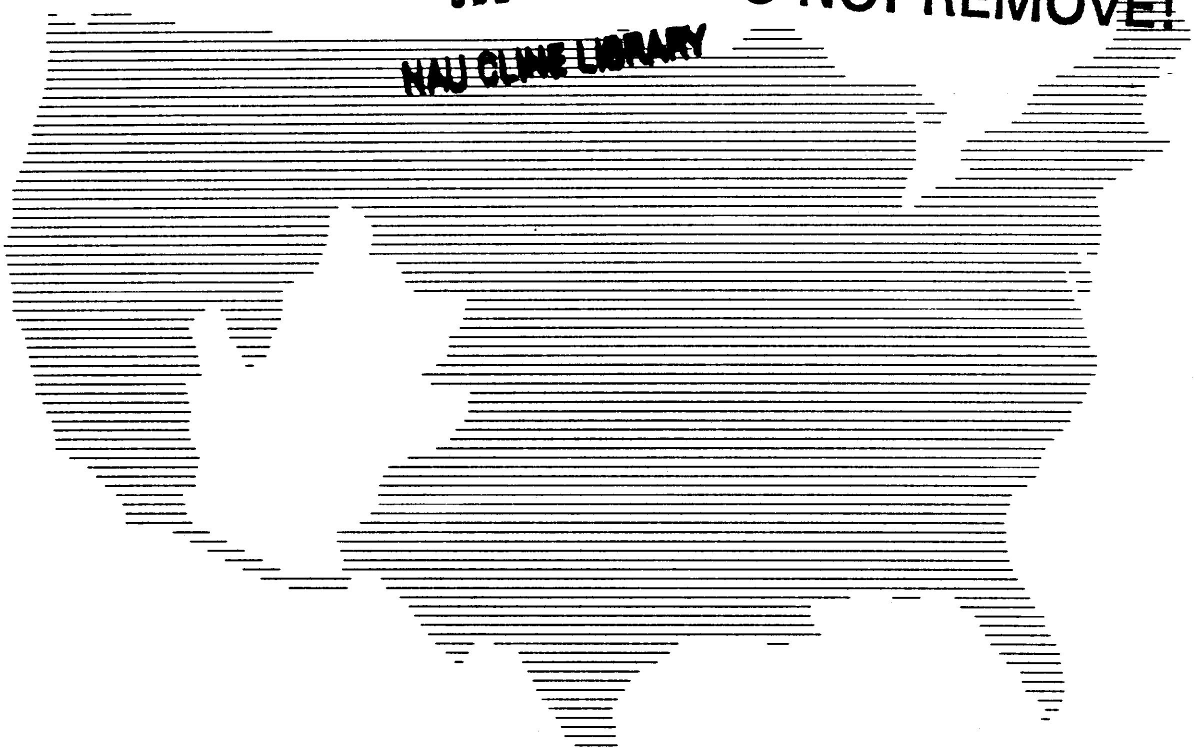
# CRSS Colorado River Simulation System





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16. ABSTRACT

The CRSS (Colorado River Simulation System) is a set of computer programs, data files, and data bases used by water resource managers to assist them in long range planning for the Colorado River Basin. The CRSS is used to address the many "what if" questions that arise from proposed basin development or proposed changes in the methods of operating the river. The CRSS simulates riverflows, water deliveries, water shortages, reservoir operations, water quality, and hydroelectric power production. The CRSS applies runoff forecasting, flood control regulations, operating strategies of the system (shortage and surplus strategies), hydroelectric power generation, and legislative requirements.

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Nothing in this document is intended to interpret the provisions of the Colorado River Compact (42 Stat. 171), Upper Colorado River Basin Compact (63 Stat. 31), Water Treaty of 1944 with the United Mexican States (Treaty Series 944, 59 Stat. 1219), the decree entered by the Supreme Court of the United States in Arizona versus California, et al. (376 U.S. 340), Boulder Canyon Project Act (45 Stat. 1057), Boulder Canyon Project Adjustment Act (54 Stat. 774; 43 U.S.C. 618a), Colorado River Storage Project Act (70 Stat. 105; 43 U.S.C. 620), or the Colorado River Basin Project Act (82 Stat. 885; 43 U.S.C. 1501).

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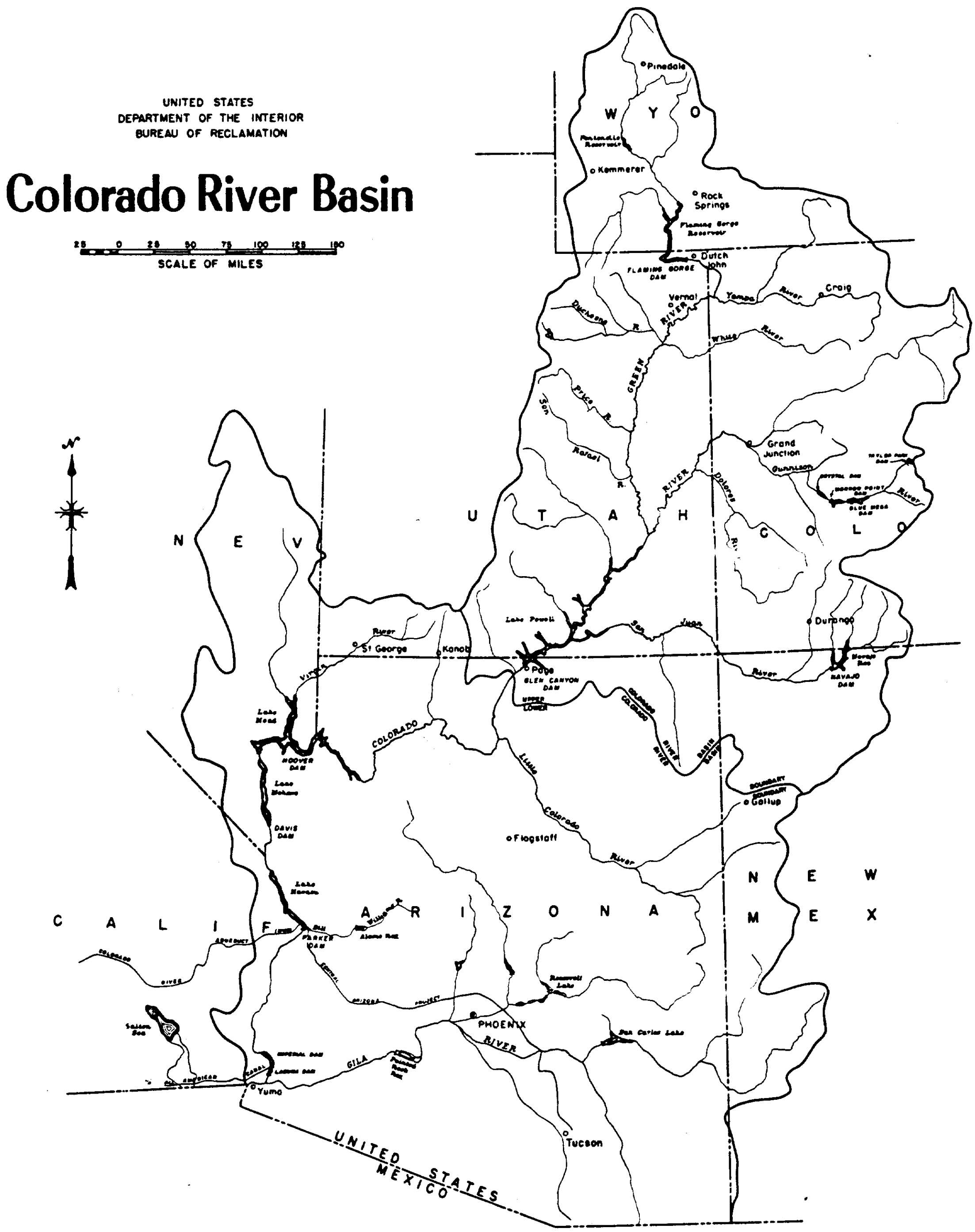
## FIGURES




Frontispiece. – Colorado River Basin.

# Introduction

The Colorado River and its major tributaries originate as snowmelt-fed streams high in the Rocky Mountains. The river drains approximately 242,700 square miles from seven states as its winds its way southward to Mexico and the Gulf of California. The annual natural flow of the Colorado River at Lees Ferry, Arizona has ranged from 5.0 to 24.5 million acre-feet of water over the last 80 years, with a mean of approximately 15 million acre-feet. Ten major storage dams provide a storage capacity of approximately 60 million acre-feet. The storage projects serve a number of purposes including flood control, irrigation water supply, municipal and industrial water supply, power generation, water quality improvement, fish and wildlife propagation, and recreation.

The Colorado River is probably the most legislated and regulated major river in the world as it is governed by more than 20 major legal actions, congressional acts, United States Supreme Court decisions, intrabasin compacts, and international treaties. The amount of water that is legally apportioned is greater than the estimated average annual water supply of the river. Due to the many different uses of Colorado River water and the overapportioned future water supply, management and development of the Colorado River is a highly complicated and technical task. The CRSS (Colorado River Simulation System) is a comprehensive tool designed to assist water resource managers in successfully performing this task.

The purpose of this Executive Summary is to provide a brief, nontechnical overview of the applications, capabilities, and characteristics of the CRSS.

## Purpose of Colorado River Simulation System

The CRSS is a tool used by water resource managers to assist them in long range planning for the Colorado River Basin. The CRSS is used to address the many "what if" questions that arise from proposed basin development or proposed changes in the methods of operating the river.

## Applications

The CRSS is used to study a variety of future events to determine:

- Effects of proposed basin development or changes in present water use.
- Effects of proposed changes in imports to and exports from the basin
- Effects of proposed changes in the methods of operating the river
- Effects of water quality improvement projects
- Effects of weather modification
- Future water supply

The CRSS can provide more than 60 output parameters for studying the effects previously listed. The most frequently obtained parameters are:

- Quantity of water in the river
- Quality of water in the river
- Reservoir operation parameters (water surface elevation, surface area, surface storage, bank storage, evaporation, sediment accumulation, and water quality)
- Water shortages
- Hydroelectric power production (energy and capacity)

## Past Studies

The CRSS has been used in a number of specific studies by both the public and private sectors. Some of the larger studies are:

- Westwide water studies
- Upper Colorado Emerging Energy Technology Study
- Lower Colorado Emerging Energy Technology Study
- CREST (Colorado River Enhanced Snowpack Test)
- Quality of Water Progress Report
- Evaluation of Salinity Control Programs in the Colorado River Basin
- Hydrologic yield studies
- Colorado River Alternative Operating Strategies for Distributing Surplus Water and Avoiding Spills
- Western Area Power Administration operation studies for power marketing and power rate determination
- Bureau of Land Management oil shale development studies
- Study to evaluate impacts of the maximum error term in the Lake Mead inflow forecast
- Central Arizona Project Water Supply Study

# General Description of CRSS

The CRSS is comprised of computer programs, data files, and data bases. The main component of the CRSS is the CRSM (Colorado River Simulation Model), referred to as the "model." This computer model, generally speaking, is a water and salt accounting program. Water is brought into the basin at several points, routed through the system, and deliveries made. Salt is introduced to the basin through inflows and return flows, and is routed through the system along with the water. However, there are a number of features that make the CRSM much more than an accounting tool. The model additionally applies runoff forecasting, reservoir operations (rule curves, evaporation, bank storage, and sediment accumulation), flood control regulations, operating strategies of the system (shortage and surplus strategies), hydroelectric power generation, and legislative requirements.

Two additional components of the CRSS are the hydrology data base and the demand data base. The hydrology data base contains the flow and salt data for the Colorado River Basin. The demand data base contains the diversion data. Other components of the CRSS consist of computer input data files, computer programs that process the information in the hydrology and demand data bases, and computer programs that process the output data that is generated by the model.

# Basic Characteristics and Limitations

The basic characteristics of the model and data bases are:

- The major **rivers** modeled are the Colorado, Gunnison, Dolores, Green, Yampa, Duchesne, White, San Rafael, San Juan, and Virgin Rivers. These are modeled with inflows, diversions, and reservoirs. Other rivers like the Paria, Little Colorado, and the Bill Williams are modeled as inflows to the Colorado River.

- **Reservoirs** modeled are Taylor Park, Blue Mesa, Morrow Point, Crystal, Fontenelle, Flaming Gorge, Starvation (a composite of eight small reservoirs), Navajo, Powell, Mead, Mohave, and Havasu.

- The model uses a **monthly time frame** to simulate riverflows, water deliveries, reservoir operations, water quality, and hydroelectric power production.

- The **basin** is divided into 25 reaches. Each reach contains inflow points, diversion points, and possibly a reservoir. Inflow points are used to model headwaters, return flows, or gains and losses to the system. Diversion points are used to model demands on the system.

- The **hydrology** data base consists of natural flow and salt data for 29 inflow points. Natural data are defined as historical or gauged data adjusted to remove the effects of human development; i.e., consumptive use, reservoir regulation, imports, and exports. The data is complete for the years 1906-85 and is updated every 5 years.

- The **demand** data base contains the diversion point data. The data consists of annual schedules of withdrawals and depletions, monthly distributions, salt pickup data, and type of water use information.

- The CRSS satisfies the provisions of the *Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs*. These **Operating Criteria** have been adopted by the Secretary of the Interior as specified in the Colorado River Basin Project Act (Public Law 90-537) to comply with and carry out the provisions of the Colorado River Compact, the Upper Colorado River Basin Compact, and the Mexican Water Treaty.

- Most of the items listed above are **variable.** For example, the number of reaches, inflow points, diversion points, or reservoirs can be changed; a stochastic hydrology data base can be used in lieu of the natural data base; and values used to model the Operating Criteria can be varied.

- The CRSS contains approximately 22,000 lines of **computer code** and 11,000 lines of data. The computer code is written in Fortran IV and uses software routines that are unique to Control Data Corporation Cyber computer systems.

Limitations of the model and data bases are:

- A maximum of 150 **years** can be modeled in one simulation model run.

- Each **reach** can model up to 10 inflow points, 10 diversion points, and 1 reservoir. Each diversion point can model up to 10 users or demands on the system.

- **Salinity** is the only water quality parameter modeled, and is modeled as total dissolved solids; precipitation and ion exchange are not modeled.

- Small reservoirs on tributaries are not modeled; therefore, some **shortages** may occur on these tributaries in the model, which would not occur under actual conditions.

- State **water rights** or priorities of water use are not modeled. Deliveries are made as the simulation proceeds downstream through each reach. If a shortage occurs, the shortage is met from an upstream reservoir, if possible, but is not met by shorting a user with a junior water right.

- **Accuracy** of the CRSS is affected by two items: (1) the accuracy of the data and (2) the ability of the model to simulate actual conditions. The former is largely dependent on the accuracy of the United States Geological Survey flow and salt measurements, which are reported in this agency's Water Resources Data Reports to be accurate to within 5 to 15 percent, 95 percent of the time. The latter has been determined by comparing simulated flow and salt values from a CRSS run with historically gauged values. The differences between the simulated and historical values were 5 percent or less, based on the average of 192 monthly values.

# How the Model Works

The Colorado River Basin is divided into 25 reaches in the CRSS. A schematic of these 25 reaches is shown on figure 1. Each reach consists of inflow points, diversion points, and possibly a reservoir. A schematic of one of these reaches, "Reach 411 – Flaming Gorge Reservoir – Green River," is shown on figure 2.

The model simulates riverflows on a monthly time frame, starting at the upstream end of the basin and proceeding downstream. Computations are done reach by reach in the order specified as input to the model. Within a reach, computations are done point by point from the upstream to the downstream end.

Riverflows are computed at each point using the following equation:

*Flow in river = Flow from point upstream*
*+ Inflow − Outflow*

If the point is an inflow point, the *inflow* is the flow into the river due to headwaters or intervening gains and losses, a return flow from an upstream diversion, or the flow from another reach. *Outflow* for this type of point is zero.

If the point is a diversion point, the *outflow* is the flow diverted from the river to satisfy a specified demand. *Inflow* for this type of point is zero. If the amount of water to be diverted is greater than the amount of water in the river, then upstream reservoirs are called on to release additional water to meet the deficiency, if possible. If there is no additional water available in upstream reservoirs, then a shortage is declared that is equal to the amount of the deficiency.

If the point is a reservoir, the *flow in river* is defined as the release from the reservoir. *Inflow* is the amount of water that is released from surface storage and bank storage, and *outflow* is the amount of water that is added to surface storage and bank storage, plus evaporation.

Generally, reservoirs are operated to meet a target contents, which is a target storage level for the reservoir. The amount of water that flows into or out of storage depends on the amount of water entering the reservoir from the upstream point, the relationship between the current reservoir contents and the target contents, and the maximum and minimum contents and releases allowed for the reservoir. After a reservoir release is computed, the amount of power production is determined.

The salinity at each point in the system is determined after the riverflows are computed. Salt is added to the system through inflow points or as salt pickups by return flows. Salt is removed from the system through water quality improvement projects or exports. Complete mixing of water in a reservoir is assumed in computing reservoir salinity concentrations.

The previous description of how the model works is very basic and simplified. Much of the complexity of the model lies in the operations of Lake Powell and Lake Mead. The simulation of these reservoirs includes runoff forecasting, flood control regulations, shortage and surplus strategies, and the Operating Criteria. A discussion of these items is presented in the CRSS *System Overview*.

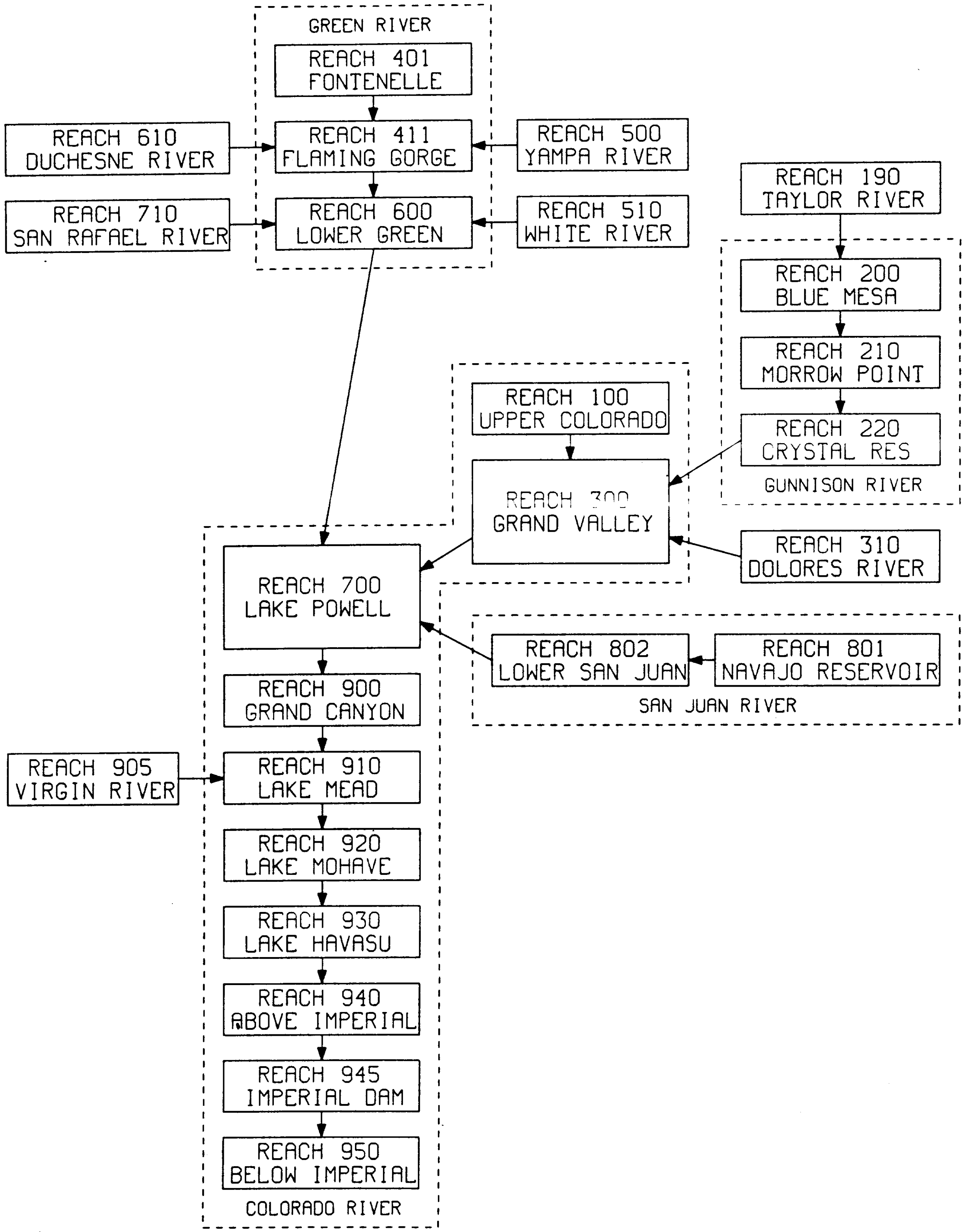



Figure 1. – Schematic of Colorado River Basin divided into 25 CRSS reaches.

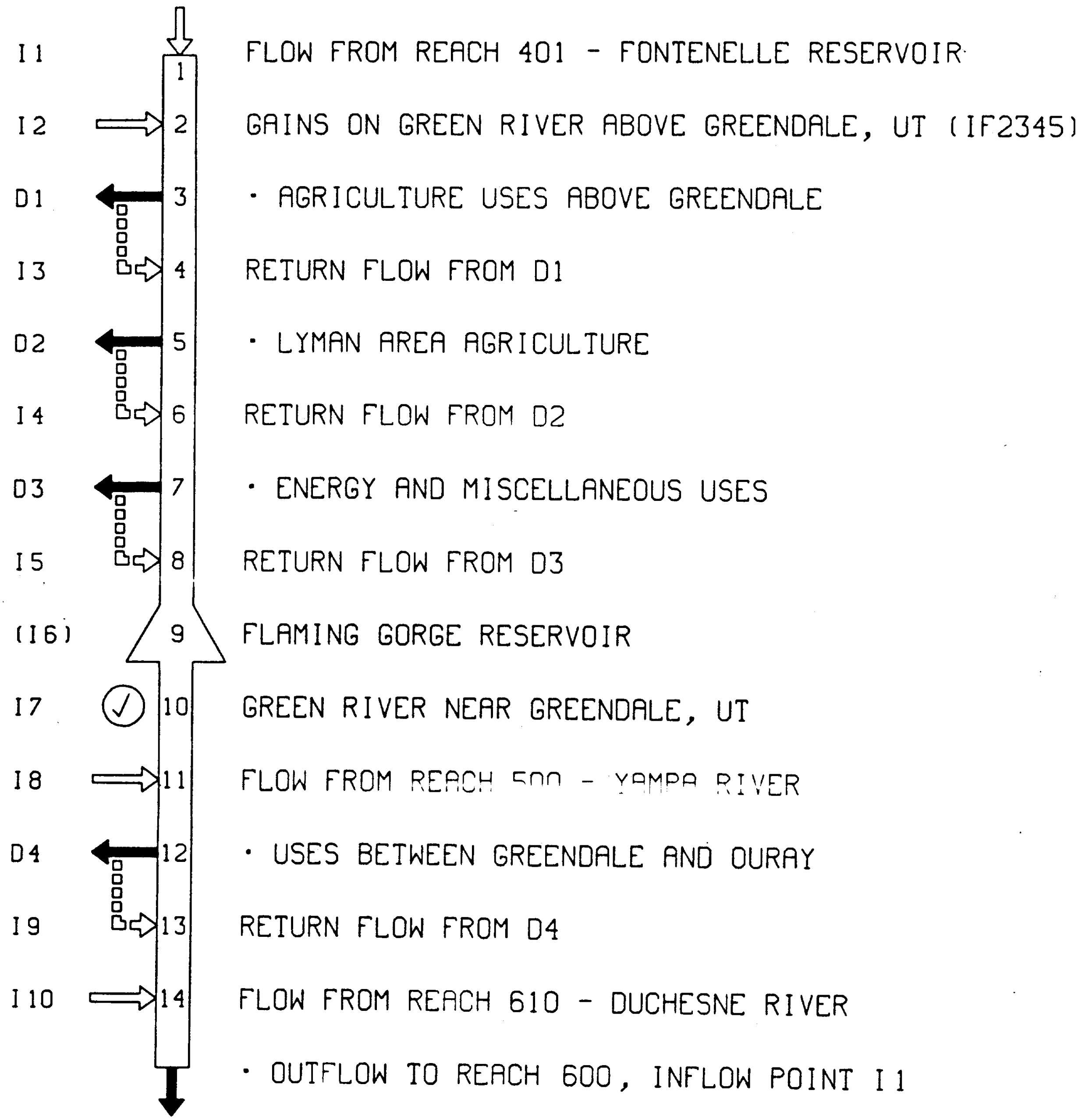



Figure 2. – Schematic of a CRSS reach. Shown is Reach 411, Flaming Gorge Reservoir, Green River.

# Example Output

The CRSS produces output in tabular and graphical forms. Over 60 types of output can be obtained. Examples of these output data are shown on figures 3 through 6. The graphs presented in these figures are only to be used as examples of CRSS output. Since the input data and modeling assumptions are not described, the graphs should not be used for any other purposes.

Figure 3 shows a graph of the annual flow of the Colorado River at Imperial Dam versus time. To generate this graph, the simulation model was run 15 times, each time modeling a different period of historical inflows. The solid line, labeled "15-Run Average," is the average of the 15 annual flow values from the 15 simulation runs. The line labeled "Maximum-3 Average" is the average of the 3 largest annual flow values from the 15 simulation runs. The line labeled "Minimum-3 Average" is the average of the 3 smallest annual flow values from the 15 simulation runs. The Maximum-3 and Minimum-3 lines delimit a range of flow values that are anticipated to occur under the 15 different periods of historical inflows that were used.

Figure 4 shows a graph of the flow-weighted salinity of the Colorado River at Imperial Dam versus time. To generate this graph, it was assumed that only a specific number of water quality improvement projects would exist in the future. The simulation model was run 15 times, using the same procedure described for figure 3.

Figure 5 shows a graph of the end of water year contents of Lake Powell versus time. To generate this graph, two different runs of the simulation model were made. The first simulation assumed that a historical pattern of inflows would occur. The second simulation assumed that a specified amount of cloud seeding would occur, in addition to the historical pattern of inflows. The graph compares the results of these two scenarios.

Figure 6 shows a graph of the water shortages throughout the Colorado River Basin versus time. This graph was generated using the same two scenarios described for figure 5. Consequently, this graph compares the water shortages that could occur with and without a specified amount of cloud seeding.

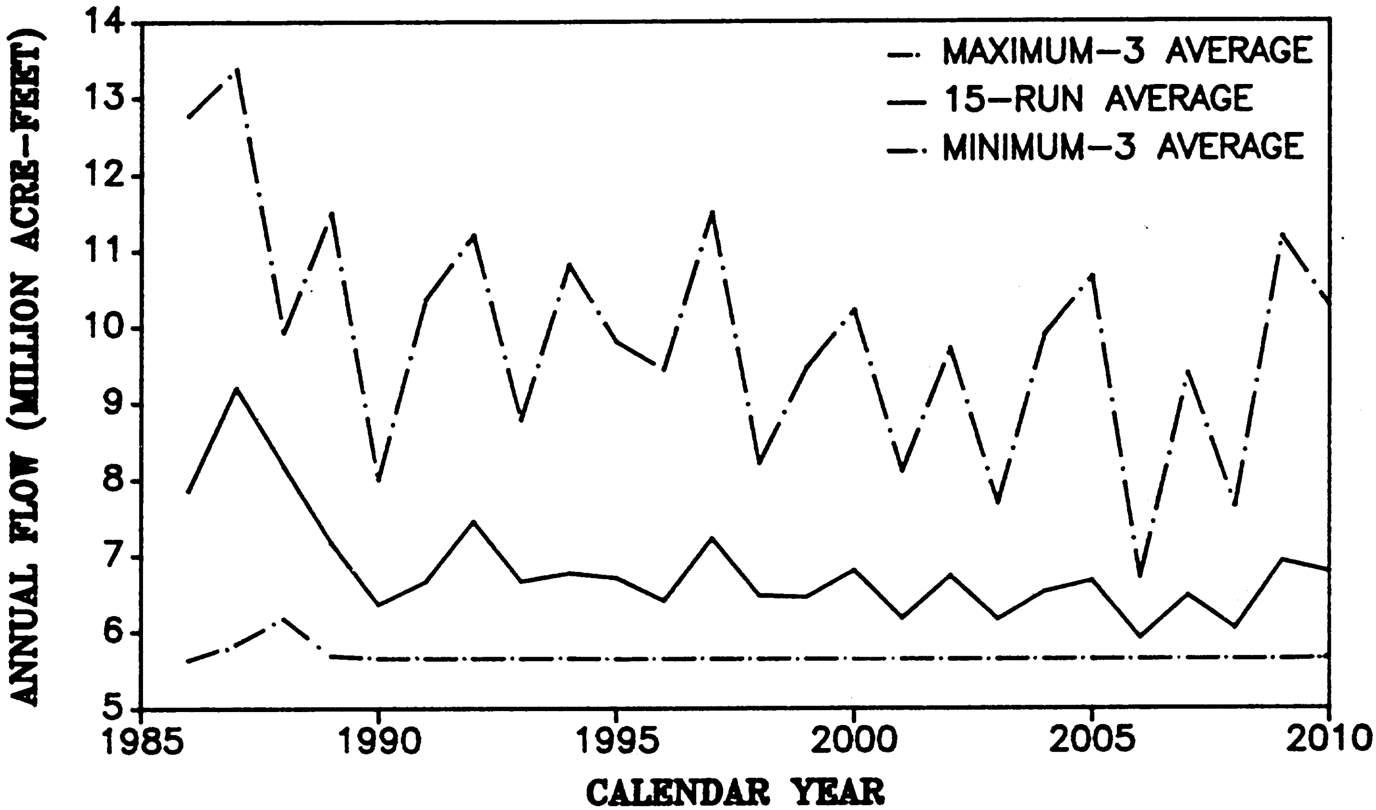



Figure 3. – Example CRSS output of annual flow of Colorado River at Imperial Dam.

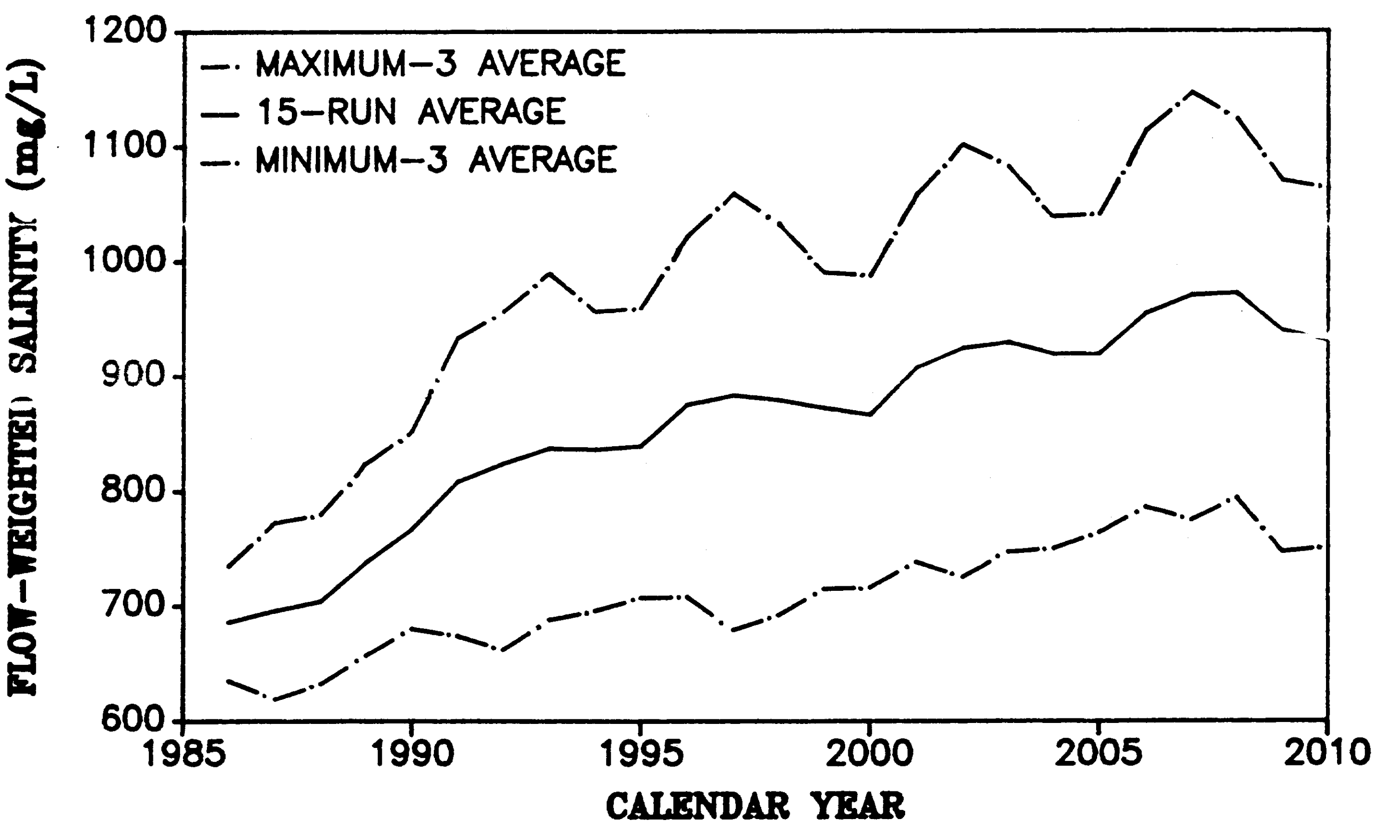



Figure 4. – Example CRSS output of annual flow-weighted salinity of Colorado River at Imperial Dam.

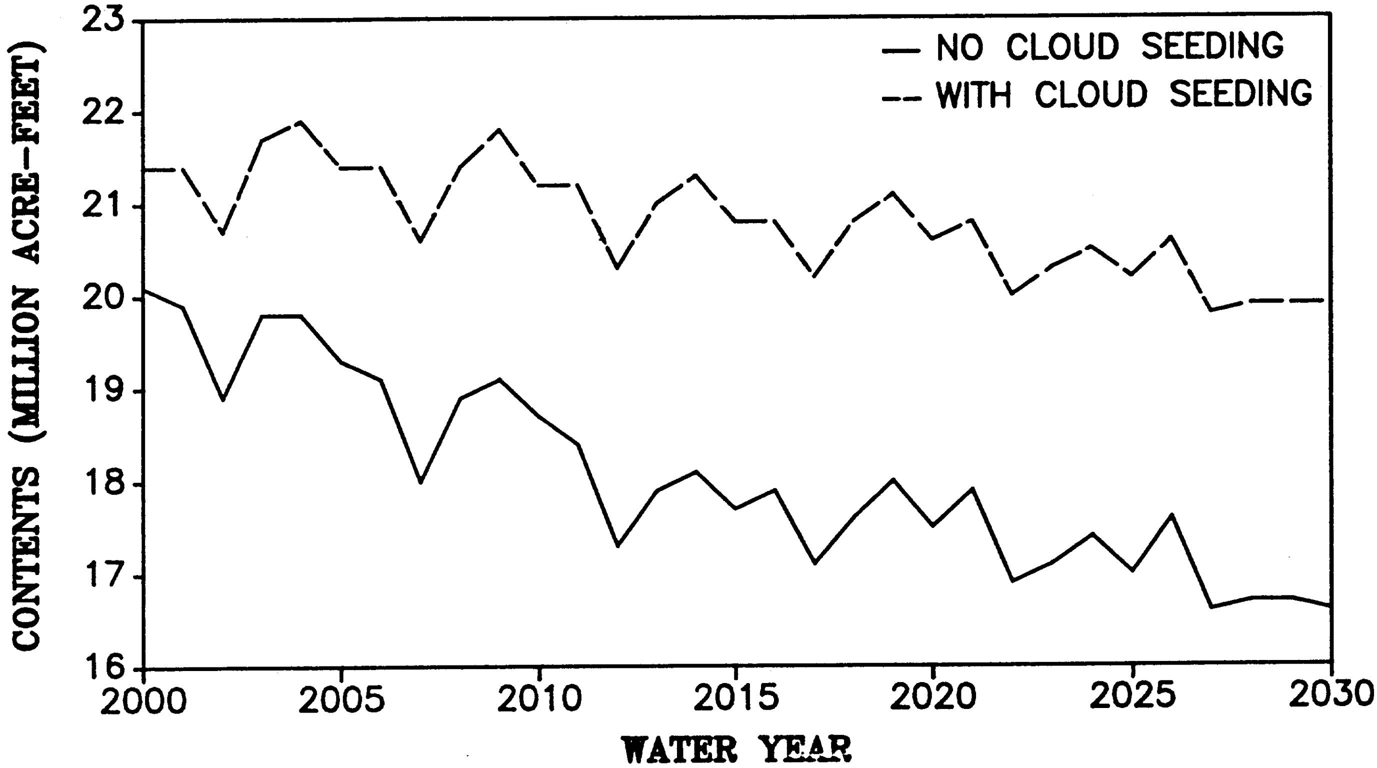



Figure 5. – Example CRSS output of end of water year contents of Lake Powell.

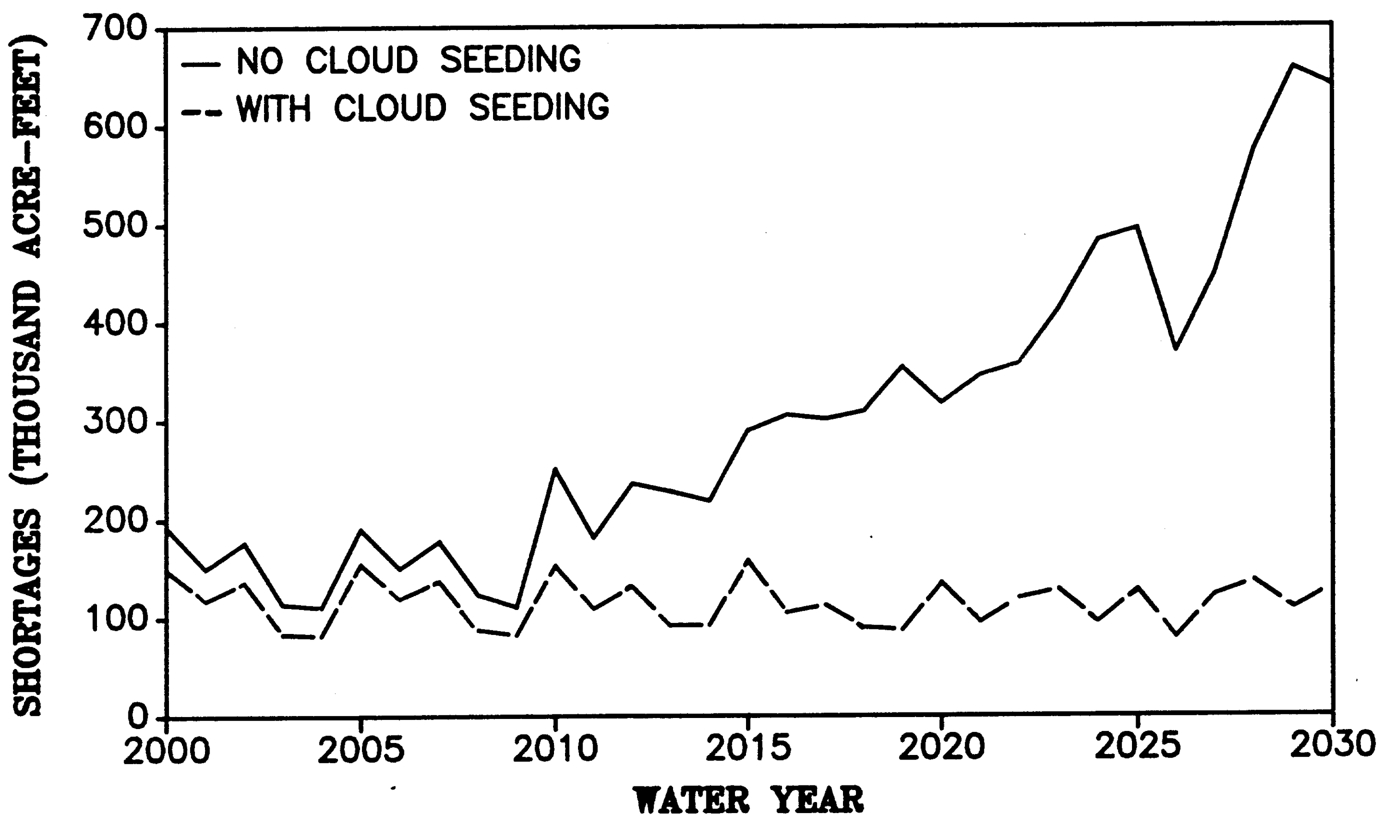



Figure 6. – Example CRSS output of total system water shortages.

## Cost-Reimbursable Studies

Simulation model runs or studies using the CRSS are performed by members of the CRSS Technical Management Team on a cost-reimbursable basis. Costs for these runs or studies include staff costs, computer costs, and output costs. For more information, contact one of the CRSS Coordinators listed below.

## Additional Information

A number of publications and manuals documenting the CRSS are available. The *System Overview* is a 150-page document that gives a detailed description of the CRSS, including underlying assumptions of the model and data bases. This document is available to anyone requiring a more detailed discussion than is presented in this *Executive Summary*. This document is available by writing to:

Technical Services Staff
Bureau of Reclamation
Engineering and Research Center
Attention: D-3215
P.O. Box 25007
Denver, Colorado 80225

*Hydrology Data Base, Upper Colorado Region* is a 150-page document describing the derivation of the upper basin portion of the hydrology data base. *Hydrology Data Base, Lower Colorado Region (Lees Ferry to Imperial Dam)* is a 100-page document describing the derivation of the lower basin portion of the hydrology data base. Each of these documents is available from the respective Regional Office listed below.

User Manuals are available for personnel using the CRSS simulation model. These manuals are not available for general distribution.

For additional information, contact one of the following offices:

Regional Director
Bureau of Reclamation
Upper Colorado Region
Attention: UC-415
P.O. Box 11568
Salt Lake City, Utah 84147

Telephone (CRSS Coordinator)
801-524-5872 or FTS-588-5872

Regional Director
Bureau of Reclamation
Lower Colorado Region
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P.O. Box 427
Boulder City, Nevada 89005

Telephone (CRSS Coordinator)
702-293-8648 or FTS-598-7648

Chief, Division of Planning Technical Services
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303-236-3807 or FTS-776-3807