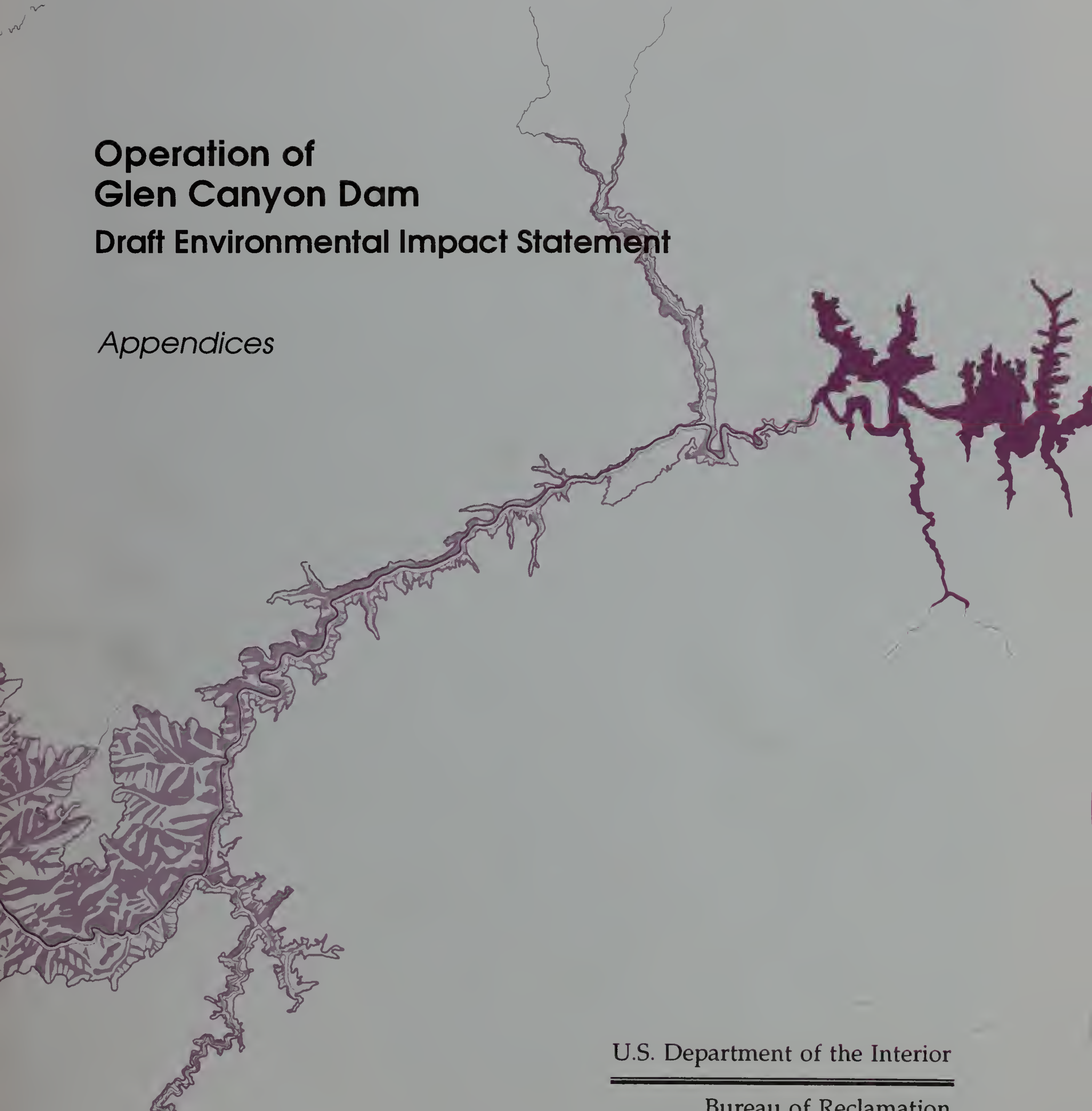
# Operation of Glen Canyon Dam

## Draft Environmental Impact Statement

*Appendices*



U.S. Department of the Interior

Bureau of Reclamation

# OPERATION OF GLEN CANYON DAM
## Colorado River Storage Project, Arizona

*DRAFT ENVIRONMENTAL IMPACT STATEMENT*

***APPENDICES***

# Preface

These appendices were prepared by technical specialists in each represented subject. Therefore, each appendix has an individual arrangement suited to its requirements and displayed in its table of contents. Appendix A contains its own addenda and bibliography. Appendix B primarily includes figures showing hydrologic patterns in more detail than could be accommodated in the EIS. Appendices C, D, and E contain additional technical discussion and illustration of their subjects. An appendix bibliography completes this volume.

# *Appendices*

Appendix A

# *Long-Term Monitoring and Research*

# LONG-TERM MONITORING IN GLEN AND GRAND CANYON: RESPONSE TO OPERATIONS OF GLEN CANYON DAM

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# Contents

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# LONG-TERM MONITORING IN GLEN AND GRAND CANYON: RESPONSE TO OPERATIONS OF GLEN CANYON DAM

## INTRODUCTION

Grand Canyon is an internationally significant natural landscape feature. Ironically, the Colorado River, the physical feature responsible for carving Grand Canyon, is now the most heavily regulated large river in North America. The physical hydrology of Colorado stream flow, as with the associated sediment load and dissolved constituents transported by the river, have changed dramatically since closure of Glen Canyon Dam in 1963. Numerous studies, including those sponsored by the U.S. Bureau of Reclamation's Glen Canyon Environmental Studies since 1982, have documented these changes.

The Grand Canyon Protection Act of 1992 has directed the Secretary of the Interior to establish and implement long-term monitoring programs and activities that will ensure that Glen Canyon Dam is operated "... in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established...". In response to this directive, the Glen Canyon Dam EIS resource management agencies and interests have initiated the planning of a long-term monitoring program which would permit continued evaluation of the effect of Glen Canyon Dam operations, as described in the Record of Decision, on the riverine environment of Grand Canyon.

This document describes the long-term monitoring program. It does not project costs for any of the long-term monitoring program components. These would be determined on (1) availability of funds, (2) priorities assigned to the various monitoring components, and (3) costs proposed by those entities responding to the "Request for Proposals" which would be used to develop and select the detailed methodologies and procedures of this long-term monitoring program.

### Purpose of Long-Term Monitoring in Grand Canyon

Long-term monitoring is used for a variety of purposes including, but not limited to, assessing (1) baseline conditions, (2) trends of attributes, (3) implementation of a decision, (4) effectiveness of a decision, (5) project impacts, (6) model efficacy, and (7) compliance to a set of standards. Many of these purposes are attributable to the evaluation of the impacts of Glen Canyon Dam operations.

Long-term monitoring would be designed to provide regular feedback for adaptive management. This permits mid-course adjustments in the operations of the dam to ensure achievement of the goals of the EIS and the management objectives of the resource management agencies and interests.

Long-term monitoring would also be used to determine variability over time and space of the resources being monitored. This needs to be done in conjunction with appropriate controls to evaluate the source of the variability. In addition, long-term monitoring would provide clues for identifying associations, understanding system behavior, and guiding future process-based research.

Long-term monitoring is the "repetition of measurements over time for the purpose of detecting change" (MacDonald et al 1991). These measurements, because they are made over a period of time, are different from an inventory, which is a measurement, or a number of measurements, made at a specific point in time. Inventories, or establishing baseline conditions, are often the first step in conducting a monitoring effort, but the measurement of possible change over time is the distinguishing attribute of a monitoring effort. Research, on the other hand, is used to test or understand the relationships between and among various attributes of the system. Inventory and monitoring information may be used in research. This document addresses only the long-term monitoring program which emphasizes measurement of those parameters, or attributes, that might change with time and whose change might be related to operations of Glen Canyon.

This proposed long-term monitoring program for the river corridor in Grand Canyon would not be considered equivalent to a long-term monitoring plan for all of Grand Canyon, or in fact for the whole river corridor ecosystem. Although the difference between the two objectives may seem to be semantic, it is critical to distinguish this program, whose intent is the monitoring of the effectiveness of the prescribed operations of Glen Canyon Dam in meeting the objectives of the EIS, the 1992 Grand Canyon Protection Act and the management objectives of the resource management agencies and interests, from a general ecosystem monitoring plan for the river corridor. Clearly, the two objectives are closely aligned because it is impossible to interpret change related to dam operations without understanding the broad range of ecological interactions. Nevertheless, the ultimate purpose of this program is to monitor ecological changes that are related to dam operations.

## A Monitoring Philosophy for Grand Canyon

Grand Canyon is a unique environment. It is also a highly regulated system, both in terms of river flows and use. Its uniqueness demands careful stewardship. In the face of evolving scientific understanding about Grand Canyon's riverine ecosystem, it is not yet possible to identify only a few attributes that characterize the entire system. In light of this uncertainty, it would be irresponsible to restrict monitoring within the river corridor ecosystem to a very small number of attributes and assume that all other attributes are related to those measured.

This proposed program attempts to strike a balance between the extremes of (1) very restricted monitoring which recognizes the impacts of scientific study on the essence of what Grand Canyon means to most humans, and (2) full measurement of all ecosystem attributes predicated on a belief that an unmeasured parameter might be critical at a later time.

### Critical Attributes

This proposed program emphasizes measurement of attributes deemed critical by the resource management agencies and interests (re: Draft EIS), and the scientific community which has studied the system for decades, for evaluating the effects of alternative operations of Glen Canyon Dam. The prediction and significance of the attribute response to dam operations is discussed in the monitoring program section for each attribute. Under the long-term monitoring program, responses of these attributes would be used in adaptive management decisions. These attributes are:

1. Quantity and quality of water from Lake Powell and in the Canyon.
    a. annual streamflows
    b. discharge rates and spill volume and frequency
    c. chemical, physical and biological characteristics of water in Lake Powell and the Colorado River from Glen Canyon Dam to Lake Mead

2. Sediment dynamics and sediment budget.
    a. stored riverbed sand
    b. sandbar topography
    c. elevated sandbar erosion
    d. dynamics of debris fans and rapids

3. Fish.
    a. aquatic food base
    b. reproduction, recruitment and growth of native fishes
    c. reproduction, recruitment and growth of non-native warmwater and coolwater fishes including trout

4. Vegetation.
    a. area of woody riparian plants and species composition
    b. area of emergent marsh plants and species composition

5. Wildlife and wildlife habitat.
    a. area and species composition of riparian habitat for associated vertebrates and invertebrates
    b. aquatic food base for wintering waterfowl

6. Endangered and other special status species, their habitat and food base.
    a. humpback chub
    b. razorback sucker
    c. bald eagle
    d. peregrine falcon
    e. southwestern willow flycatcher
    f. belted kingfisher
    g. Kanab ambersnail
    h. other federal and state species of concern

7. Cultural resources.
    a. archaeological sites directly, indirectly, or potentially affected
    b. Native American traditional cultural properties directly, indirectly, or potentially affected

8. Recreation.
    a. fishing trips and angler safety
    b. day rafting trips attributes and access
    c. white-water rafting trip attributes, camping beaches, safety, and wilderness values
    d. net economic value and regional economics

9. Powerplant supply of hydropower to network and customers at lowest costs.
   a. changes in power operations
   b. power marketing benefits lost or gained

10. Non-use valuation.
   a. Values placed on Glen and Grand Canyon riverine system by the public.

This program also adopts a conservative approach of measuring attributes which reasonably might be affected by dam operations and for which no surrogate attributes exist. However, this program does not propose measurement of those attributes clearly unrelated to dam operations or which are adequately represented by other parameters. It also emphasizes use of data collected in Grand Canyon that are not field intensive. Wherever possible, monitoring should be conducted using non-invasive means.

To reduce the overall impact and cost of this program, data generated from other complementary long-term monitoring programs in the Grand Canyon region (e.g., Lake Powell long-term studies, and the Programmatic Agreement for Compliance with Section 106 of the National Historic Preservation Act) would be used when appropriate for evaluating the effects of the operations of Glen Canyon Dam. There are also background and input data collected from other sources (e.g., climatological and hydrological data) that are critical to interpretation of the long-term monitoring information. These types of data are discussed in the addenda.

Lastly, this program is designed to respond to the long-term missions, goals and management objectives of the resource management agencies and interests. Acceptance of changing conditions of each of the above attributes as it responds to the environment created by the prescribed dam operation is contingent upon these management objectives. A change in an attribute, determined through the long-term monitoring program, may represent a deviation from an acceptable condition (determined by management agencies and interests) that would trigger consideration of suggested changes in dam operations as described in the "Adaptive Management" section of chapter II. The long-term monitoring program would, therefore, use methodologies that offer appropriate information about the response of the critical attributes to enable an Adaptive Management Work Group to evaluate these changes in light of the overall management objectives for "the Canyon".

## Management Objectives

The following statements represent an abbreviated version of the management objectives of each of the resource management agencies and interests. For many of these agencies and interests, these management objectives for specific attributes represent goals rather than existing baseline conditions at initiation of long-term monitoring or response conditions at some point after the effects of dam operations have occurred. Although not specifically stated below, they also recognize the importance of existing laws and statutes, for example, the Endangered Species Act, Trust responsibilities to Indian Tribes, and Cultural Acts. A more comprehensive statement for each interest is presented in chapter II of the DEIS.

National Park Service

The National Park Service, represented by Grand Canyon National Park and Glen Canyon National Recreation Area, has management objectives based upon both the ecosystem that existed prior to construction of Glen Canyon Dam and the ecosystem that has developed post-construction. Objectives are to attempt to maintain the essential dynamic elements and processes that existed pre-dam through restoration, maintenance and protection. The NPS is committed to managing the Colorado River ecosystem and its attendant cultural resources as a coherent whole that, to the extent possible, simulates the ecosystem that existed prior to the construction of the dam.

Bureau of Reclamation

As manager of the Colorado River, the Bureau of Reclamation's management objectives are to strike a balance among water releases established under the "Law of the River" and the Annual Operating Plan for Glen Canyon Dam, the hydroelectric power requirements of Western Area Power Administration, and "protection" of the downstream ecosystem under the 1992 Grand Canyon Protection Act. The priorities given to each of these components under the EIS and long-term monitoring program are dependent on potential risk for change in Canyon resources or attributes of concern, and laws and regulations that direct the Bureau's operations.

Fish and Wildlife Service

The management objectives of the Fish and Wildlife Service in the Grand Canyon, as elsewhere, are to conserve, protect, and enhance fish and wildlife and their habitat for the continuing benefit of the public. In the Canyon emphasis is placed on threatened and endangered species, migratory birds, and native fish and sports fisheries.

Western Area Power Administration

Management objectives of Western Area Power Administration (Western) are the marketing and transmission of electricity generated at Federal water power projects.

Bureau of Indian Affairs

The Bureau of Indian Affairs has no management role in the proposed action. However, it has management goals, among which is fostering of self-determination of Indian Tribes. Its goal is to assure that the interests of Indian Tribes are coordinated with other Federal agencies and to supply advice and assistance to Tribes when requested to do so.

Hualapai Tribe

Management objectives of the Hualapai Tribe are long-term sustainable and balanced multiple uses of its resources through natural integrated resource management. These resources include natural and cultural resources including sacred ceremonial and burial sites within the Canyon located outside the boundaries of the Reservation Lands.

Other Indian Tribes

The management objectives of other Indian Tribes with interest in Glen and Grand Canyons, but whose lands do not border the mainstem of the Colorado River, are the preservation of the natural and cultural resources of the Canyon to maintain their values to the tribes. This includes spiritual and ancestral stewardship and management responsibilities to the Grand Canyon and specific places contained therein.

Arizona Game and Fish Department

The management objectives of the Arizona Game and Fish Department are to conserve, enhance and restore Arizona's wildlife and habitats, and to provide wildlife and safe watercraft recreation for the enjoyment, appreciation and use of the public.

## The Geographical Scope of Monitoring

The area to be monitored is primarily the Colorado River corridor between Glen Canyon Dam and Lake Mead reservoir. This area is about 255 miles long, as the headwaters of Lake Mead vary with reservoir elevation. Because the overwhelming effect on the ecosystem along the shores of Lake Mead reservoir comes from operations of the reservoir and Hoover Dam, the Grand Canyon monitoring program would end at Separation Canyon (RM 240), the generally accepted head of Lake Mead. However, the affects of fluctuations in Lake Mead and the influence of changes in the Colorado River below Separation Rapids resulting from dam operations might be considered as extensions of the geographical scope of the long-term monitoring program.

Delineation of the upstream boundary of Grand Canyon monitoring is also inexact. Water molecules and dissolved constituents may travel to Grand Canyon from any part of the Colorado River watershed, and sediment particles may be transported to Grand Canyon from much of southern Utah and northern Arizona. Geochemical transformations occur in Lake Powell reservoir that directly affect the chemical quality of water discharged into Grand Canyon.

Many of the relevant upstream data are already collected by the U.S. Geological Survey, National Oceanic and Atmospheric Administration, and the Bureau of Reclamation. Other information, such as from an expanded program of limnological monitoring of Lake Powell, are not available. Despite the linkages that exist between Grand Canyon and the entire upstream basin, the appropriate upstream limit for Grand Canyon monitoring, as related to effects of dam operations, is the forebay of Lake Powell, the intake point for water into the water release structures of the dam. Because of the critical role of reservoir-scale geochemical processes in determining the quality of water at the intake sites, the separate long-term monitoring effort of Lake Powell would continue as a valuable input to this program. The Lake Powell long-term monitoring program would not, however, be considered part of the Glen and Grand Canyon long-term monitoring program. Along this same line, ongoing studies in and along the shoreline of Lake Mead within normal pool fluctuation would not be considered part of the Glen and Grand Canyon long-term monitoring program.

The lateral extent of the monitoring effort is defined by the extent of processes and conditions influenced by dam discharges and river flows. The relevant discharge might be: (1) maximum powerplant discharge (31,500 cfs), (2) maximum regulated discharge and mean annual pre-dam peak flow (100,000 cfs), or (3) maximum pre-dam flood (220,000 - 300,000 cfs). Because this proposed monitoring program is long-term in scope, the minimum discharge considered ought to be 100,000 cfs. However, the old high-water zone vegetation community begins at about this elevation and extends to higher levels and arroyo head cutting may extend above this level. Thus, it is prudent in some areas of the Canyon to include elevations above the stage associated with a discharge of 100,000 cfs.

Thirteen reaches, varying in length between 2 and 12 miles were established by GCES as Geographic Information System (GIS)-reaches, and detailed topographic data at a scale of 1:2400 is available for these reaches. The availability of detailed data for these reaches would lead to integrated resource perspectives in these areas and would necessarily focus data collection in these sites. These sites were selected because they represented reaches of the Colorado River in which there were ongoing studies or potentially important ecological conditions. However, the scientific basis for their selection was not necessarily for the long-term monitoring program because it was anticipated that the whole system would eventually be put into the GIS. As a consequence, additional sites may need to be selected to adequately represent each of the geomorphically distinctive reaches of Grand Canyon.

### Information Management

Information management is an integral part of data collection and long-term monitoring. It includes, characteristics of the data base, protocols for data collection and processing, protocols for data analysis and reporting, and the use of GIS and remote sensing. A discussion of information management is intended to give guidance to those who will manage the long-term monitoring program and its extensive data base and will be making adaptive management recommendations and decisions, and those who will prepare proposals and reports as part of their activities relative to this program. The success of the long-term monitoring program depends on the dependability, integrity and credibility of data generation and information management. For this reason, a discussion of information management and how it applies to the Grand Canyon Long-term Monitoring Program is presented in the addenda.

## LONG-TERM MONITORING PROGRAM

### Quantity and Quality of Water: Lake Powell and The Canyon

#### Lake Powell

The water discharged from Glen Canyon Dam represents water from Lake Powell whose quality is a product of lake tributaries, level and mixing processes. A model explaining these relationships is being developed by a selective withdrawal study team and the Lake Powell study group. The model is not sufficiently developed to presently be used in long-term monitoring, although data for its development would continue to be gathered.

The quality of the discharge water may influence many of the aquatic biological processes within the Canyon. If these biological processes change, the cause for the change would be better interpreted if the quantity and quality of the discharge stream is known. Thus, the objectives of sampling in Lake Powell are to determine the quality of the water in the dam intake region in order to characterize dam discharges, and to determine whether the prescribed dam operations, especially if a selective withdrawal structure is used, affect the water in the forebay region of the dam as predicted by studies of the selective withdrawal study team. (This research, which includes collecting data on reservoir level and storage, and tributary inputs, is a parallel program to the long-term monitoring program, but it is essential for interpreting the affects of Lake Powell water chemistry and circulation on the below-dam aquatic ecosystem.)

Sampling stations in Lake Powell as part of the long-term monitoring program would be limited to the forebay above Glen Canyon Dam. Information from the long-term monitoring program of Lake Powell would be used to help interpret the findings in the forebay area. The forebay area is the direct input point to the below-dam ecosystem. At these stations physical, chemical and biological parameters would initially be measured monthly during studies of selective withdrawal and then quarterly in the water column at a sufficient number of locations to determine statistical variability. Physical parameters would be limited to temperature and light penetration. Chemical parameters would include pH, conductivity, nitrogen, phosphorus, dissolved oxygen and particulate organic matter. Biological parameters would include algae (especially blue greens and diatoms), zooplankton, total chlorophyll and chlorophyll a. Monitoring protocols would be developed to reduce the taxonomic and biomass studies of phyto- and zooplankton and replace these with chlorophyll a and other surrogate measurements.

**Colorado River Mainstem**

Dam Discharges. Dam discharges create the physical conditions that control many of the downstream ecosystem processes, for example, sediment dynamics, habitat development, and biotic recruitment and survival. The objectives for monitoring the outputs of Glen Canyon Dam are to determine how closely dam discharge follows the prescribed operations of the dam and the extent of the variability in discharge, should it occur. These outputs, which also include discharges or spills above dam hydropower operations, would be measured both at the dam, based on power production, and at the U.S.G.S. gage just downstream. Outputs to be monitored include, hourly water discharge (both flow rate and volume) and ramping rates (changes in discharge over the hour). From the above data, information on maximum and minimum daily discharges and daily fluctuations, and frequency and volume of spills, can be determined and placed in a perspective of average conditions and variance.

Water and Sediment Transport. The transport of water and sediment through the Canyon are interconnected (e.g., sediment transport curves). Discharge rates and changes in river stage influence the amount of sediment transported and stored in the system; sediment being the primary substrate for many Canyon biological processes as well as camping beaches. The objectives for monitoring changes in water and sediment transport are to determine whether the flux of water and sediment through the Canyon is as at the level predicted by the EIS for the prescribed dam operations, and whether the flux varies as expected within different reaches of the Canyon. Measurement objectives are: (1) continuously measure the flux of water through Grand Canyon (2) periodically measure flux of sediment through the Canyon, and (3) measure the differences in flux in different reaches. Measurements of flux not only permit comparison of measured differences in fluxes which can be compared with measured storage changes, but the fluxes themselves are critical determinants of biological processes.

Although a water flow and sediment routing model is being developed by the U.S. Geological Survey, it is not yet time to solely rely on this model to estimate fluxes; field measurements must be continued. Gaging stations do not exist at the end points of each geomorphologically distinct reach in Grand Canyon (whether using the classification of Schmidt and Graf, 1990; and others), and new gaging stations would not be established through the main channel to define each geomorphically distinct reach. The emphasis of long-term monitoring would be on maximizing the analysis of data collected at existing gages. Because most river managers have expressed greatest concern about impacts of dam operations on upstream reaches of Grand Canyon, and because those reaches have been shown to have the greatest potential for sediment storage deficit, it is important that gaging stations on the Colorado River at Lees Ferry, above the Little Colorado River, and upstream from Bright Angel Creek be maintained as sediment measurement stations as well as discharge stations. It is also critical to measure outflow from the system and therefore, of existing gaging stations, the station above Diamond Creek would be maintained. It is less critical to evaluate flux differences between miles 87-225, and the gage above National Canyon is considered the least important gage presently existing in Grand Canyon, although it continues to be useful for bed movement studies and sediment transport modelling. If one gage is removed in Grand Canyon, it should be the National Canyon gage although the economy of this decision over the long-term might be questionable.

If one gage were to be added in Grand Canyon, it should be located upstream from Nankoweap Creek (perhaps upstream from Buck Farm Canyon), so that fluxes could be measured through the distinctly different reaches of upper and lower Marble Canyon, reaches in which impacts from upramping waves are greatly attenuated. However, addition of a new gage in Grand Canyon would represent a significant increase in the impact of scientific activities on the Canyon, and the U.S. Geological Survey should explore alternative strategies to installation of permanent cableways for purposes of water and sediment gaging.

The ongoing water and sediment modeling effort, although primarily a research effort, would be included in the monitoring program because the modeling effort represents a long-term alternative to continued widespread gaging presence in Grand Canyon. Such modeling also holds out the hope for calculation of flux differences in short reaches of Grand Canyon. Other modeling efforts, although of possible use in long-term management of Grand Canyon, would not be considered part of a long-term monitoring program but rather long-term research. This is not to imply that development of these models would be discontinued as continued long-term research is essential to success of the long-term monitoring program.

Measurements of sediment fluxes would be the basis for computing annual reach-scale sediment budgets of Grand Canyon. The sediment budget approach to river management has been endorsed by geomorphology and sediment researchers (GCES Fort Collins, 1992). Because there are insufficient gages to compute sediment budgets for all geomorphic reaches of Grand Canyon, such budgets would only be computed for the following reaches: Lees Ferry to Little Colorado River, Little Colorado River to Bright Angel Creek, and Bright Angel Creek to Diamond Creek.

Calculation of these budgets also necessitates measurement of sediment inflow from tributaries. The Geological Survey would continue to operate its stations on the Paria River at Lees Ferry and Little Colorado River near Cameron. Sediment from Moenkopi Wash, a major sediment contributor to the Little Colorado River, is not measured and consideration would be given to developing a measurement station on this wash. New sediment measurement stations would not be established on other tributaries to the mainstem because sediment input from these tributaries is inconsequential compared to inputs from the Paria and Little Colorado Rivers. This is not necessarily the case for water discharge data, and gages for these measurements on major tributaries might still be considered.

Water Chemistry. Chemistry of water in the mainstem of the Colorado influences most aquatic and riparian biological processes. Changes in water chemistry and temperature may alter physiological processes of aquatic biota potentially triggering changes in the aquatic trophic dynamics of the Canyon. Nutrient trapping by Glen Canyon Dam, changes in nutrient transport within Lake Powell resulting from changes in lake level, and in the mainstem resulting from water transport fluxes all influence the water chemistry of the mainstem below the dam. Thus, the objective of water chemistry monitoring is to determine the aquatic environment of the Canyon and evaluate this in terms of maintenance of those riverine ecosystem components deemed critical by the resource management agencies and interests; that is, fish, aquatic food base and riparian vegetation.

Evaluation of chemical and biological changes in the riverine ecosystem would be dependent, in part, on river discharge, water temperature and sediment data collected at the recommended gages on the mainstem and at the point of discharge from the dam (tailrace). Basic data on water temperature, conductivity and pH would be measured at these gages and the discharge point at the same time interval established for sampling discharge and/or sediment transport. Measurements of dissolved oxygen, particulate and dissolved organic matter, and nitrogen and phosphorus would be made seasonally.

**Canyon Tributaries**

Tributaries to the mainstem of the Colorado River in Glen and Grand Canyons are influenced by dam operations primarily at their confluence with the mainstem. With the exception of the influence of rising and falling river levels at the confluence, tributaries are an input to the mainstem. As such, the objective for collecting long-term monitoring information on changes in tributary characteristics is to evaluate possible causes of mainstem changes, that is, dam vs non-dam operational causes. Tributaries of the Colorado River are relatively pristine refugia for native fish, trout and other non-native fishes as well as riparian ecosystems. For this reason, they would be included in the long-term monitoring program where they would be considered as "control" for evaluating changes in selected attributes in the mainstem (e.g., aquatic biota), and as a source of attribute inputs.

Tributary inputs to the mainstem include hydrological, sediment and limnological attributes. Not all tributaries can be monitored thus emphasis would be limited to those with major inputs, either abiotic or biotic. In addition to water and sediment discharges from the Paria and Little Colorado Rivers mentioned earlier, tributary discharges, water chemistry (see parameters above for mainstem) and biological attributes (see aquatic food base) would be monitored at the Paria and Little Colorado Rivers, and Kanab, Bright Angel, and Havasu Creeks. Measurements would be continuous for discharge rates, and seasonally for chemical and biological attributes and would be taken in conjunction with these measurements at the gages in the mainstem. Discharge rate monitoring would require maintenance, reinstallation, or installation of a gaging system in the above tributaries and the significance of the necessity for this invasive technology would be considered. Other selected tributaries, especially with perennial flows, would be sampled quarterly for comparison with primary tributary and mainstem data; measurements being limited to water chemistry and biological attributes.

## Sediment Dynamics

Sediment in the Canyon is either in transport or in storage above or below the river surface. Sediment transport flux is monitored periodically at the gage sites in the Canyon. Stored sediment in the channel and eddies is the source and foundation of elevated sediment deposits. The prescribed dam operations in the Record of Decision would consider sediment accumulation in the riverine system, in the channel or eddies and as elevated deposits (e.g., beaches). Therefore, the objective of monitoring changes in stored sediment is to evaluate the sediment budget predictions of the EIS relative to the selected alternative. In order to determine the influence of dam operations on the integrity of these deposits, the measurement objective of the monitoring program is to determine the changes in sediment storage in different reaches of Grand Canyon. The accomplishment of this objective would permit measurement of temporal change in the status of critical bar and bank sediment deposits and in debris fan deposits, and to place that change within the context of measurements of all sediment storage change in Grand Canyon.

Selected campsite beaches would continue to be measured annually. Established survey techniques would be employed by trained surveyors. Measurement of short-term changes on bars, although of interest in determining sediment dynamics, are not the focus of the long-term monitoring program.

Measurement of bar changes throughout the Canyon would be made using air photo interpretation and video imaging analysis strategies. Such measurements permit wider ranging measurements using less invasive measurement strategies. Short-term repeat photography is not recommended as part of the long-term sediment monitoring program except perhaps at sensitive archaeological sites (see Cultural Resources section).

## Fishes and Aquatic Food Base

### Aquatic Food Base

Many wildlife species, including fishes, depend on the aquatic food base for their survival. Fluctuations in aquatic food resulting from dam operations or other influences would invariably cause changes in some or all of the populations of native and non-native fish species. The preferred alternative includes prediction of enhancement of the aquatic food base to ensure sufficient food for the endangered fish species and the economically valuable trout population. For this reason, the objective of the long-term monitoring program is to determine whether the biomass, habitat and composition of the aquatic food base is responding to dam operations as expected.

Aquatic food base monitoring would be seasonal and include the mainstem, and tributaries. Quantification of changes in species survival and productivity within categories or functional groups of lower trophic levels in the ecosystem may be used as gross indicators of change. Standing crop (biomass), dominance and habitat requirements of phyto- and zoobenthos, and phyto- and zooplankton would be measured seasonally at the dam, Lees Ferry, Little Colorado River and Diamond Creek and at least two wide-reach sites and two narrow-reach sites between the Little Colorado River and Diamond Creek. When appropriate, sampling protocol would be comparable with the protocols used during GCES II research to ensure compatibility of data.

The sampling protocol would sort the benthos into biotic categories. Numbers of organisms and ash-free dry mass would be determined for multiple samples numerous enough for each biotic category to assure statistical reliability. Complementing biotic sampling, the following abiotic parameters would be ascertained for comparison with abiotic data from gage sites: water temperature, dissolved oxygen, pH, and conductivity. Substratum, microhabitat conditions, turbidity, water velocity, stage, and depth would be recorded at each sampling site.

**Fishes**

Fishes are an important part of the Colorado River ecosystem because of their intrinsic value if native, the trophic role of both native and non-native taxa, the important recreational value of non-native trouts, and because some native taxa are listed as endangered or candidates for listing under the Endangered Species Act. Fish populations depend on appropriate habitat and an adequate food base. Both of these factors may change as a result of dam operations. Habitat determination for many of the species is a result of the GCES research program. However, reproduction, recruitment and growth of various species in response to the aquatic environments created by dam operations would result in different demographic distributions of native and non-native species within the Canyon. Operations of the preferred alternative are predicted to enhance recruitment of native fish species through reduction of "flushing" of larval fish from tributaries into the mainstem for example, and trout through reduction in loss of spawning habitat (redds) and stranding of young. Loss of spawning habitat through armoring of normal redds areas may also be a consequence. In addition, dam operations are expected to enhance the food base to ensure growth and maintenance of the existing populations. The objective of this program, therefore, is to monitor the condition and population fluxes of native and non-native fish species to evaluate their response, as predicted, to dam operations.

Monitoring would include all native and non-native species. There would be a long-term data base existing for the status of adult fishes when the long-term monitoring program is initiated; information on pre-adult life stages would likely be less complete.

Sampling time-frames would differ for different taxa and life stages. Because information on some of the fish species is not complete, adults of long-lived taxa would be sampled annually. As information becomes more complete, sampling would be on a four-year cycle. Short-lived species and young-of-the-year of all taxa would be sampled twice annually during the period of larval fish presence (spring) and following the period of summer flooding. Sampling locations would correspond as closely as possible to those selected for monitoring of the aquatic food base, but would also include selected tributary sites (e.g., Paria, LCR, Bright Angel, Nankoweap, Havasu, and others to be determined). The assumption is that by the time long-term monitoring is initiated, sufficient understanding of many relationships among sampling sites and ecosystem parameters would have been established to allow use of sampling site data for assessing overall status, trends and changes of fish populations as well as the aquatic food base.

The sampling protocol for adults of long-lived species would be comparable with that used during GCES II research and interim flow monitoring to ensure compatibility of data. Monitoring in the Little Colorado River would be comparable with protocols developed during the GCES II humpback chub research program. Sampling protocols for short-lived species and young of others would be determined through evaluation of monitoring proposals but would produce data compatible with those generated through monitoring of other age classes.

Creel data, regular surveying of fishing guides, and other methods compatible with protocols developed by Arizona Game and Fish Department would be used for assessing trends in trout populations in the Lees Ferry reach, while protocols developed by Arizona Game and Fish and the Hualapai Wildlife Management Department to assess recreational fish populations would be used for lower reaches. Timing of those activities would be determined by the resource management agencies, but would not exceed an annual reporting schedule. Data collection and reporting from the two departments would be compatible.

## Riparian Vegetation

### Mainstem Vegetation and Habitats

Riparian vegetation along the Colorado River and its tributaries is important for streambank stability, wildlife habitat, campsite modification and aesthetic values. Riparian vegetation along the mainstem comprises three distinct communities, old high water zone (OHWZ), new high water zone (NHWZ), and near-shoreline wetlands (marshes). All of these communities are important ecosystem components; however, only the NHWZ and marshes would be impacted directly by dam operations. Maintenance of these vegetational communities for wildlife habitat is a predicted ecosystem response to the preferred alternative in the EIS. The National Park Service and the Hualapai Tribe consider the OHWZ important in maintaining relicts of the pre-dam ecosystem. The OHWZ may be maintained by periodic habitat maintenance flows through wetting of the substrate in the root zone downslope toward the river. These habitat maintenance flows are recommended for most of the alternatives with low or non-fluctuating discharge. The objective of this long-term program, therefore, is to monitor all three vegetation communities to determine the level of maintenance of these communities by the prescribed dam operations.

The National Park Service has established permanent quadrants along the mainstem and in selected perennial and ephemeral tributaries for the purpose of evaluating long-term responses of riparian and wetland communities to natural and anthropogenic influences (Stevens 1992). Equivalent quadrants have been established by the Hualapai Tribe in the riparian zone during interim flow monitoring. A statistically significant number of these quadrants, distributed throughout Schmidt and Graf's (1990) geomorphic reach designations between Glen Canyon Dam and Diamond Creek, and those below Diamond Creek on the Hualapai reservation, may be the appropriate sampling locations for riparian vegetation because they can be considered baseline information locations. Stage-to-discharge relationships would also have been developed for each by the time the long-term monitoring program begins. The geomorphic settings examined at each area would include marsh, NHWZ (which includes low bar, general beach, channel margin, debris fan) and OHWZ (see Stevens 1992 for stage elevations of these settings).

Because of different response rates to changes in river dynamics, sampling procedures (particularly timing) must differ in the different communities. Marshes and low bar settings would be sampled frequently (e.g., twice a year for the first five years and annually thereafter, except when there are unusual hydrological events, and then immediately after and again twice a year for three years). General-beach, channel-margin and debris-fan settings would be sampled annually, while OHWZ settings would be sampled infrequently (e.g., every five years).

Annual video- or photography of the Canyon would be used to map and quantify changes in cover of riparian vegetation in established (or expanded) GIS reaches. This would be linked with equivalent monitoring of sediment and bar changes.

### Tributaries

Riparian vegetation near the mouths of the primary tributaries, but outside the influences of the mainstem, would be characterized and used as reference points for autogenic changes. Characterization would be limited to community structure and species composition and sampled about every five years after a baseline has been established. Tributary quadrants would be located in comparable settings as along the mainstem (i.e., channel margin, and debris flow terrace). Timing (i.e., time of year) of sampling along the tributaries would correspond with equivalent settings along the mainstem.

## Riparian Wildlife and Wildlife Habitat

### Riparian Habitat

Habitat relations of most riparian fauna in the Canyon have not been well established. Determination of faunal responses to dam operations is extremely difficult and is dependent on known faunal responses to changing ambient conditions. Thus, to achieve the objective of monitoring the response of faunal assemblages to dam operations, it might be best to align these responses with sampling of riparian vegetation, recognizing that not all riparian fauna are associated with vegetation.

## Invertebrates

It is unlikely that a completed baseline of invertebrate assemblages will be available when long-term monitoring begins, although there presently exists a large database. Monitoring key taxa, when such are identified, may permit evaluation of responses to dam operations. An inventory of the invertebrate fauna would be established by the National Park Service and Hualapai Tribe as part of a general inventory program, but an extensive and intensive long-term monitoring program would even then disallow more than an estimate of invertebrate responses to variation in river discharges. Thus, as part of a long-term research program, it is essential to establish the invertebrate assemblages (e.g., selected taxa) that are associated with different riverine and shoreline vegetation communities. Long-term monitoring of these vegetation communities may in this way be used as a surrogate for estimating responses of invertebrates to operational changes.

## Terrestrial Vertebrates

The intensity of effort required for sampling terrestrial vertebrates (herpetofauna, mammals and birds), and the low potential for distinguishing between responses to non-dam changes and those caused by dam operations, limit usefulness of long-term population studies as indicators of change in the riverine ecosystem. In addition, baseline data to support a long-term monitoring program are minimal (except for avifauna), indicating the need for more inventory of terrestrial vertebrates by the National Park Service and the Hualapai Tribe. When inventory is complete and habitat relations of selected assemblages (especially herpetofauna and birds) are established, data from long-term monitoring of vegetation and other habitat components would indicate the probable status of many terrestrial vertebrate populations.

Avifaunal data are perhaps most extensive (see Brown 1989), and a substantial baseline may, in fact, be available if synthesized with the long-term monitoring program in mind. Avifaunal inventory and monitoring, if undertaken, would emphasize riparian-obligate species, resident non-obligate species, migrant species in a biogeographic/geomorphic/seasonal context, listed or special status taxa (e.g., bald eagle, peregrine falcon, southwestern willow flycatcher, belted kingfisher), and wintering and breeding waterfowl. Locations of birds and nests observed would be mapped on the GIS system within the Schmidt and Graf (1990) canyon reach designations. Intensive sampling would occur at the large sample sites (also to be used for herpetofauna and mammals, see below). Nest sites would be mapped and habitat described. [Annual survey of wintering bald eagles/trout population relationships at Nankoweap, representative of the impacts of aquatic responses on listed avian populations, would continue into the long-term monitoring using techniques compatible with those in National Park Service (1992).]

Monitoring of vertebrates, if determined to be essential, would require large study sites where full descriptions of vegetation, soils and topography are available. Spot sampling elsewhere might also be required to expand the long-term monitoring data base. For herpetofauna and mammals, a seasonal sampling schedule is recommended. Establishment of a baseline is necessary for assessing population changes over time and the expense and effort to do this may be too great to include terrestrial vertebrates in the long-term monitoring program. This does not exclude the necessity of the National Park Service and the Hualapai Tribe in initiating or continuing its inventory of these taxa, but not as part of the long-term monitoring program.

## Endangered and Special Status Species

Information on the response of endangered and special status species to dam operation may be crucial to the species' recovery. In addition to their special status, these species are considered important because many were part of the pre-dam ecosystem. The objective of the long-term monitoring program is to track the populations of these species as they respond to changes in their habitat and food base caused by dam operations and other factors which are expected to enhance the chances of their survival and/or recovery. Of the list presented earlier in this document, humpback chub and razorback sucker would be monitored under the fish monitoring program, while the bald eagle, peregrine falcon, southwestern willow flycatcher, belted kingfisher and Kanab ambersnail would be monitored under the wildlife monitoring program.

## Cultural Resources

Cultural resources include archaeological sites, traditional Indian cultural properties, and historical sites. All of these resources have the potential of being altered or lost through processes caused by dam operations as well as other factors, especially those within the discharge potential of the dam or along arroyos that may be influenced by loss of the sediment foundation. It is the objective of this long-term monitoring program to track the integrity of these resources over time and to determine possible mitigating measures when appropriate.

### Physical Sites

The long-term monitoring program for physical sites would adopt the Programmatic Agreement for Compliance with Section 106 of the National Historic Preservation Act between the National Park Service, Indian Tribes, Bureau of Reclamation, the Arizona State Historic Preservation Office and the Advisory Council on Historic Preservation, as the monitoring design under this long-term monitoring program. The important aspects of that agreement (from Balsom et al 1991) are presented here.

To effectively monitor impacts of dam operations on cultural sites, baseline information must be complete, with accurate maps, descriptions, and photographs of each site having potential of being impacted. The long-term monitoring program must be sensitive to the fragile nature of sites, the dynamic geomorphic conditions under which they persist, and the delicate situations relative to Indian Tribes and agency responsibilities for their protection and preservation.

The monitoring program must be designed to identify both the present condition of sites and actual changes resulting from dam operations and other factors. (Monitoring data would be used to guide mitigative measures to preserve sites in as pristine a condition as possible.)

Not all sites would be monitored. An extensive representation of sites with evidence of impact by mainstem discharges, including flooding, would be included, while a smaller representative sample of sites not presently impacted by river flows would also be monitored. If observations indicate that specific sites within the population of sites from which the sample was selected show evidence of impacts from dam operations, these sites would be added to those monitored under the long-term monitoring program. Sites to be monitored would be categorized into the following groups from which decisions on intensity of monitoring can be made: (1) direct impact, inundation or bank cutting within the site area in recent years; (2) indirect impact A, bank slumpage or slope steepening adjacent to the site, and B, evidence within the site of accelerated erosion exacerbated by the proximity to river eroded sediments; (3) potential impact A, buried in or located on old river alluvium and below the 300,000 cfs discharge zone, and B, located below the 300,000 cfs discharge zone and not situated in or on river alluvium.

Other impact categories dealing with arroyo cutting (from external causes not head cutting from the river), recreational use (unless evidence of changes in recreation resulting from dam operations), or sites located above the 300,000 cfs discharge zone are not included in this long-term monitoring program, but should be monitored under a continuing cultural site inventory and monitoring program of the National Park Service, the two efforts to be closely coordinated.

Representative samples of sites would be chosen, randomly and non-randomly, within the above categories to insure that sites in the greatest danger of impact are closely monitored and remedial actions taken when required. Sites that have no potential for external impacts would be identified and used as controls.

Schedule for monitoring cultural sites would be dependent on the baseline condition of the site. It is assumed that all sites will have been categorized and described, including geomorphological settings, prior to initiation of the long-term monitoring program. Sites that are directly impacted by river discharges (including loss of sediment foundation) would be monitored quarterly, while a sample of other sites (ca. 20%) would be visited annually. Selection of these latter sites would be based on sensitivity, tribal concerns and other factors determined by archaeologists, respective Indian Tribes and geologists. Sites which are not impacted by river discharges, but show impacts due to such factors as arroyo cutting, would be integrated with the long-term monitoring program. Annual aerial photo- or videographs would also be used to evaluate site changes, especially of those of sufficient size to allow remote sensing of change. This work would be coordinated with the sediment dynamics monitoring program. Sites with potential for rapid degradation would be monitored weekly through the use of oblique photography using hidden time-lapse cameras. If rapid loss is discovered, recovery archaeology and/or mitigation would immediately be initiated.

**Tribal Cultural and Spiritual Values and Tribal Concerns.**

Monitoring of tribal values and concerns with dam operations and impacts would be an integral part of the long-term monitoring program. Tribal attitudes and values may change over time, both in response to passing years but also as a result of actual or perceived changes in the Canyon ecosystem or other influences or factors. The objective of this program is to monitor these values and attitudes on an ongoing basis and to structure them to allow for quantitative analytical techniques and to determine possible changes in attitude or values in relation to dam operations.

Each affected Tribe should develop and implement a set of visitations on an annual basis. These visitations should include established sets of questions, determined by the Tribe and comparable over time, dealing with the Canyon resources. Questions and timing of visitations should be determined by each Tribe in cooperation with the organization responsible for the overall long-term monitoring program.

## Recreation

Recreational use of the Canyon is of economic and environmental importance. As a major use of the Canyon, recreation creates jobs and financial support within the region, but also is a significant component of impact analysis. The preferred alternative in the EIS has considered impacts on recreation and has attempted to enhance the recreational experience in the Canyon and increase safety. Also of importance are the possible impacts of recreation on Canyon resources. The objectives of the long-term monitoring program, therefore, are to determine whether recreation is enhanced and safety improved over impacts of the historic operation of the dam, and whether changes in recreational patterns resulting from the selected dam operational alternative have any effect on the Canyon.

To determine whether dam operations are affecting the pattern and amount of use in the Canyon, data on use and changes resulting from recreation would be compiled annually. Such data can be utilized to assess changes in use, but also may help determine causes of some changes in other resources (e.g., fish populations, and beach sizes or qualities, etc.). Recreation use data are available from or can be obtained through the National Park Service, Arizona Game and Fish Department, Native American tribes, and fishing guide, angler and boatman surveys, including the following: (1) Whitewater rafting, including commercial, private and tribal enterprises. Data would include user days, length of trip, put-in and take-out points, beaches used, and safety (accident) records. (2) Angler uses, including commercial and private use above Lees Ferry. Data would include angler user days, fish catch data, and safety (accident) records. (3) Miscellaneous uses, e.g., birdwatching, use of riparian habitats (both mainstem and tributaries) for hiking, sightseeing within the Canyon, etc. to be evaluated through National Park Service and Hualapai Tribe permitting records, Game and Fish surveys, and other means. Survey results would be summarized and evaluated annually.

Beach area data would be monitored using aerial video- or photography at the same discharge levels each year. Changes in beach camping area, above high discharge levels, can be determined through digitized video- or aerial photographs and validated on a sample basis through ground truthing coordinated with beach surveys under the sediment dynamics component of the long-term monitoring program.

To determine possible reasons for changes in recreational use, recreationist's values and concerns would be monitored on a five year basis or following unusual events. This information would be gathered using surveys of appropriate user groups. Value evaluation is separate from values determined using non-use value methodologies. The former deals directly with use and experiences in the Canyon while the latter are based on no direct contact with the Canyon.

Recreationists' values to be monitored using surveys that deal with the relative value of Canyon experiences include: (1) satisfaction with existing discharge levels, (2) perceptions of effects of dam operations, (3) attitudes about congestion at beaches or high level visitor sites, and (4) attitudes toward researcher/monitoring teams in the Canyon. Information gathered during the pre-long-term monitoring period would be used as the baseline for comparison and evaluation of change in these values and perceptions.

## Power, Economic and Financial Impacts

### Hydropower Supply

Hydropower supply is an integral part of the economy of the region. Changes in power operations resulting from changes in annual dam operations would affect the power supply and its costs. The objectives of this program are to determine the impact of changes in dam operations on hydropower outputs and the concomitant power marketing and economics of the region, a concern of those agencies tied to hydropower production.

Actual power generation would be monitored on an hourly basis as input to assessing the consequences of dam operations on power economics. Power generation is also a method for estimating water discharge rates and volumes.

### Economics and Finances

Long-term monitoring would include the maintenance of a current data base for future power resource economic reviews to determine the consequences of the anticipated changes in Glen Canyon Dam operations. A periodic review of the electric power market would determine whether new information supports decisions based upon previous forecasts. The Power Resources Committee (PRC) Phase II effort would be used as the basis for the periodic review. For each review, current measured parameters can be compared to the risk and sensitivity analysis work completed in Phase II studies. If the current measures or assumptions fall within the range of assumptions made in Phase II, then the impacts can be determined from this information. Conclusion can then be made regarding the degree of influence changes in certain measured parameters (i.e., load growth, fuel escalation rates) would have on the economic and financial impacts.

A more detailed review would involve assessing the significance of changes in the value or financial benefits of power and recreational uses which might impact the economic and social benefits of changes in Glen Canyon Dam (GCD) operation. A detailed review would take place when a different operational alternative for GCD is proposed. The decision to go to this level of analysis, based in part on a recommendation of the Adaptive Management Working Group, would be made on a case-by-case basis.

In preparation for these reviews, a data base of revenues, rates, supplies, purchases and loads must be established through monitoring the following parameters: (1) annual revenue requirements of Western Area Power Administration (Western), (2) rate charges for

Western wholesale power, (3) regional power supply adequacy for Western Systems Coordinating Council (WSCC) annual reports (moving, 10-year projection), (4) historical regional power loads from WSCC, (5) annual evaluation of costs of power purchases and sales within and outside the region available from EIA, (6) updates of utility data already collected by the PRC.

Concomitant with evaluation of impacts on power revenues, should be an evaluation of impacts on the economics and revenues of other uses of Glen and Grand Canyon. These uses especially include recreational revenues, but changes in other regional revenue sources resulting from the selected dam operation would be considered.

The detailed review would follow procedures established by the PRC of Glen Canyon Environmental Studies to evaluate the economic impacts of various dam operation alternatives for the Glen Canyon EIS. If required, additional transmission related and short-term operational reviews may be necessary with any further changes at Glen Canyon Dam.

Evaluation of the non-use values of the Glen and Grand Canyon riverine system would also be part of the economic and financial component of the long-term monitoring program. It is possible that the public's perception of the Canyon may change as a result of the future operations of Glen Canyon Dam; thus it is valuable to determine this perception through use of non-use economic methodologies.

## LITERATURE CITED

(An extensive reference listing of ecological and environmental impact studies within Glen and Grand Canyons can be found in the EIS.)

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## ADDENDA

### Addendum 1.
### Background and Input Attributes and Benchmark (Unaffected) Sites

Background and input attributes are those factors whose variation may be used to help explain changes in the mainstem Colorado River corridor ecosystem. They occur or are located above and/or below the dam, but are not those attributes along the mainstem corridor influenced by dam operations. Information on background and input attributes is important to archive for use by the long-term monitoring program on effects of dam operations, however, gathering of this information is not part of that program.

#### The Role of External Factors and Benchmark (Unaffected) Sites

Although long-term monitoring of the Grand Canyon ecosystem may detect temporal change which might be associated with dam operations, other possible causative factors, such as climate, will exist. Thus, identification of external factors that may be regularly monitored for other purposes such as climatological data, and identification and monitoring of unregulated analogues to the Grand Canyon ecosystem could provide an opportunity to distinguish "natural" change from dam-related change.

Benchmark (unaffected) sites are locations that might be considered as control sites similar in geomorphology to the Grand Canyon that can be used to analyze differential influences of dam and non-dam variables. Unfortunately, there is insufficient scientific data on which to identify unregulated analogues to the Grand Canyon at this time. Candidate areas include Cataract Canyon and the Grand Canyon tributaries. The latter are only relevant for biological parameters. Research should be considered in Cataract Canyon to determine its possible analogue status as an "unregulated Grand Canyon". At a later time, the National Park Service might propose a companion Cataract Canyon monitoring program as one basis for interpreting environmental change in Grand Canyon.

Some ecological monitoring of tributary conditions in Grand Canyon is included in this program, however, such efforts would be limited. Further research is necessary to determine the nature of appropriate comparisons between the "big river ecosystem" of the Colorado River and the "small river ecosystems" of the tributaries.

The external factors that would be used for differentiating between natural and dam caused changes are discussed below.

Meteorology/Climate

Regional Meteorology/Climate. Hydrology of the Glen Canyon/Grand Canyon region is a consequence of regional precipitation and temperature patterns. Tributaries, especially the Little Colorado River, Paria River and Kanab Creek, are all important in the dynamics of the river. As part of the background data base for long-term monitoring, and for interpreting different causes of change in the Colorado River ecosystem, it is essential to include climatological data from NOAA weather stations that influence major tributaries to the Colorado River above and below Glen Canyon Dam. The minimum set of climatological stations would include: Page, Jacob Lake, Kanab, Cameron, Supai, Pipe Springs NM and Peach Springs. Additional stations at the headwaters of the Little Colorado River, Kanab Creek and Paria River would also be considered. When necessary, data from stations at the headwaters of the San Juan, Green and Colorado Rivers would be archived.

Hydrometeorology. In addition to climatological data, it is essential to archive information on hydrometeorological changes. These include not only precipitation (part of climatological data), but snowpack and runoff in the major tributaries to Lake Powell and the Colorado River below Glen Canyon Dam. Hydrometeorological data are presently collected for some of the tributaries of Lake Powell. Snowpack measurements are also a regular part of the predictive models used by the Bureau of Reclamation in its forecasts for annual and monthly releases of water from Glen Canyon Dam. These data, however, would not only be used for predictive purposes but as part of the overall data set archived for the monitoring program.

Local Microclimate. There is a very limited set of local meteorological stations in the Grand Canyon, the primary one being at Phantom Ranch (Grand Canyon NP). Changes in the Colorado River riverine/riparian ecosystem may be a response to non-anthropogenic environmental changes as well as changes or influences from dam operations. As part of its inventory and monitoring program, NPS would need to upgrade and add to local climatological stations to give adequate coverage for interpreting local climatological influences. The Phantom Ranch station would be instrumented to measure solar radiation in addition to temperature and precipitation. Complete weather stations would be established at Lees Ferry. The Hualapai Tribe should add a complete weather station at Diamond Creek near the river as part of its long-term resource studies. Other stations within the Canyon, for example, Indian Gardens, would be upgraded to full climatological station status. Data from these stations then become part of the background archives for the long-term monitoring program. The importance of upgrading or adding climatological stations for data input into the long-term monitoring program cannot be over emphasized. There is such a critical need for this information, for example, the affects of solar insolation and canyon temperature on water temperature, that this effort would be considered as an integral part of the long-term monitoring program.

**Addendum 2.**
**Information Management**

## Characteristics of Long-term Monitoring

Essential to any long-term monitoring program is that it addresses management needs, specifically, it would be designed to ensure that management objectives are being met. It would also be designed to recognize the temporal characteristics of the system being monitored. In the case of the Grand Canyon, long-term monitoring in response to operations of Glen Canyon Dam would continue indefinitely, or as long as the dam is operable. Periodic review of the program is necessary to determine the intensity of the monitoring program. The potential longevity of this program would be recognized in the selection or establishment of institutions that can maintain continuity while carrying out monitoring activities. Because continuity in methodology and procedures is essential to ensure comparability of data, no monitoring activity should be based on the sole contributions of any one individual but would be aligned with an agency or long-term organization.

Monitoring activities must also recognize the spatial scale of the resources. The enormity of Grand Canyon requires that projects actually be a sample, and that an hierarchy of spatial scales (e.g., nesting or representative sample units) would be used. Selection of sample units or areas would also consider the sensitivity or fragility of the system, thus methodologies would leave as small a "foot print" as possible. The type, frequency and location of measurements would, however, invariably follow from the objectives of the long-term monitoring program.

Lastly, the long-term monitoring program would be sufficiently flexible to permit initiation of "new" monitoring activities to respond to transient events such as floods or tributary sediment pulses, and to changes in direction which may result from changes in management goals.

## Development of Long-term Monitoring Activities

Potential use and integrity of monitoring activities is dependent on their initial procedural design. Each proposed monitoring activity must be reviewed by other workers prior to implementation to ensure comparability of data, prevent overlapping efforts, and to encourage interaction and integration by using comparable spatial and temporal boundaries. Considerable resources would need to be devoted to careful documentation of procedures, quality assurance and quality control (QA/QC), definition of variability (i.e., defining uncertainty), etc. This would reduce the total amount of data which can be collected, but it is necessary to provide the documentation for future data use and interpretation.

All participants in the long-term monitoring program must be required as a condition of participation to have their data internally and externally reviewed and entered into a common data base system on a regular and timely basis. Field data must be carefully referenced to known, consistent locations (georeferenced). These reference points must be consistent among monitoring and research activities, and included as an integral part of the GIS data management system.

Effective monitoring activities must be based on a thorough knowledge of the physical and biological characteristics of the system. Because the baseline information may be limited for some areas and resources, and methodologies may not be fully tested, many activities would be initiated as "pilot projects" and the comparability of the data tested before being settled upon as a major part of the long-term monitoring program. Trade-off between minimum detectable effects and monitoring efforts and costs must furthermore be accepted as part of the evaluation procedures for selection of monitoring projects within the long-term monitoring program.

**Protocols for Data Collection and Processing**

Each component of the long-term monitoring program must have an explicit, detailed protocol which spells out: (1) objectives, (2) experimental design, (3) procedures for data collection, QA/QC, data analysis, data storage, and reporting. This allows anyone to replicate measurements and to evaluate them in a consistent statistical manner. Where appropriate, each experimental design would be evaluated for statistical integrity. The protocol for each component would specify the level of knowledge and training required for those collecting field data, analyzing samples, entering data, and interpreting the data. There would be a comparable protocol for managing the data base.

Scientists collecting the data would be involved with data interpretation. Although the time frame of the long-term monitoring program extends well beyond the participation period of any one scientist, it is anticipated that those who collect the data would be familiar with the Grand Canyon and may use the data as part of ongoing research programs. This connection of data collection and interpretation would result in data being collected appropriately and efficiently.

Releasing and sharing data must be a requirement for every project. Those collecting original information, however, should be allowed a reasonable time for analysis and publication before releasing the data to the public. Trust must be established among data collectors and managers to ensure transfer and integration of information. Each monitoring project would prepare an annual report using a consistent and defined format, including reports from data base managers.

**Data Base Management**

A general principle is that all data would be freely available. In some cases, however, such as archaeological-site data, data that Indian Tribes define as sensitive, or information on localized endangered species, a level of confidentiality may be necessary.

A centralized, integrated data base is necessary to avoid duplication of effort and facilitate exchanges of information among projects. This includes incorporation of information from past monitoring, inventories and research. Each file in the data base must be cross-referenced to files which document data-collection procedures, variability, and uncertainties. All data would be copied and stored in at least two locations to maximize security.

Certain kinds of data and collected information are unsuitable for storage in a traditional computerized data base. These include audio and video recordings, for example, as well as biological and geological specimens and copies of historical literature and photographs. This information and collections need to be archived following procedures appropriate to their unique characteristics, and cross-referenced to other information.

**Management of the Monitoring Program**

The resource management agencies and interests have established an Adaptive Management Working Group that would oversee the management and archiving of the long-term monitoring program and data (see chapter in EIS). This group would evaluate the findings of the long-term monitoring program. This evaluation may lead to recommendations for changes in dam operations to ensure compliance with the objectives of the 1992 Grand Canyon Protection Act.

Although no specific institution has been selected for the actual management of the long-term monitoring program or archiving of monitoring information, an organizational structure needs to be set in place prior to initiation of any phase of long-term monitoring of the effects of Glen Canyon Dam operations. It would need to absorb the ongoing program of the Glen Canyon Environmental Studies which has managed data collection efforts to date and has embarked on an information management program as well (Scientific Information Management system - SIM).

**GIS and Remote Sensing**

The use of Geographic Information Systems (GIS) for data storage is an important component of the data management process; however, not all data can be put into GIS format. GIS can be an important analytical tool for integrating and comparing spatially based data, but the applicability of this technique would depend upon the particular objectives of each monitoring project. Each project would specify which GIS data layers are required.

The validity of the existing GIS reaches in the Canyon would be tested for representativeness or designation as critical reaches. Usefulness of these reaches for the long-term monitoring program would be evaluated once the objectives and priorities for long-term monitoring are established. The use of satellite and remote sensing (e.g., aerial video- and photography) data would also be evaluated relative to the level of detail needed for each monitoring project (satellite data would probably be too coarse for use in monitoring in the Canyon).

Appendix B

# Hydrology

# Contents

## Contents

## Introduction

The purpose of this hydrology appendix is to supplement hydrologic information in the main EIS document as well as to provide more technical and detailed hydrologic information for the reader who is interested in such detail. Generally, no interpretations or conclusions are provided, other than those presented in the main EIS document. Most information is presented in frequency curve formats, however, tables or pie charts are also included for some parameters. Also, a text discussion is provided concerning downstream transformation of fluctuating releases.

Hydrologic information is included to provide the following perspectives:

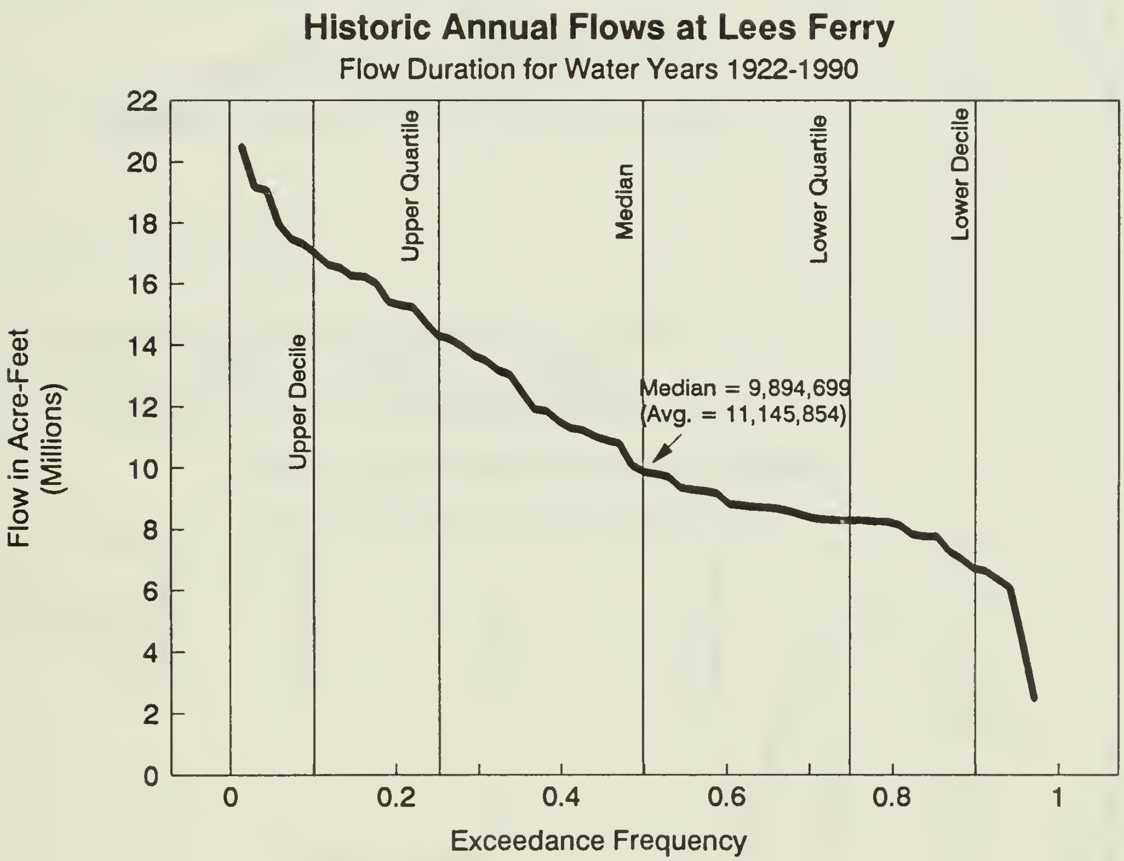
1. Predam conditions compared to postdam conditions.
2. Conditions under postdam operations compared to computer model-projected conditions under alternative future operations.
3. Frequencies of Colorado River streamflows (water releases) on hourly (including minimums, maximums, and fluctuations), daily, monthly, seasonal and annual bases.
4. Frequencies of lake Powell and lake Mead reservoir storage levels on monthly and annual bases.
5. Frequencies of Upper and Lower Basin and Mexico water depletions.
6. Example scheduling of Habitat Maintenance Flows and Beach/Habitat Building Flows.
7. Discussion of Downstream transformation of fluctuating releases.

Historic data were available from either United States Geological Survey publications or from records of the Bureau of Reclamation's Upper Colorado Region. Projected future annual and monthly operations data were generated by the Colorado River simulation system computer model. Projected hourly operations data were generated by the Environmental Defense Fund's Peak Shaving Model for the Power Resources Committee of the Glen Canyon Environmental Studies.

Frequencies of

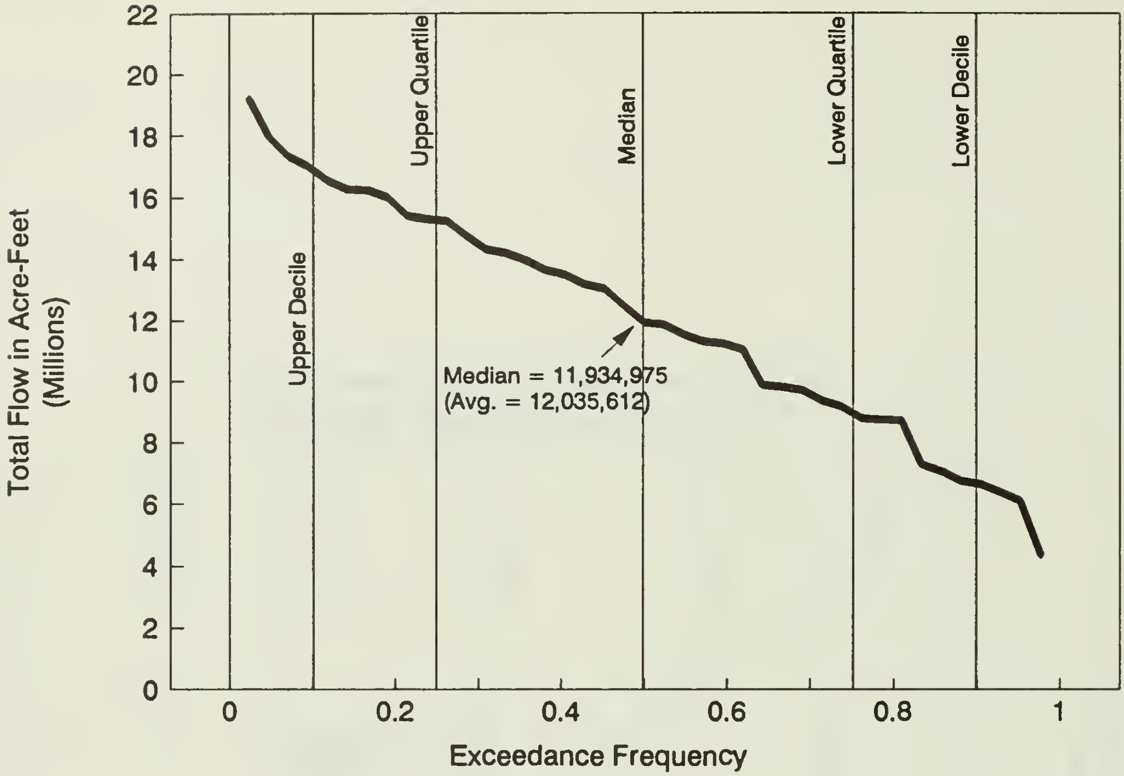
# Historic Annual Flow Volumes at Lees Ferry (acre-feet)

A. All Years (1922-1990)(1 frequency graph)
B. Predam (1922-1962) (1 frequency graph)
C. Postdam (1963-1990) (1 frequency graph)


Historic Annual Flows at Lees Ferry
Flow Duration for Water Years 1922-1990
Flow in Acre-Feet (Millions)
22
20
18
16
14
12
10
8
6
4
2
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 9,894,699
(Avg. = 11,145,854)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

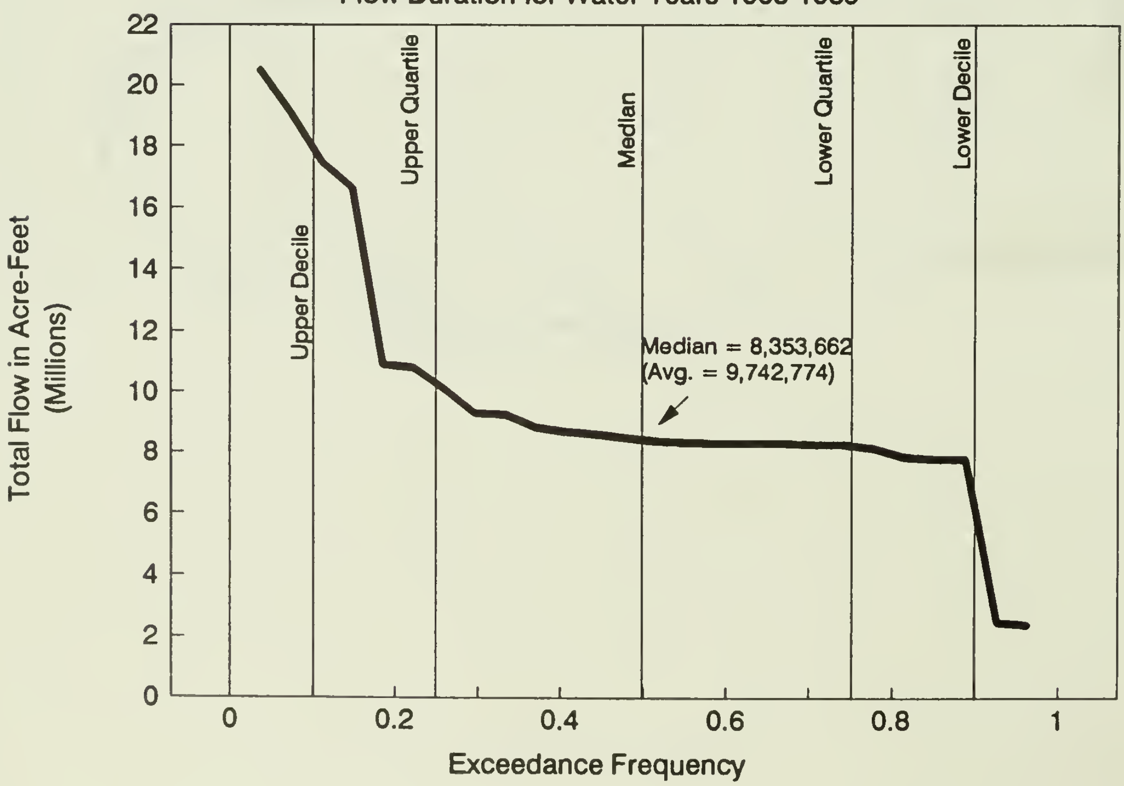
## Historic Annual Flows at Lees Ferry

Flow Duration for Water Years 1922-1962




## Historic Annual Flows at Lees Ferry

Flow Duration for Water Years 1963-1989



Frequencies of

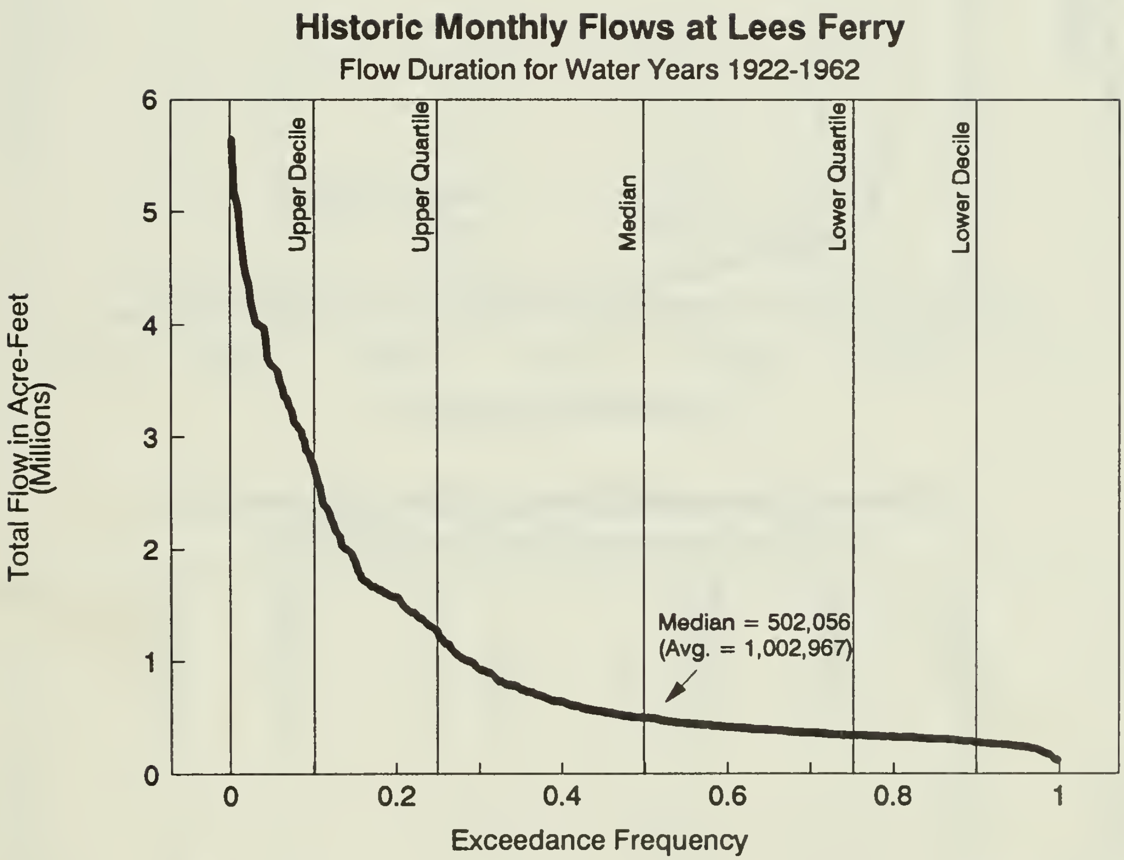
# Historic Monthly Flow Volumes at Lees Ferry (acre-feet)

A. Predam (1922-1962)

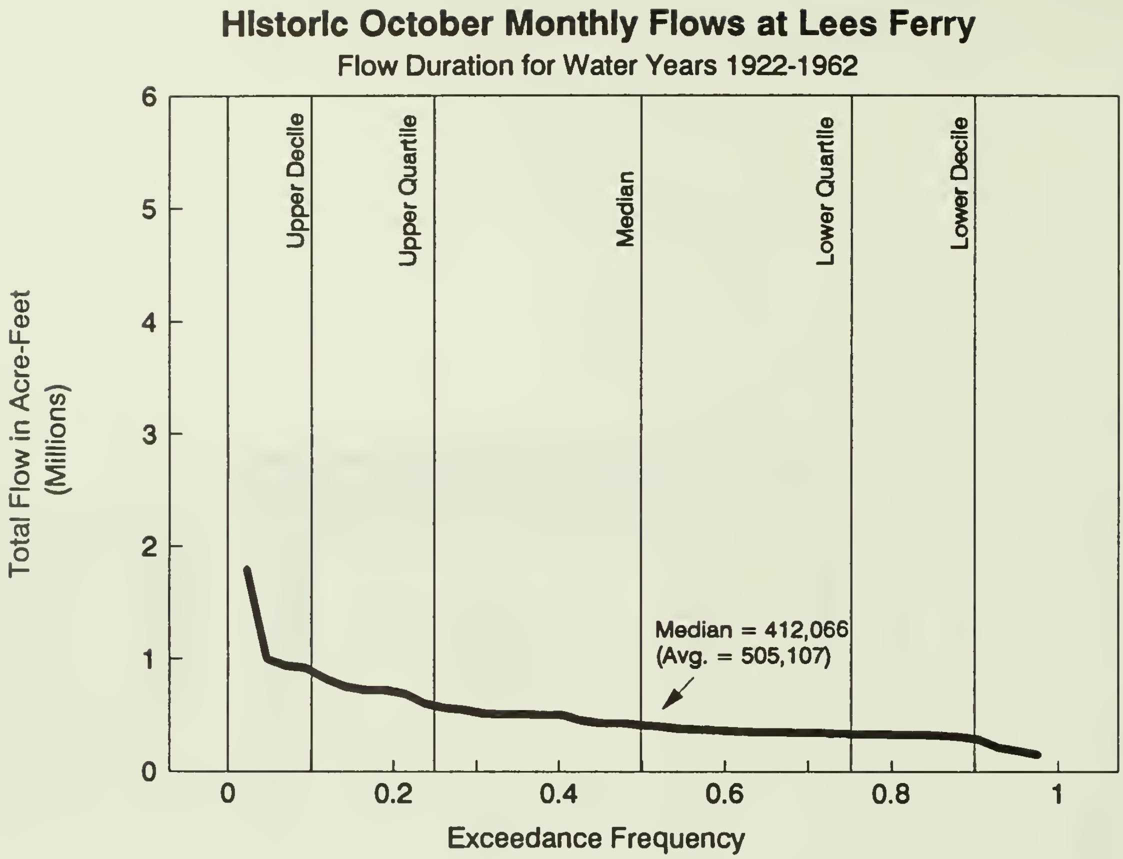
1. All Months (1 frequency graph)
2. Individual Months (12 frequency graphs)

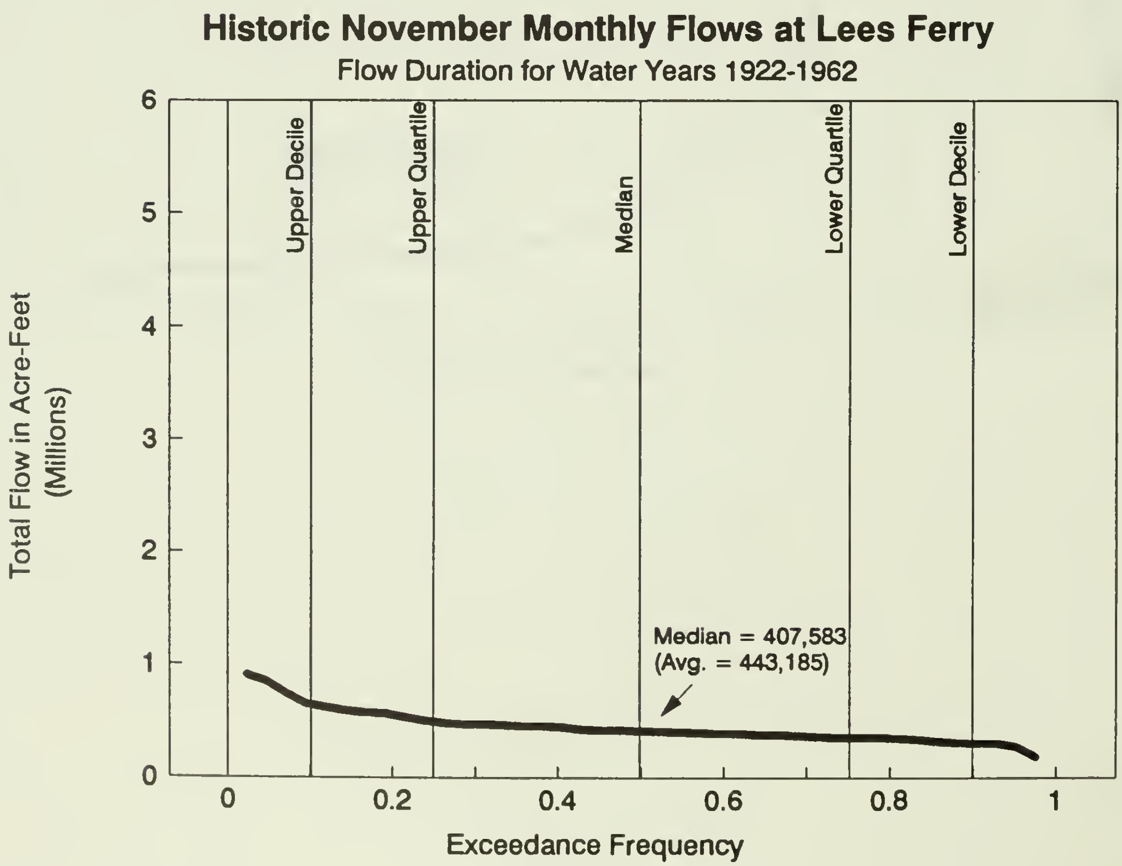
B. Postdam (1963-1990)

1. Pie Chart Summaries by Season
2. All Months (1 frequency graph)
3. Individual Months (12 frequency graphs)



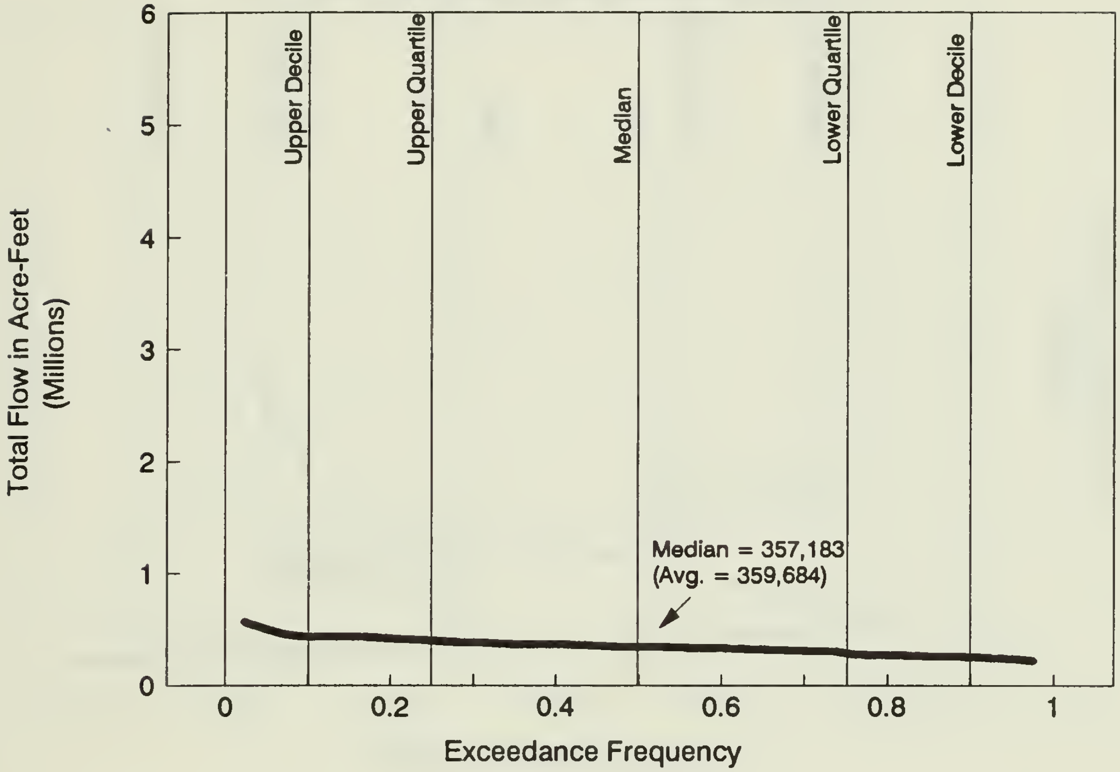
Historic Monthly Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Total Flow in Acre-Feet (Millions)
6
5
4
3
2
1
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 502,056
(Avg. = 1,002,967)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency


Historic October Monthly Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Total Flow in Acre-Feet (Millions)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 412,066
(Avg. = 505,107)


Historic November Monthly Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Total Flow in Acre-Feet (Millions)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 407,583
(Avg. = 443,185)

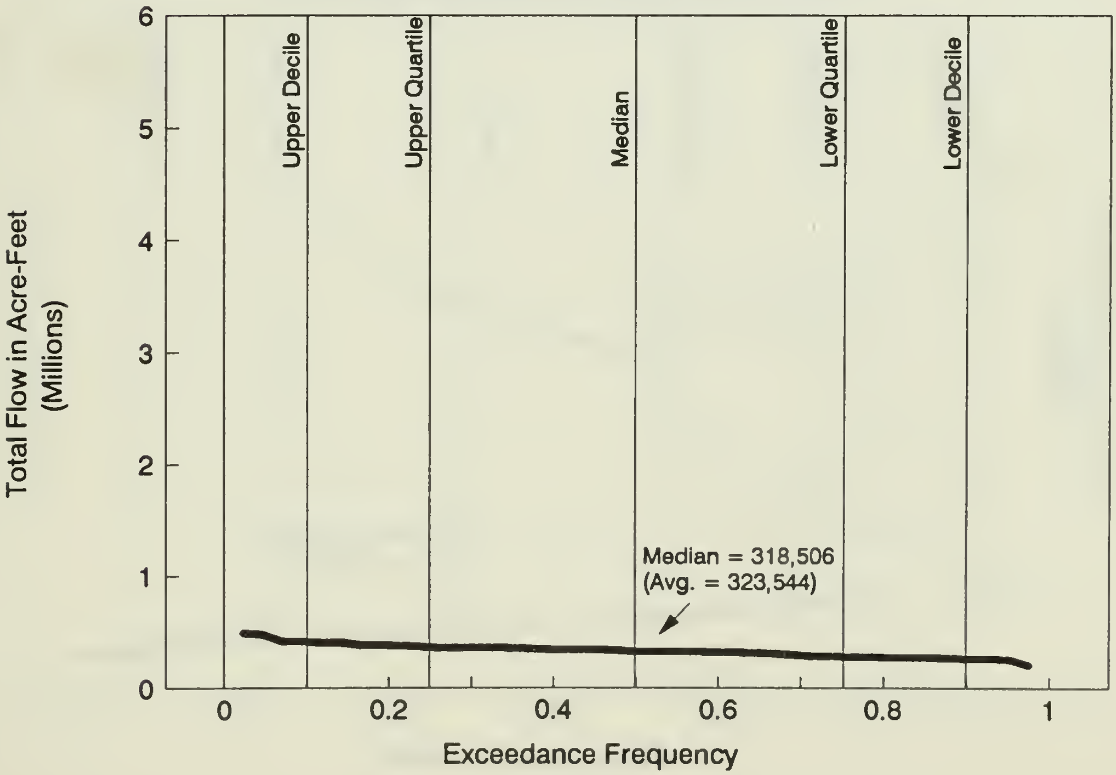
## Historic December Monthly Flows at Lees Ferry

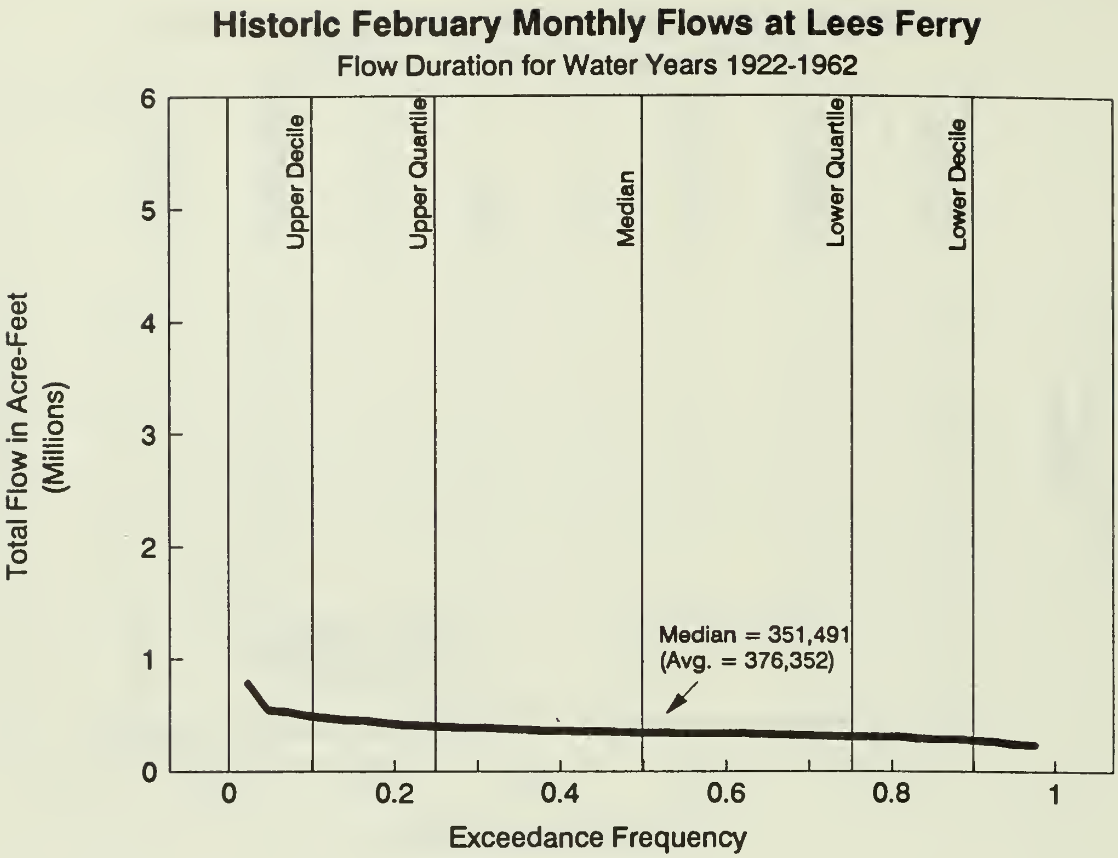
Flow Duration for Water Years 1922-1962

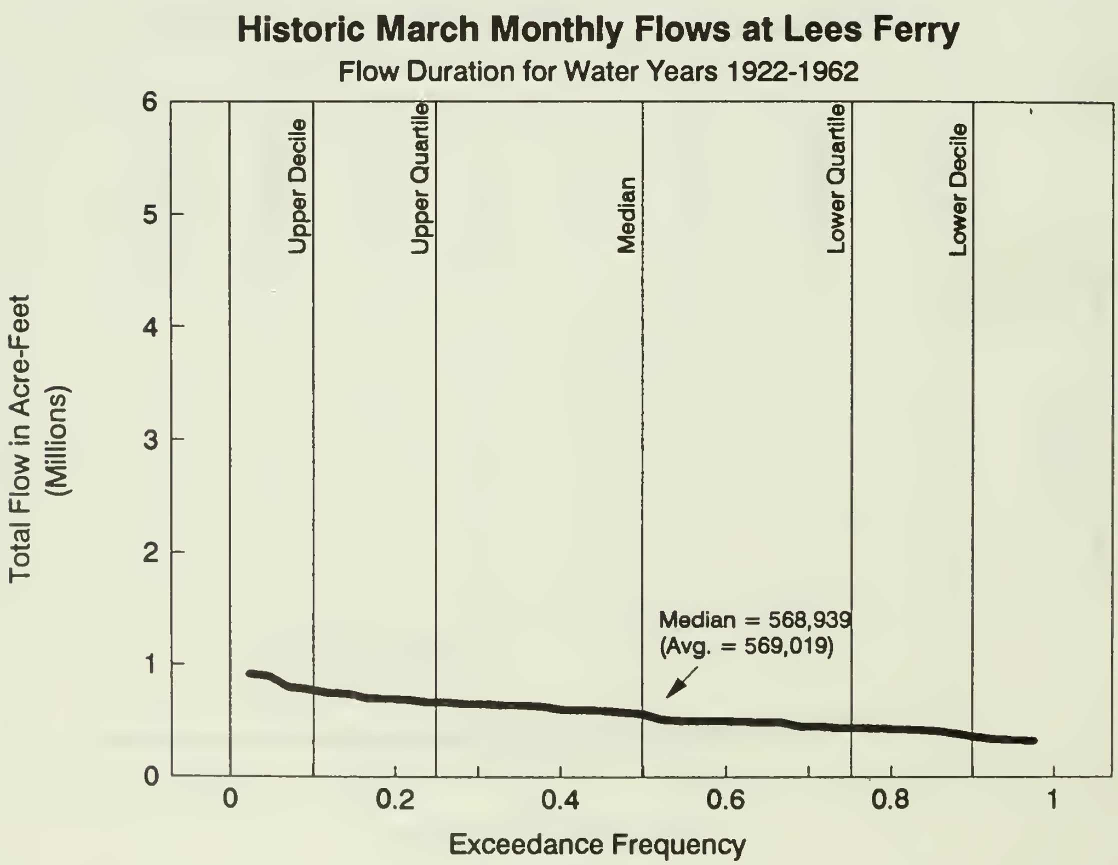



## Historic January Monthly Flows at Lees Ferry

Flow Duration for Water Years 1922-1962

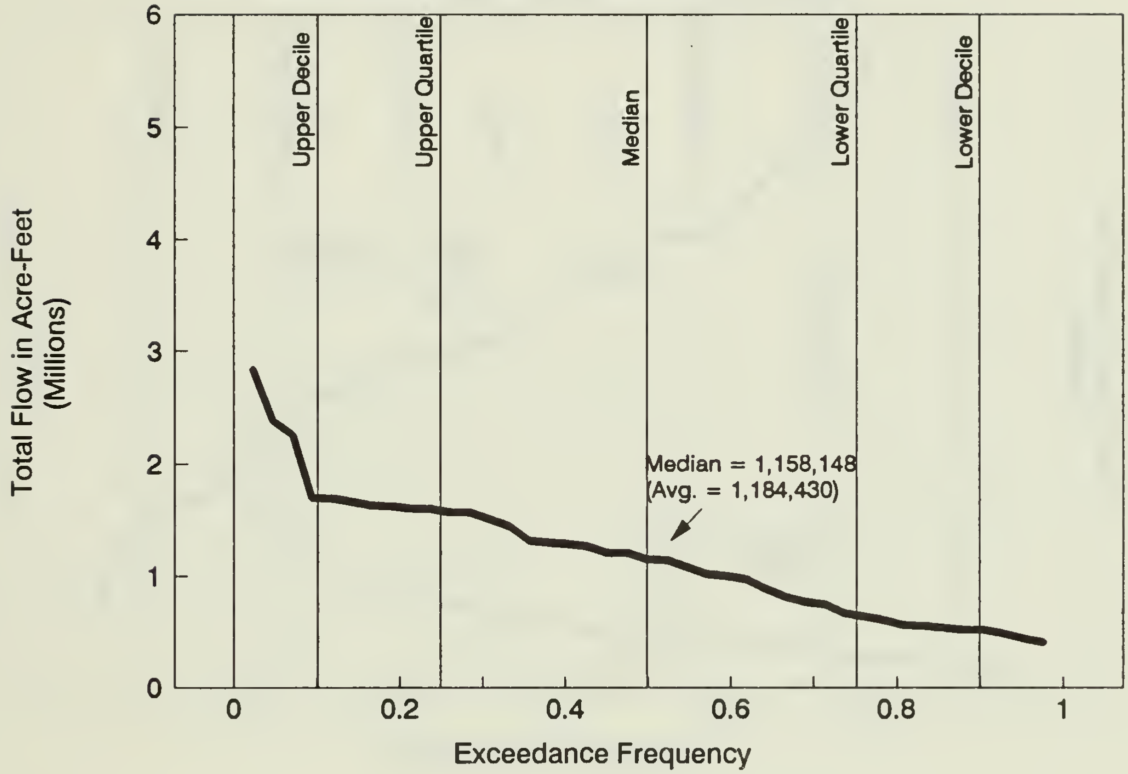



Historic February Monthly Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Total Flow in Acre-Feet (Millions)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 351,491
(Avg. = 376,352)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1


Historic March Monthly Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Total Flow in Acre-Feet (Millions)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 568,939
(Avg. = 569,019)
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1

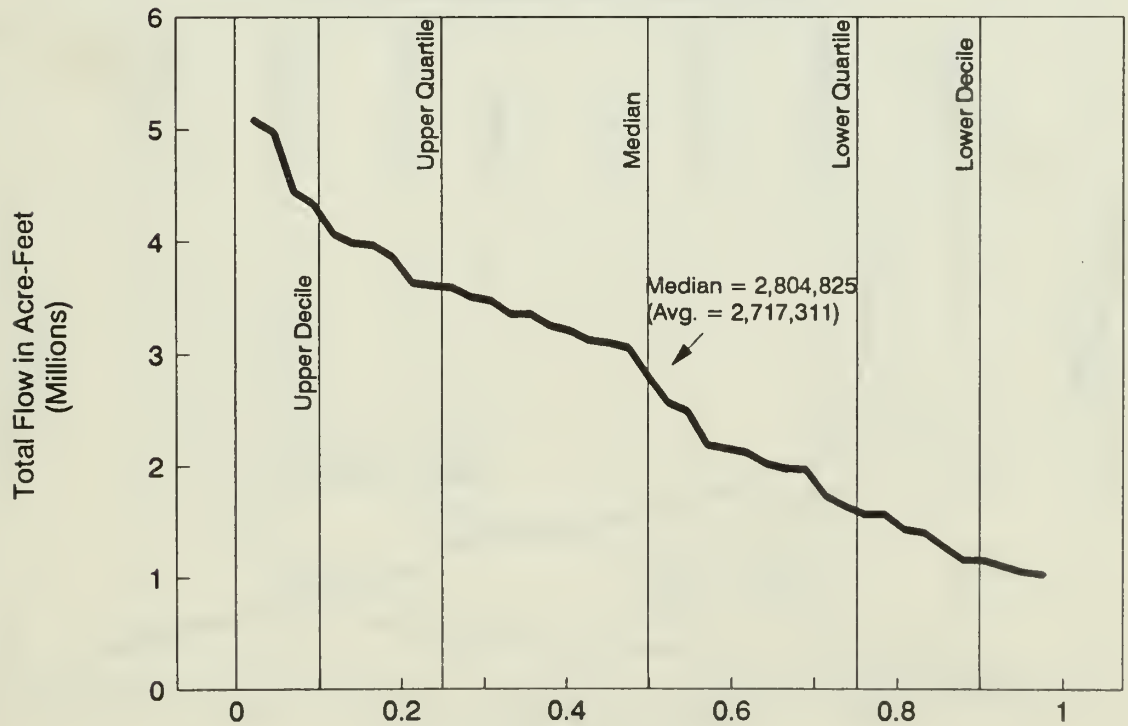
## Historic April Monthly Flows at Lees Ferry

Flow Duration for Water Years 1922-1962



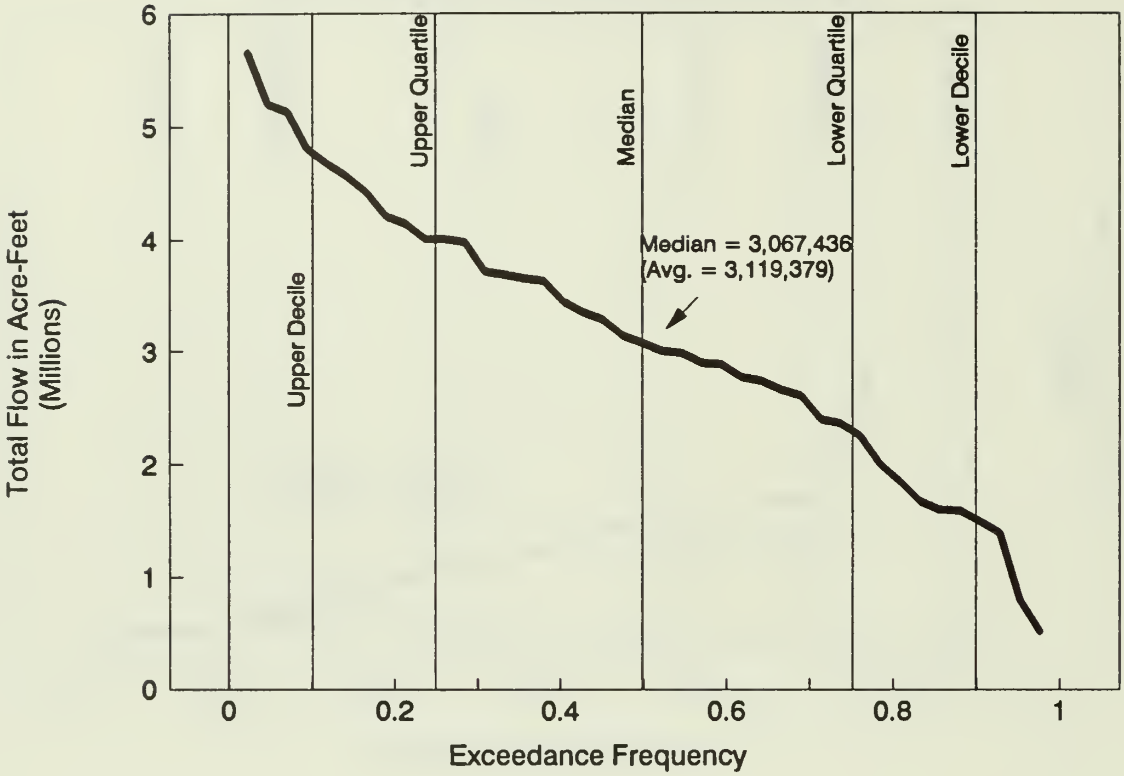

## Historic May Monthly Flows at Lees Ferry

Flow Duration for Water Years 1922-1962



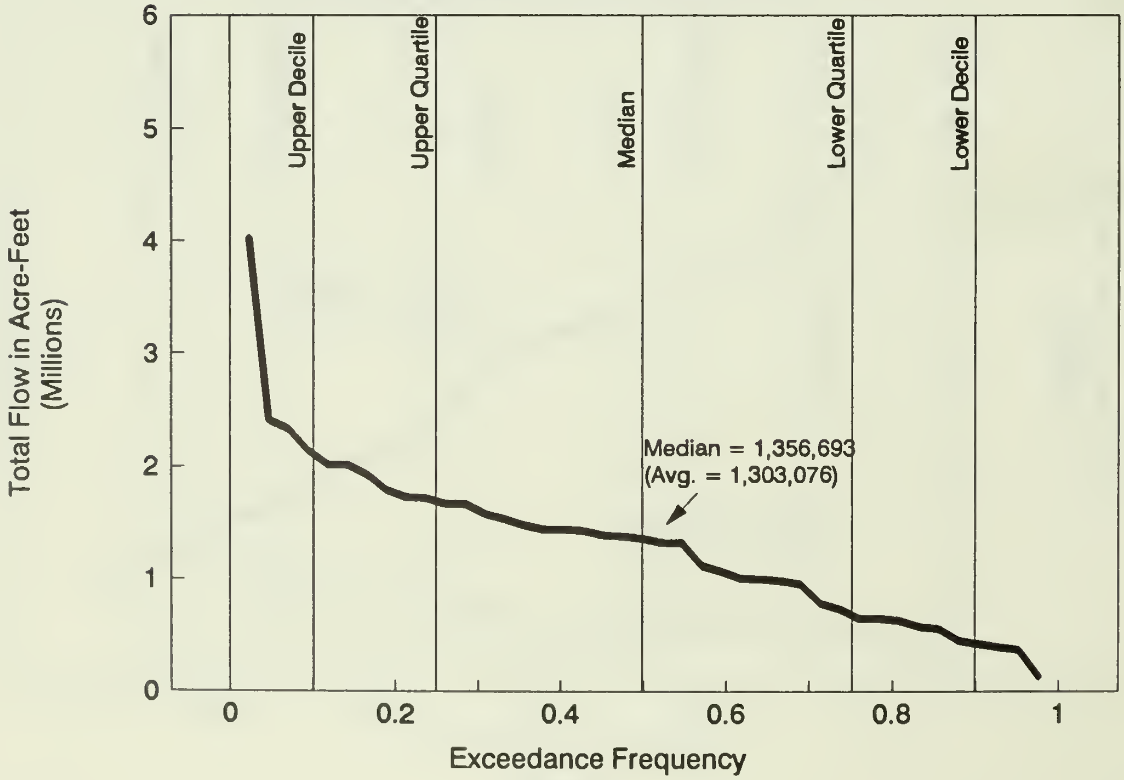
## Historic June Monthly Flows at Lees Ferry

Flow Duration for Water Years 1922-1962



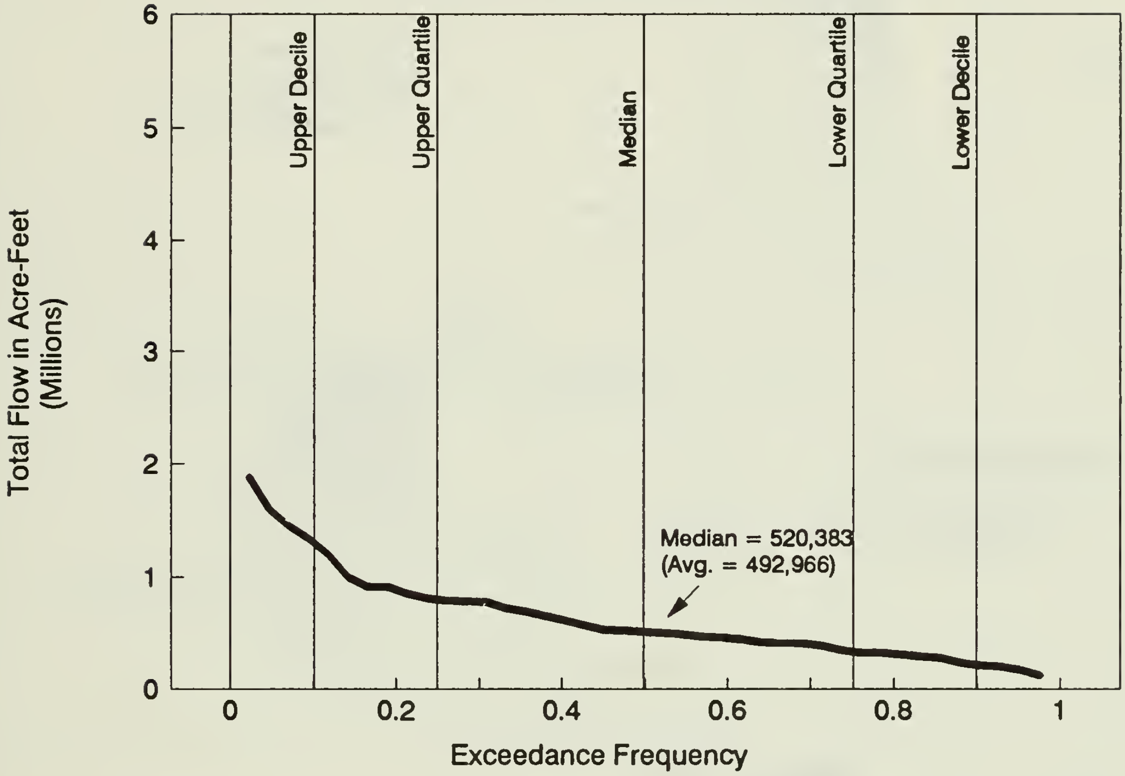

## Historic July Monthly Flows at Lees Ferry

Flow Duration for Water Years 1922-1962



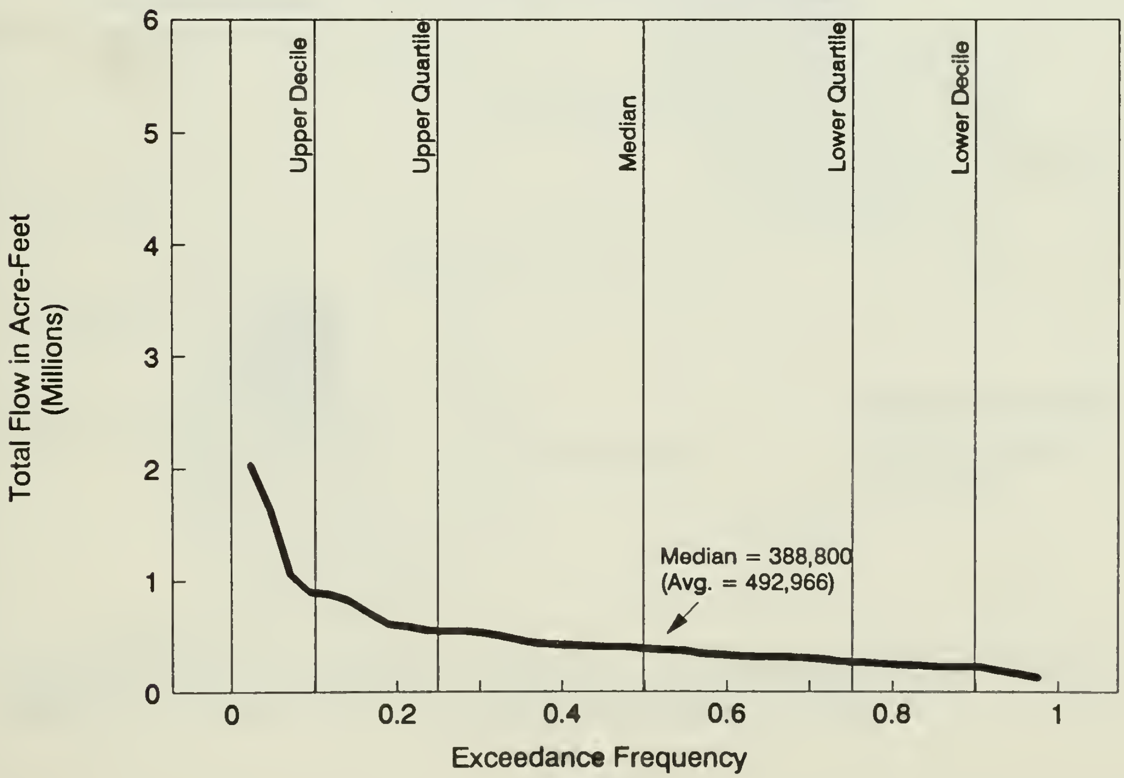
## Historic August Monthly Flows at Lees Ferry

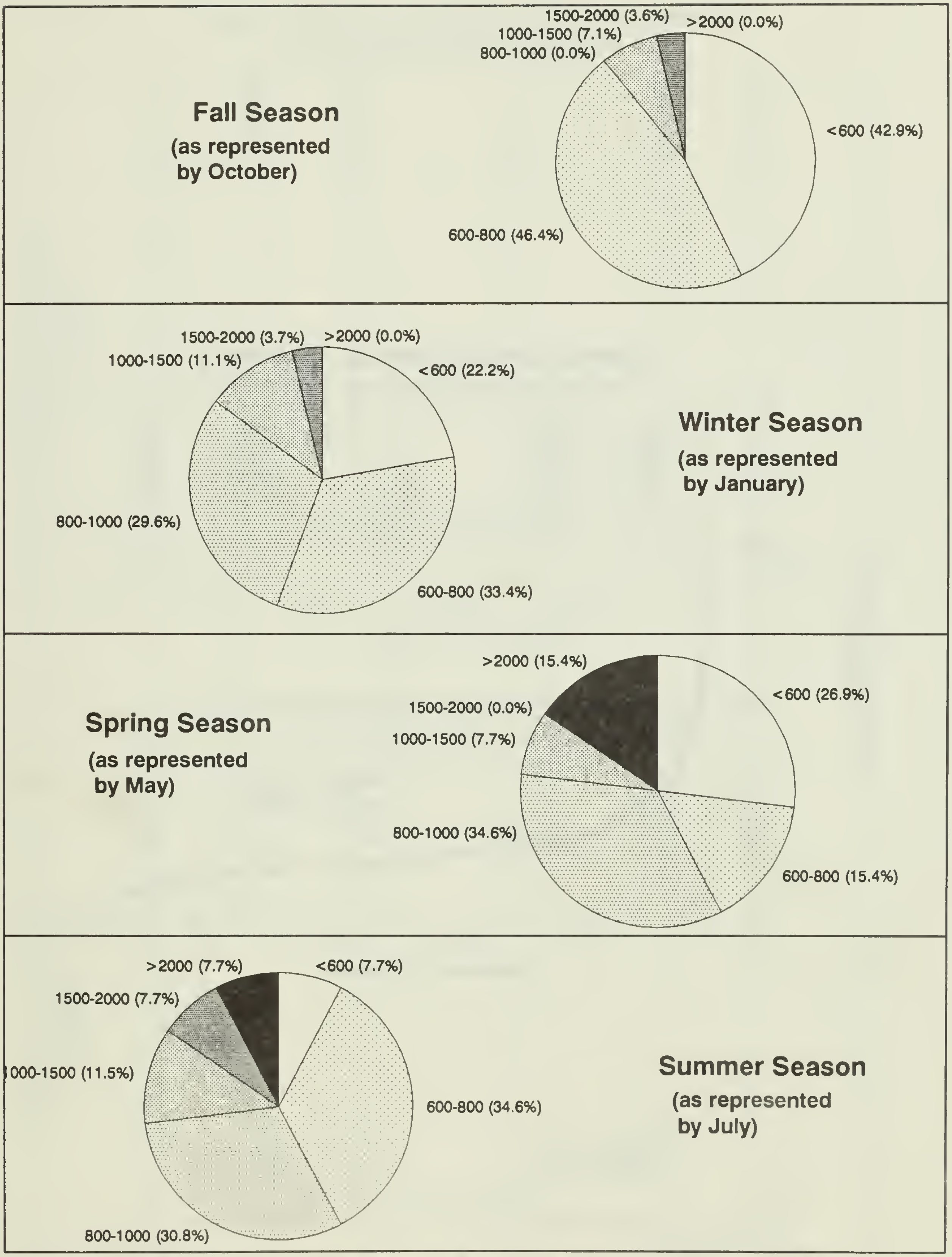
Flow Duration for Water Years 1922-1962



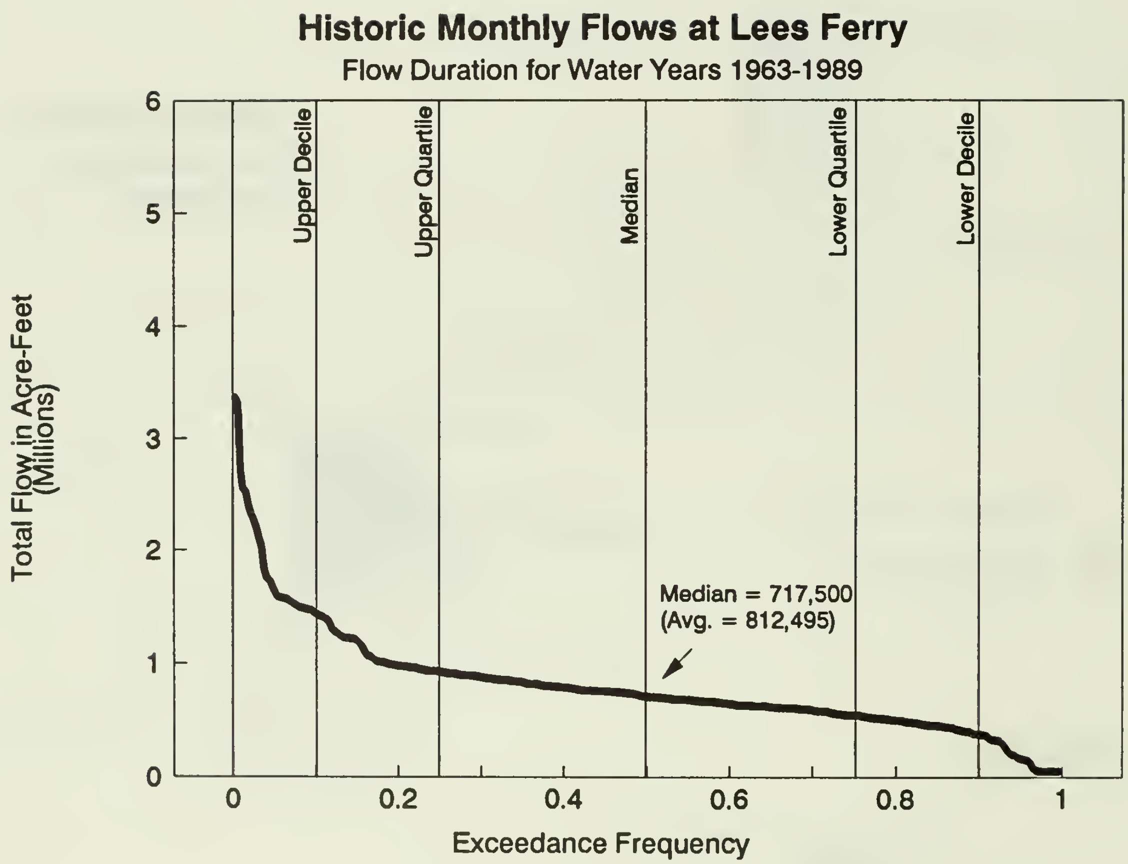

## Historic September Monthly Flows at Lees Ferry

Flow Duration for Water Years 1922-1962





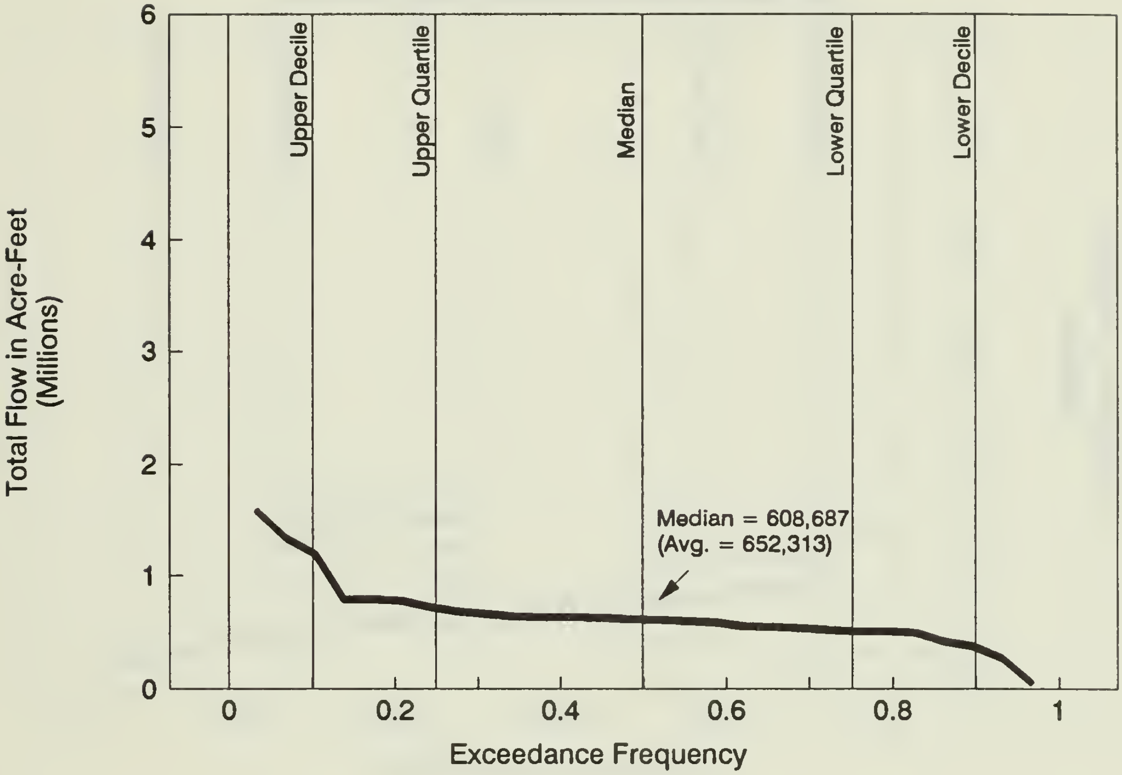

**Historic (1965-90) monthly releases from Glen Canyon Dam (1000 af)**
**(percent of months that the specified releases occurred)**



Historic Monthly Flows at Lees Ferry
Flow Duration for Water Years 1963-1989
Total Flow in Acre-Feet (Millions)
6
5
4
3
2
1
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 717,500
(Avg. = 812,495)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

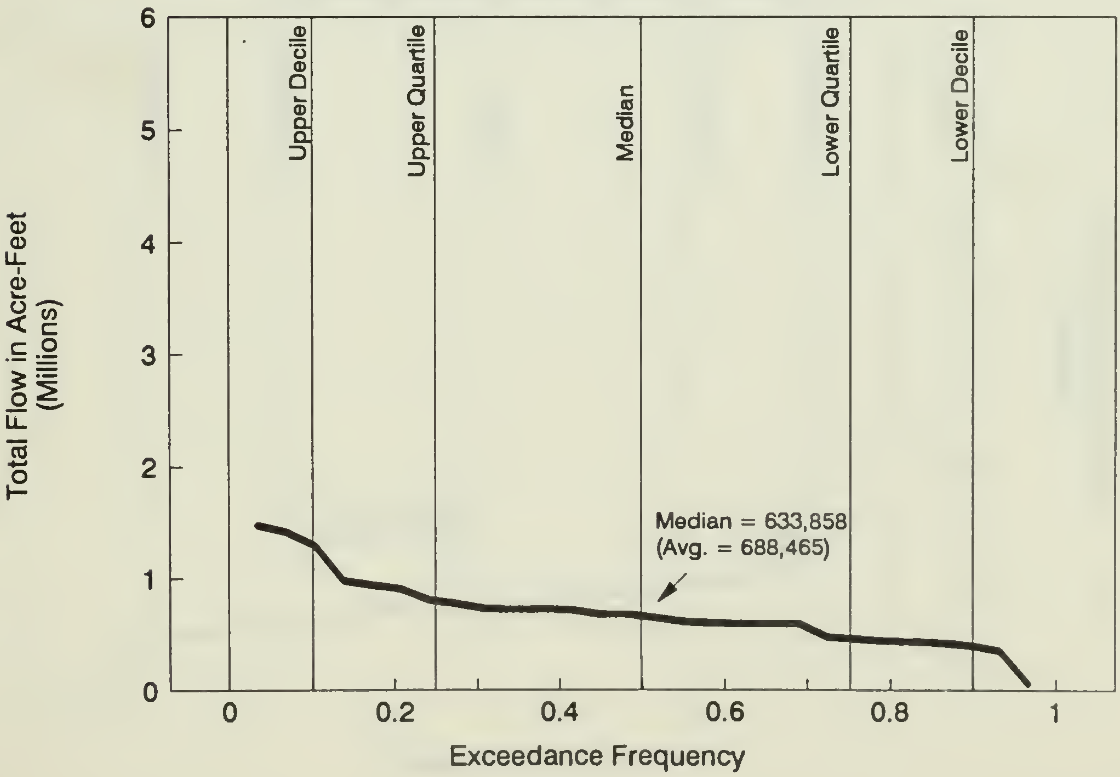
## Historic October Monthly Flows at Lees Ferry

Flow Duration for Water Years 1963-1990



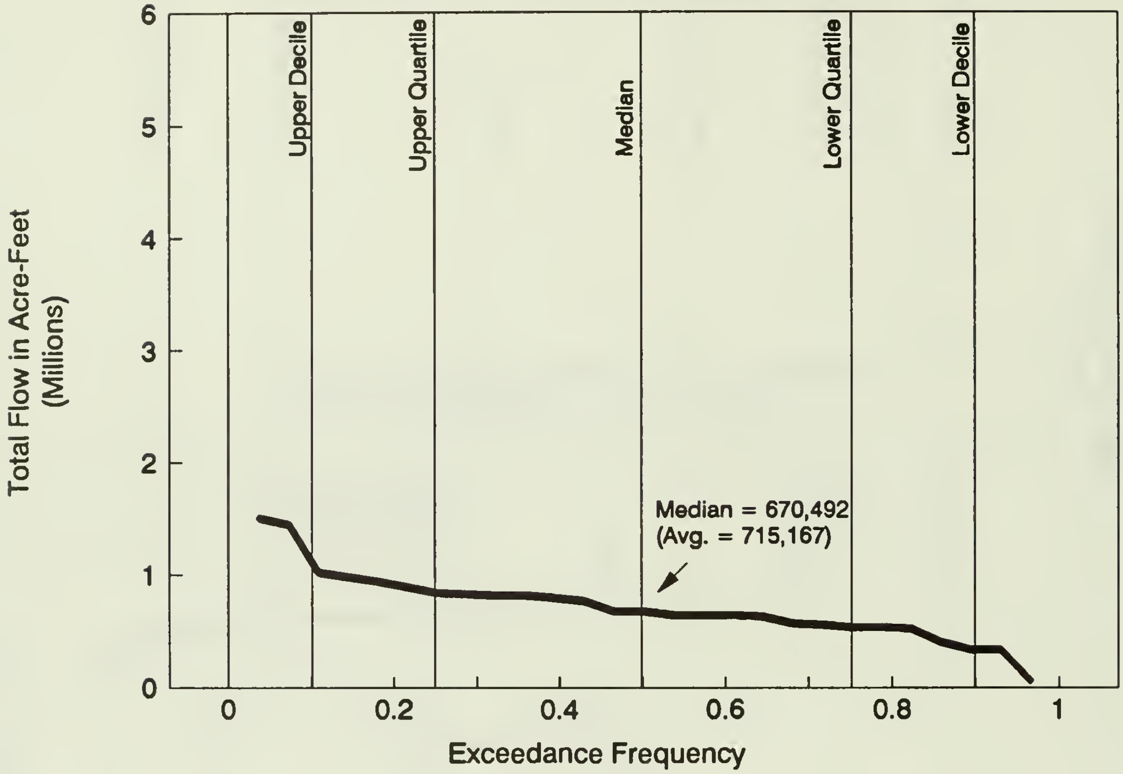

## Historic November Monthly Flows at Lees Ferry

Flow Duration for Water Years 1963-1990



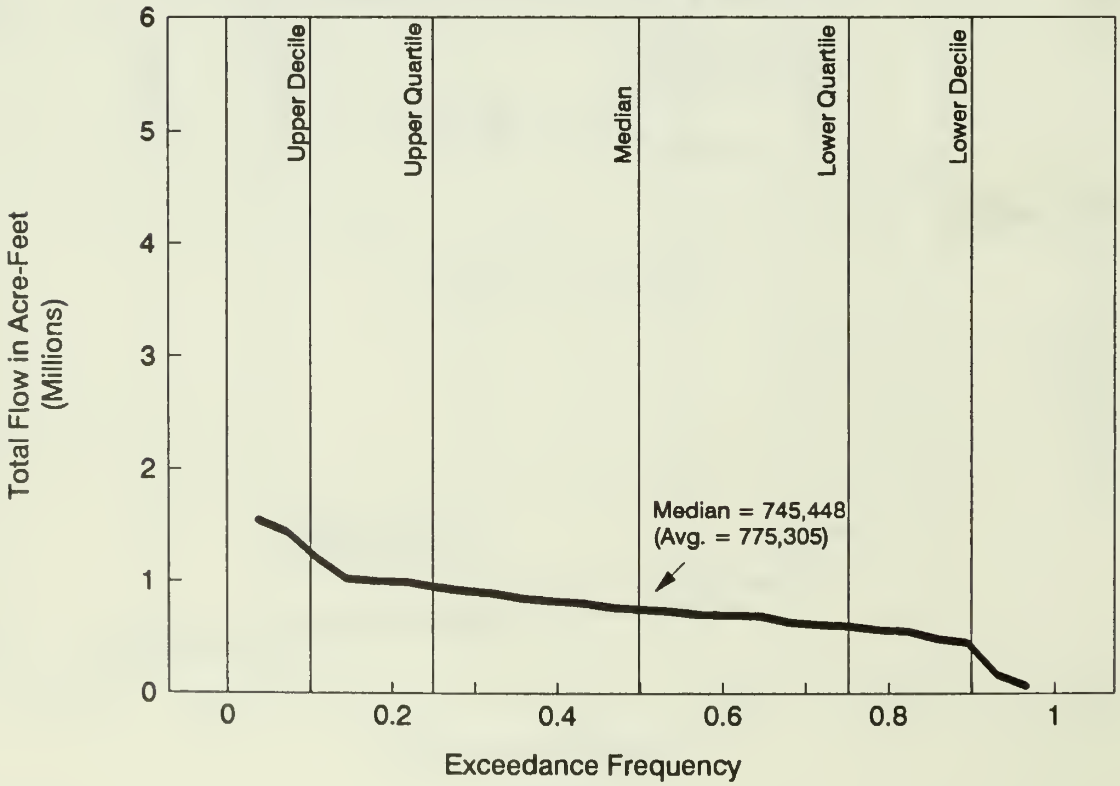
## Historic December Monthly Flows at Lees Ferry

Flow Duration for Water Years 1963-1990



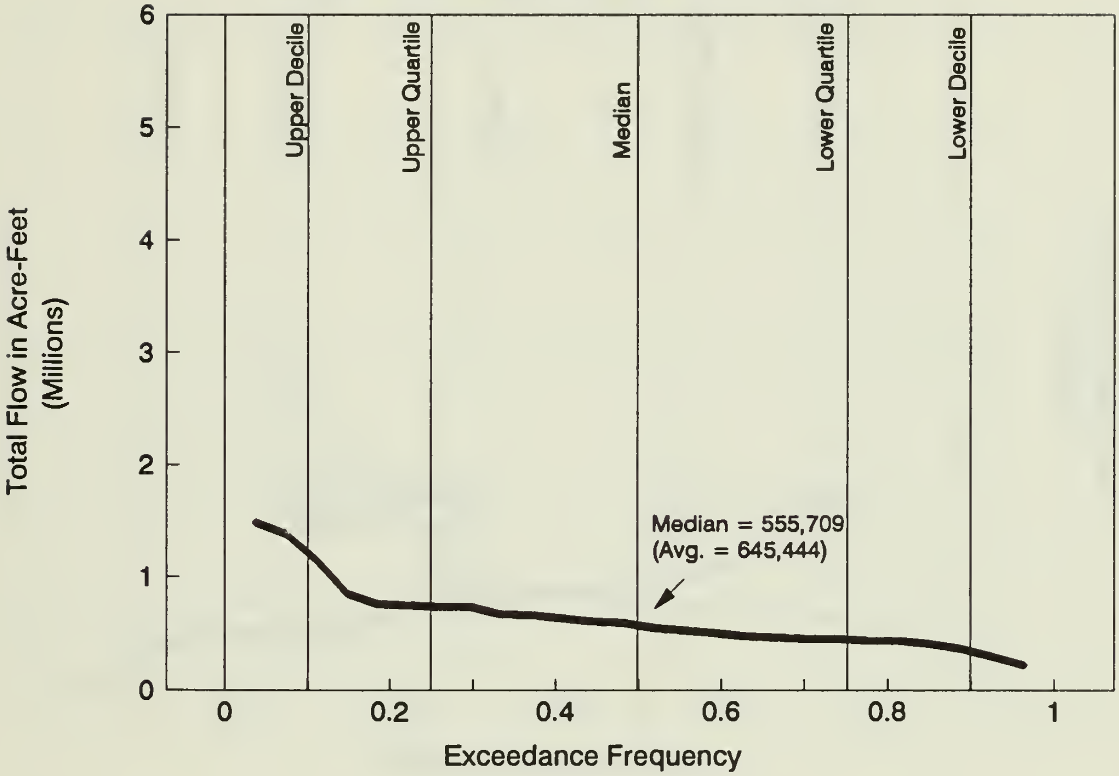

## Historic January Monthly Flows at Lees Ferry

Flow Duration for Water Years 1963-1990



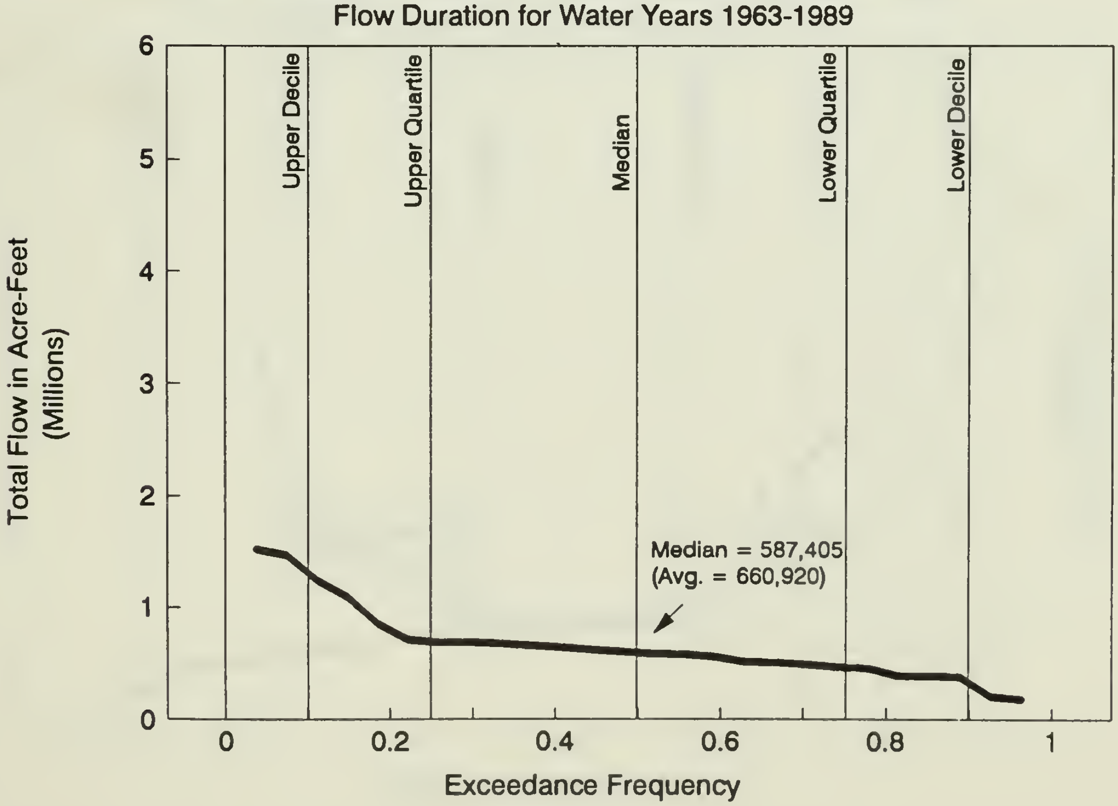
## Historic February Monthly Flows at Lees Ferry

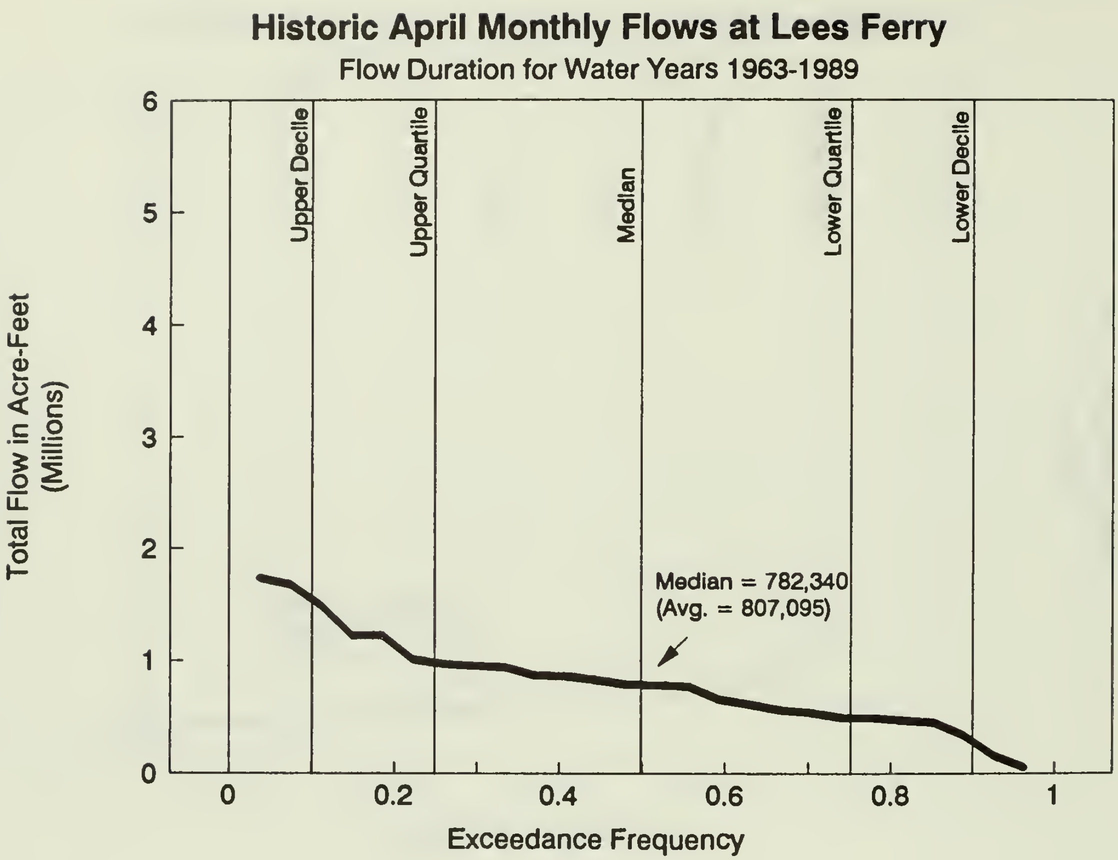
Flow Duration for Water Years 1963-1989

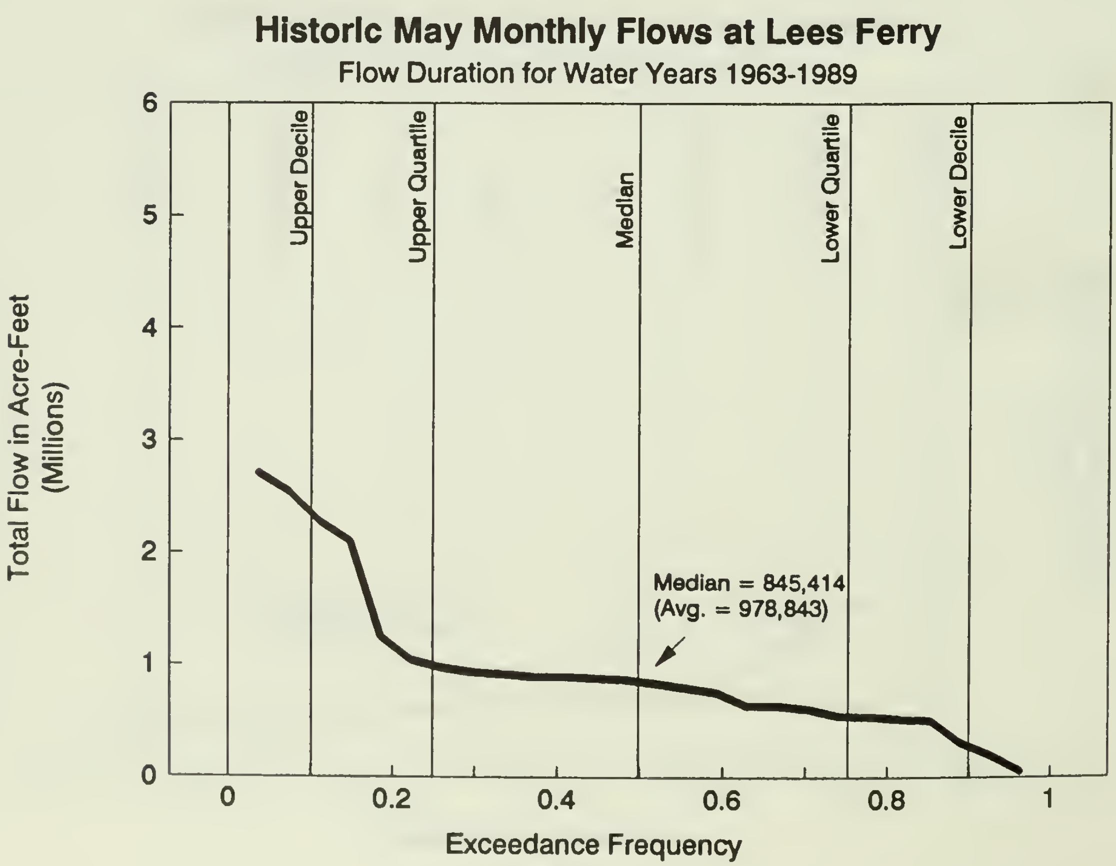



## Historic March Monthly Flows at Lees Ferry

Flow Duration for Water Years 1963-1989

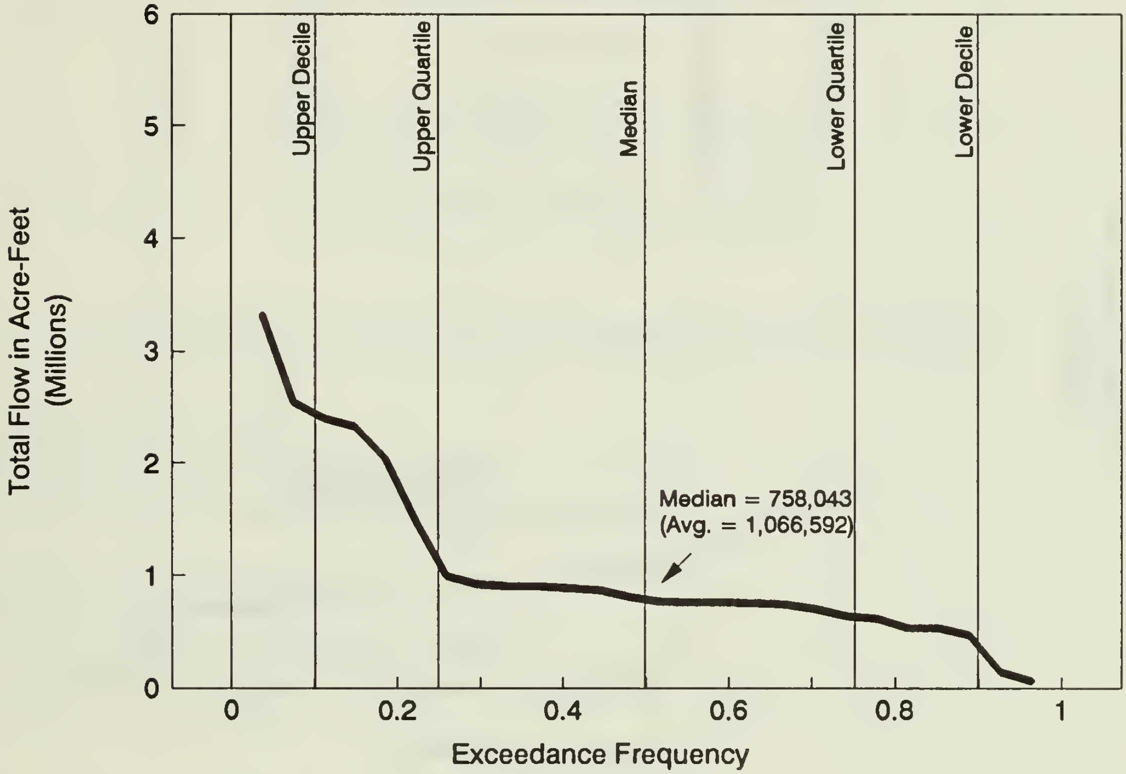



Historic April Monthly Flows at Lees Ferry
Flow Duration for Water Years 1963-1989
Total Flow in Acre-Feet (Millions)
6
5
4
3
2
1
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 782,340
(Avg. = 807,095)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency


Historic May Monthly Flows at Lees Ferry
Flow Duration for Water Years 1963-1989
Total Flow in Acre-Feet (Millions)
6
5
4
3
2
1
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 845,414
(Avg. = 978,843)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

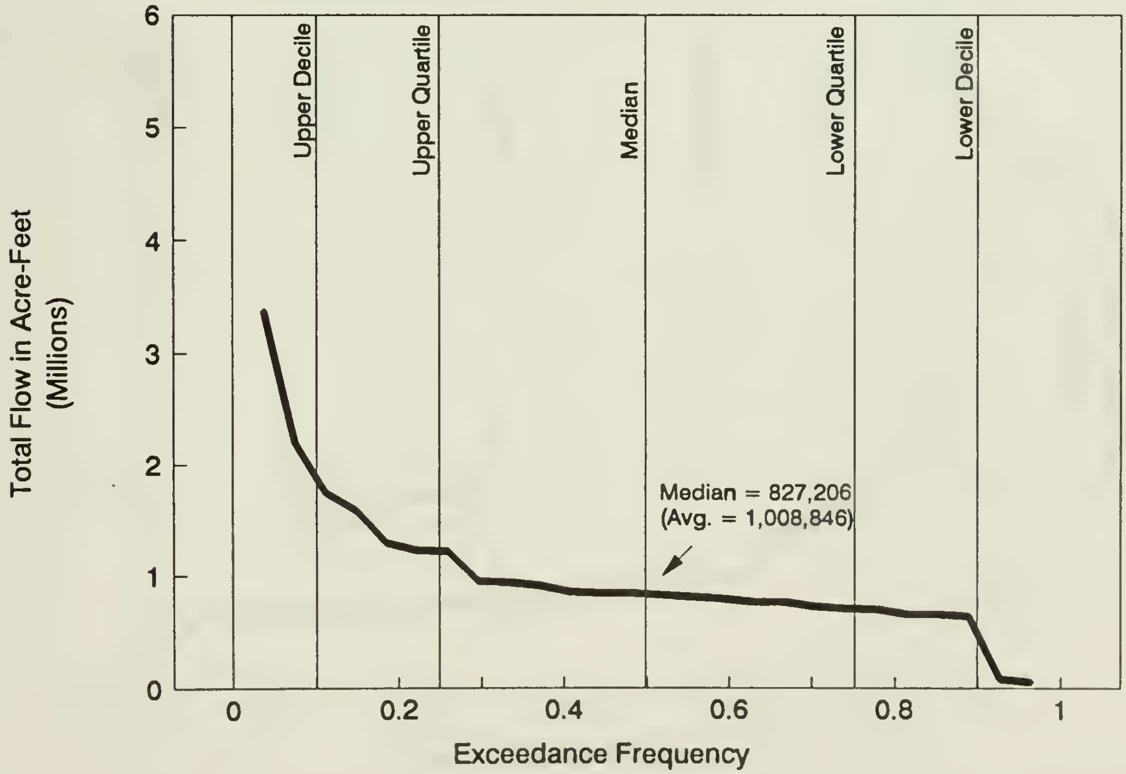
## Historic June Monthly Flows at Lees Ferry

Flow Duration for Water Years 1963-1989



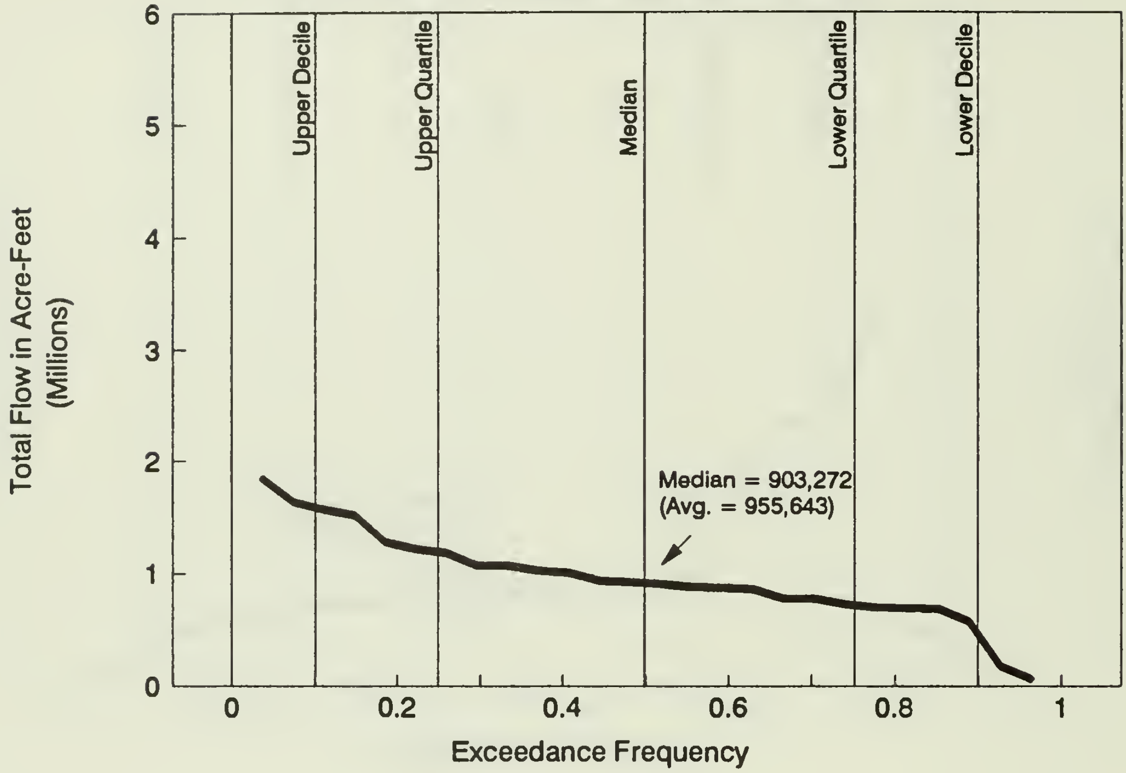

## Historic July Monthly Flows at Lees Ferry

Flow Duration for Water Years 1963-1989



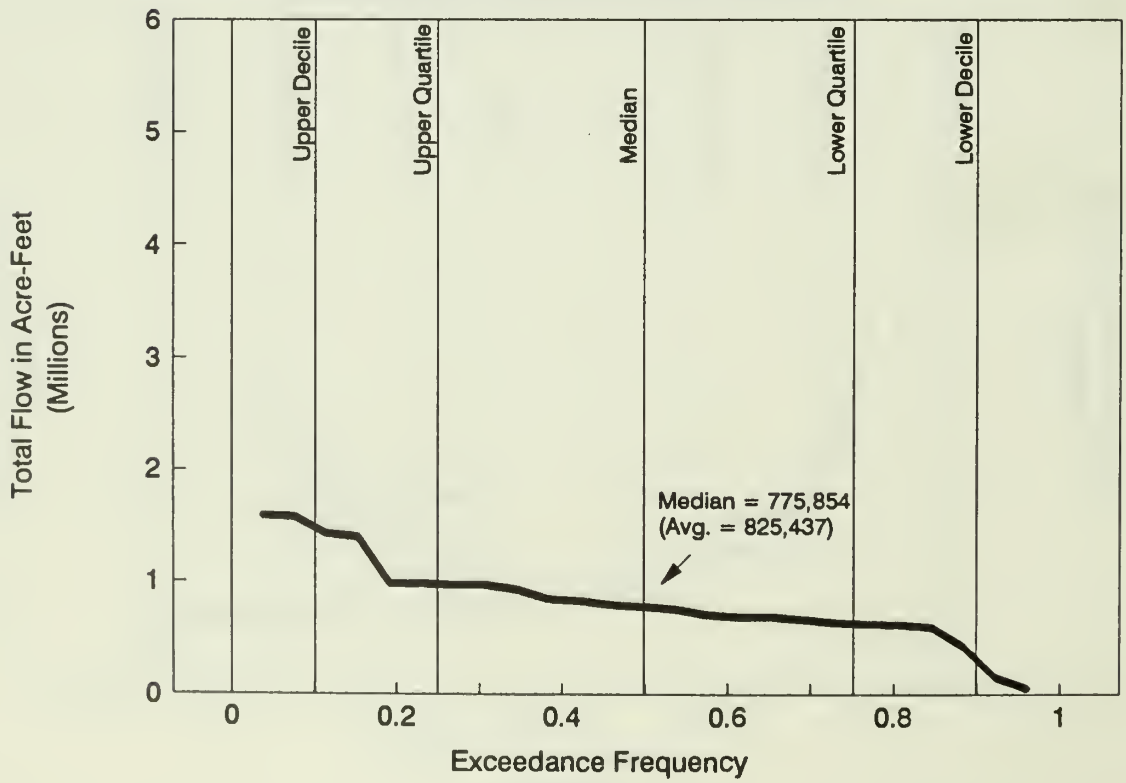
## Historic August Monthly Flows at Lees Ferry

Flow Duration for Water Years 1963-1989




## Historic September Monthly Flows at Lees Ferry

Flow Duration for Water Years 1963-1988



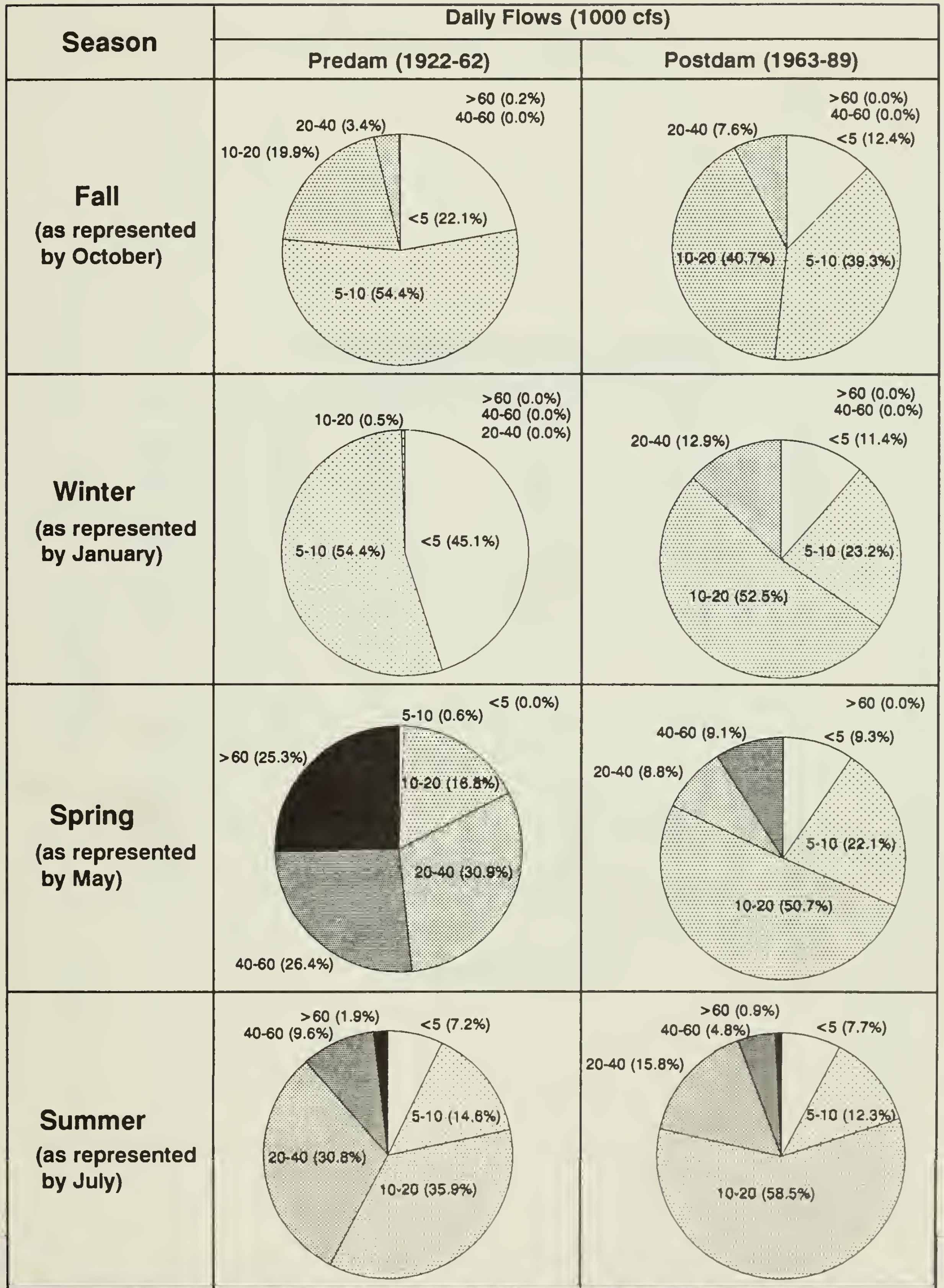
Frequencies of

# Historic Daily Flows at Lees Ferry (cfs)

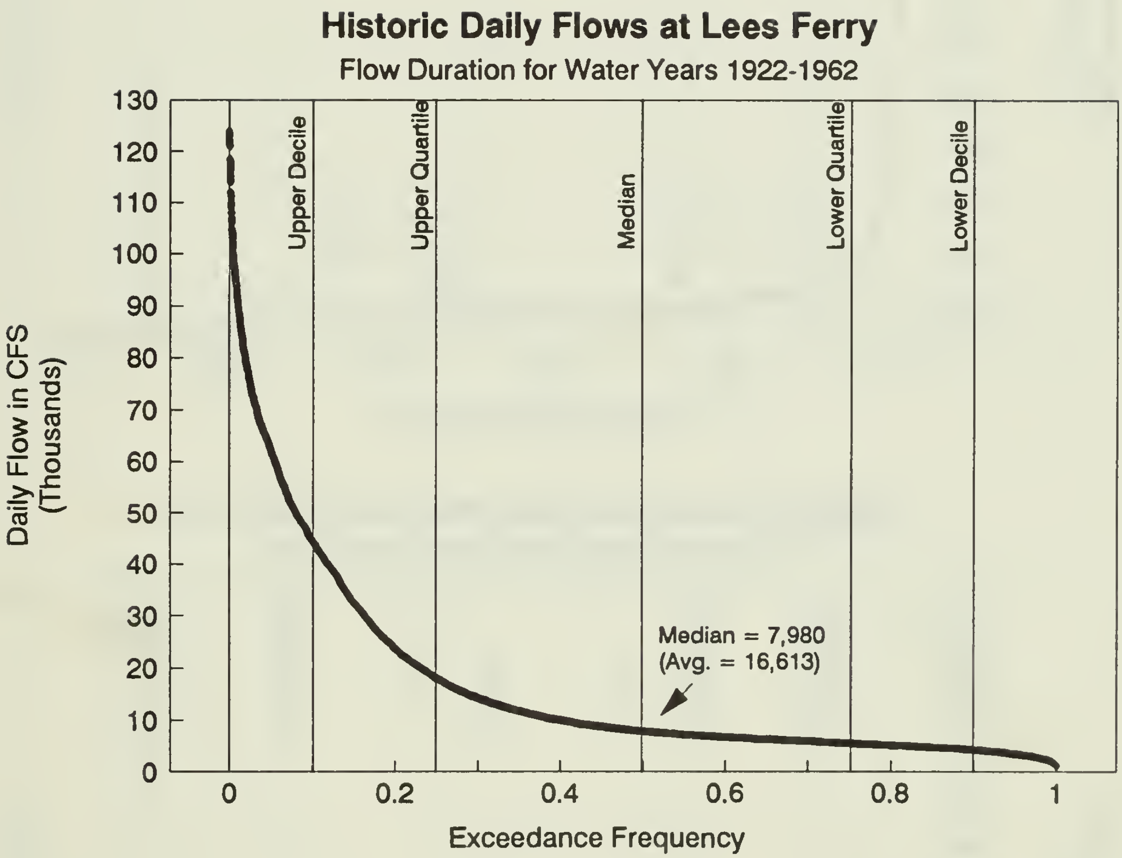
A. Pie Chart Summaries of Predam and Postdam Flows by Season

B. Predam (1922-1962)
   1. All Months (1 frequency graph)
   2. Individual Months (12 frequency graphs)

C. Postdam (1963-1990)
   1. All Months (1 frequency graph)
   2. Individual Months (12 frequency graphs)

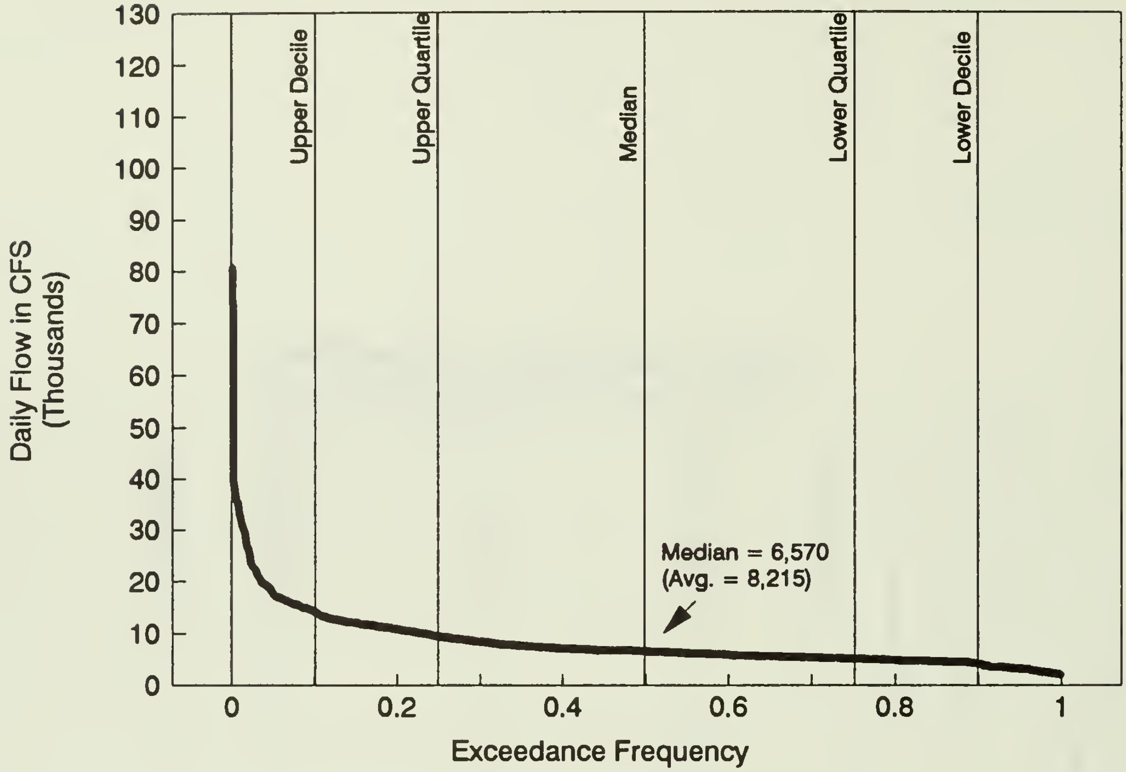



**Predam and Post Dam Daily Flows at Lees Ferry (percent of days that the specified flows occurred)**


Historic Daily Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Daily Flow in CFS (Thousands)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 7,980
(Avg. = 16,613)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

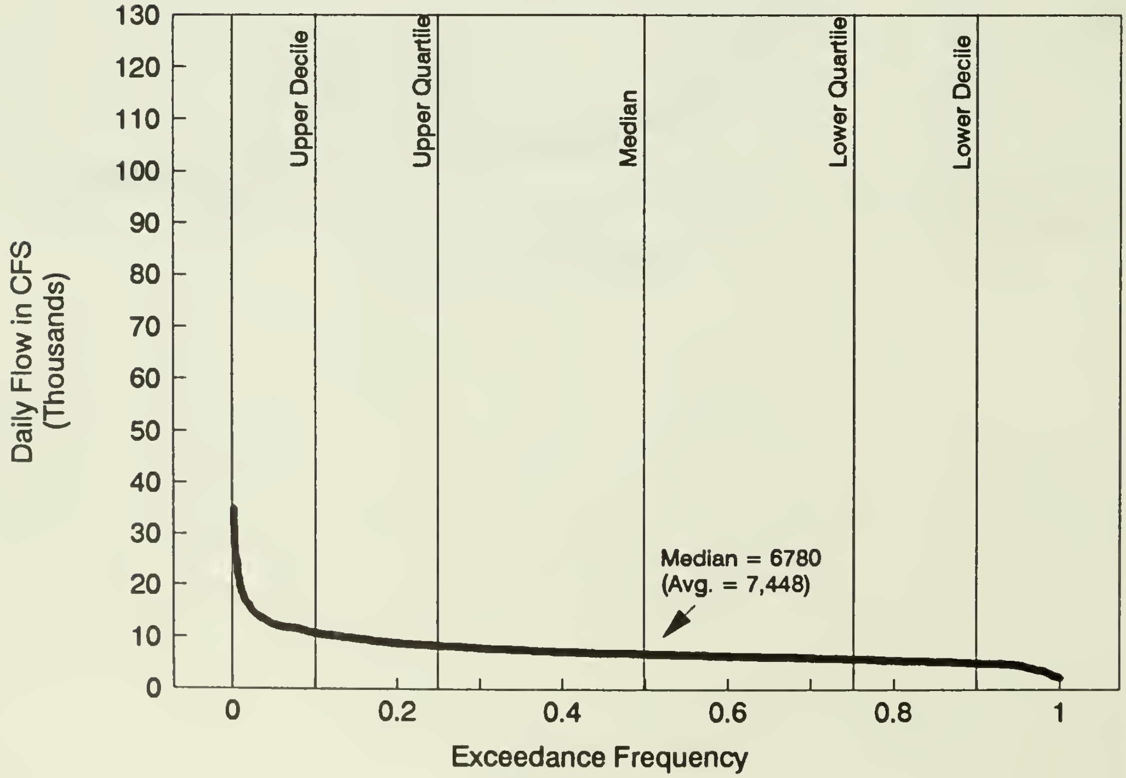
**Historic October Daily Flows at Lees Ferry**

Flow Duration for Water Years 1922-1962



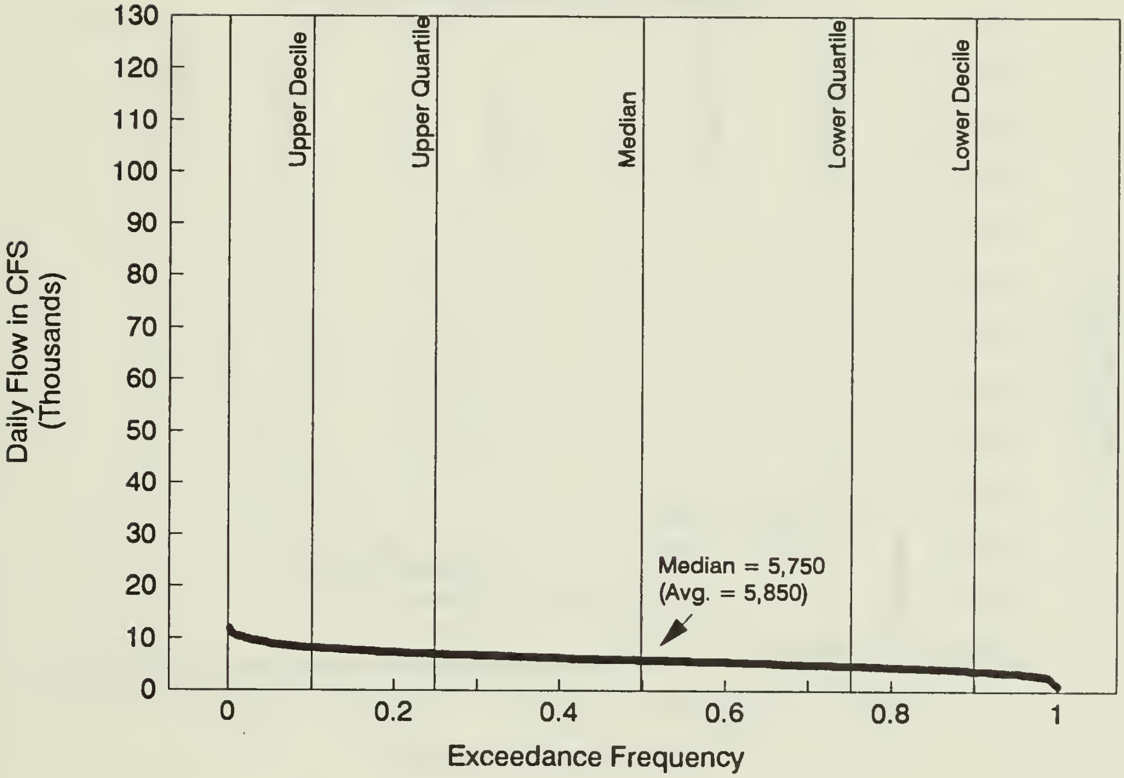

**Historic November Daily Flows at Lees Ferry**

Flow Duration for Water Years 1922-1962



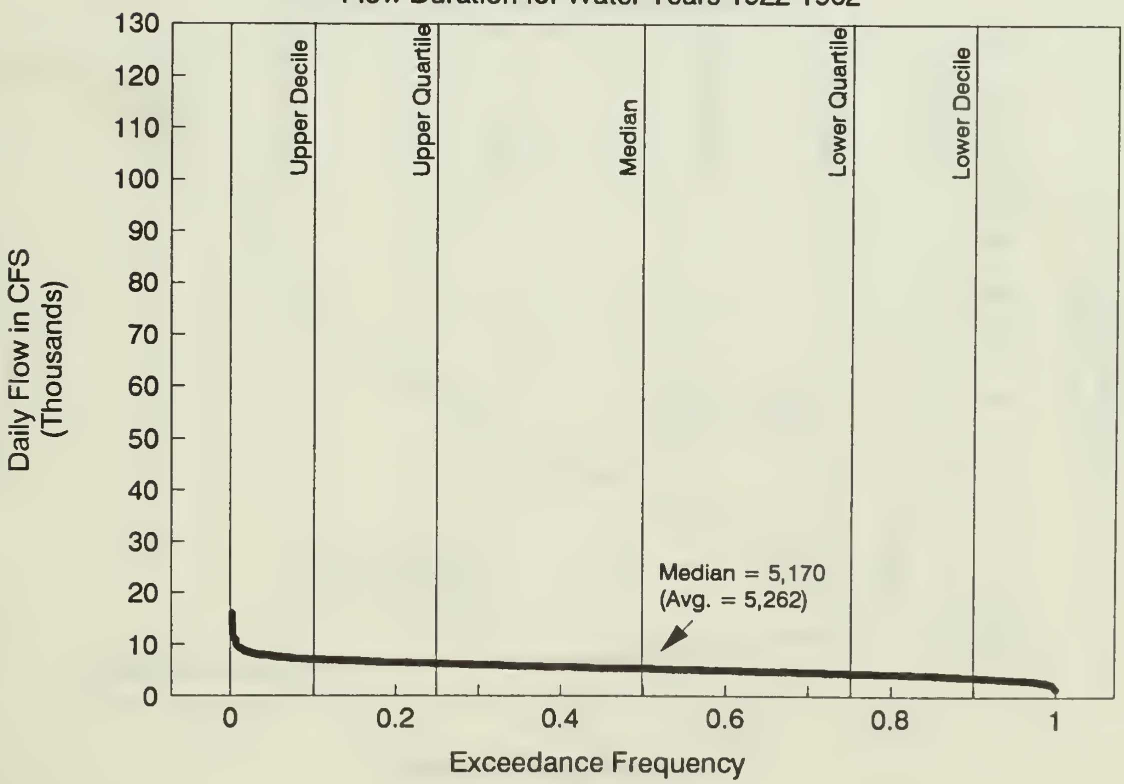
## Historic December Daily Flows at Lees Ferry

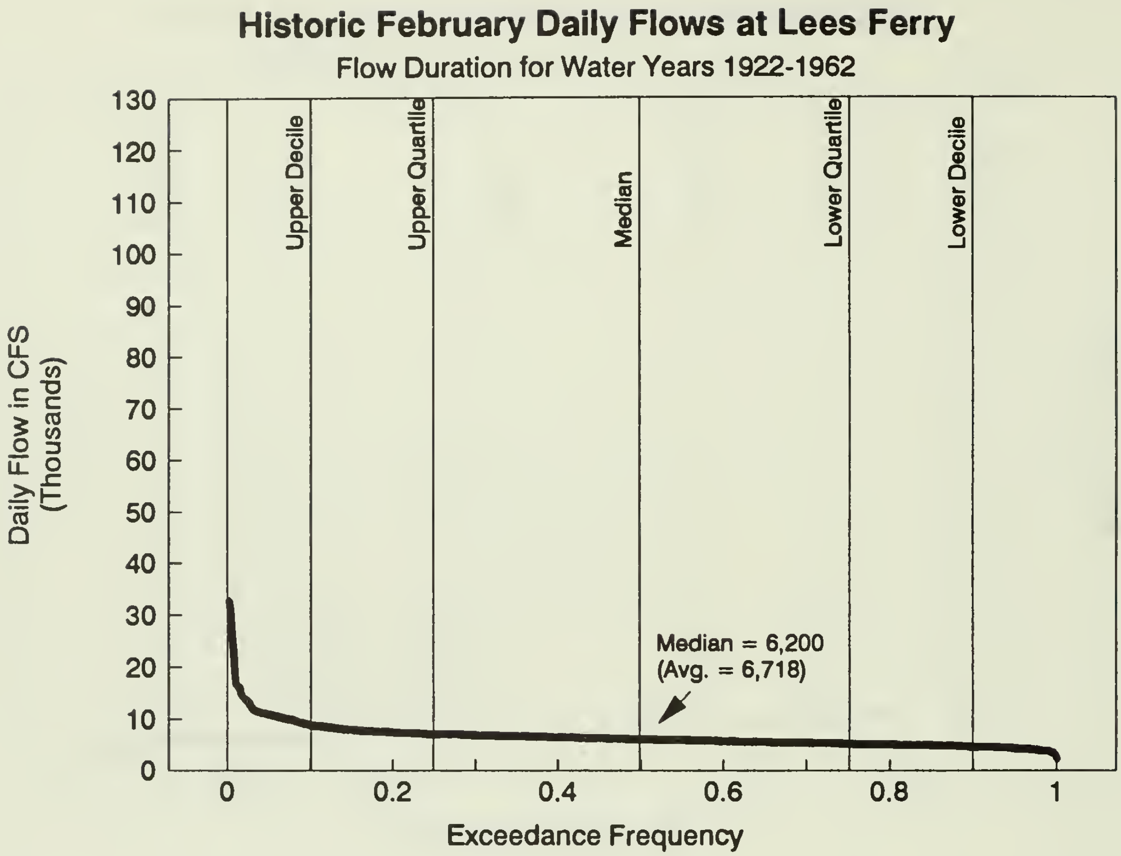
Flow Duration for Water Years 1922-1962



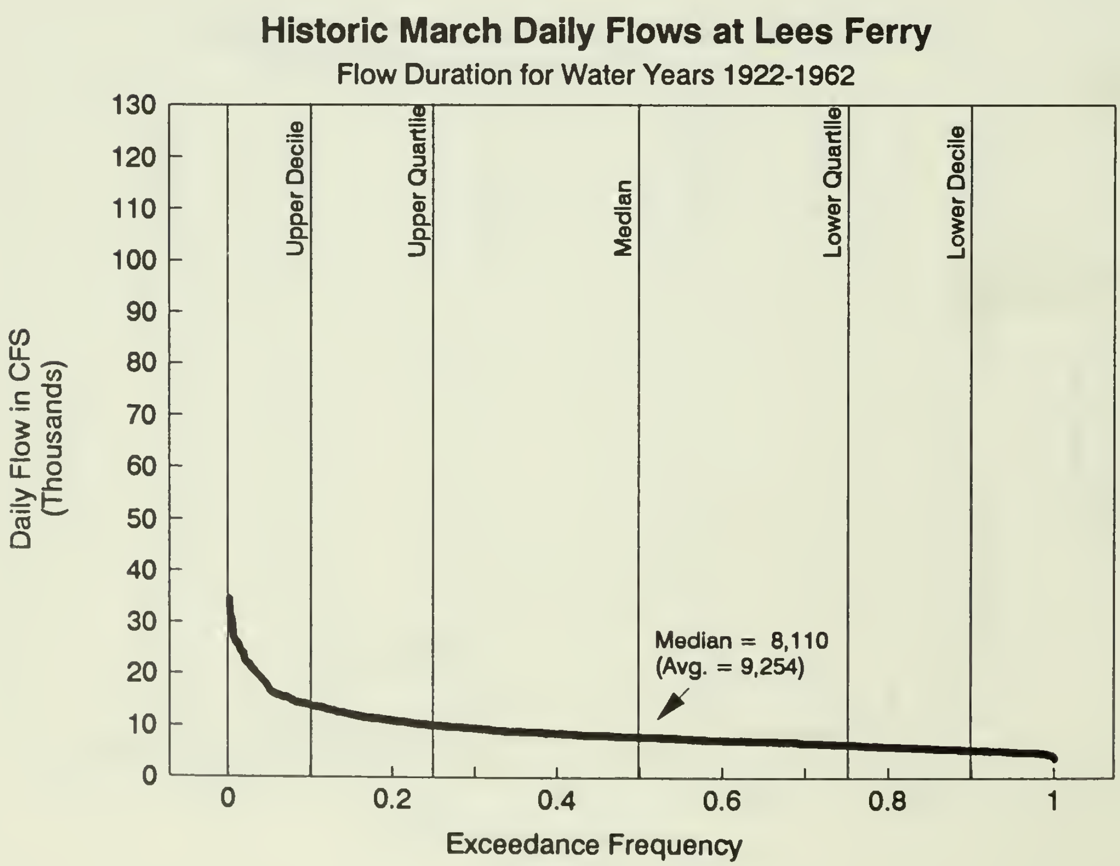

## Historic January Daily Flows at Lees Ferry

Flow Duration for Water Years 1922-1962





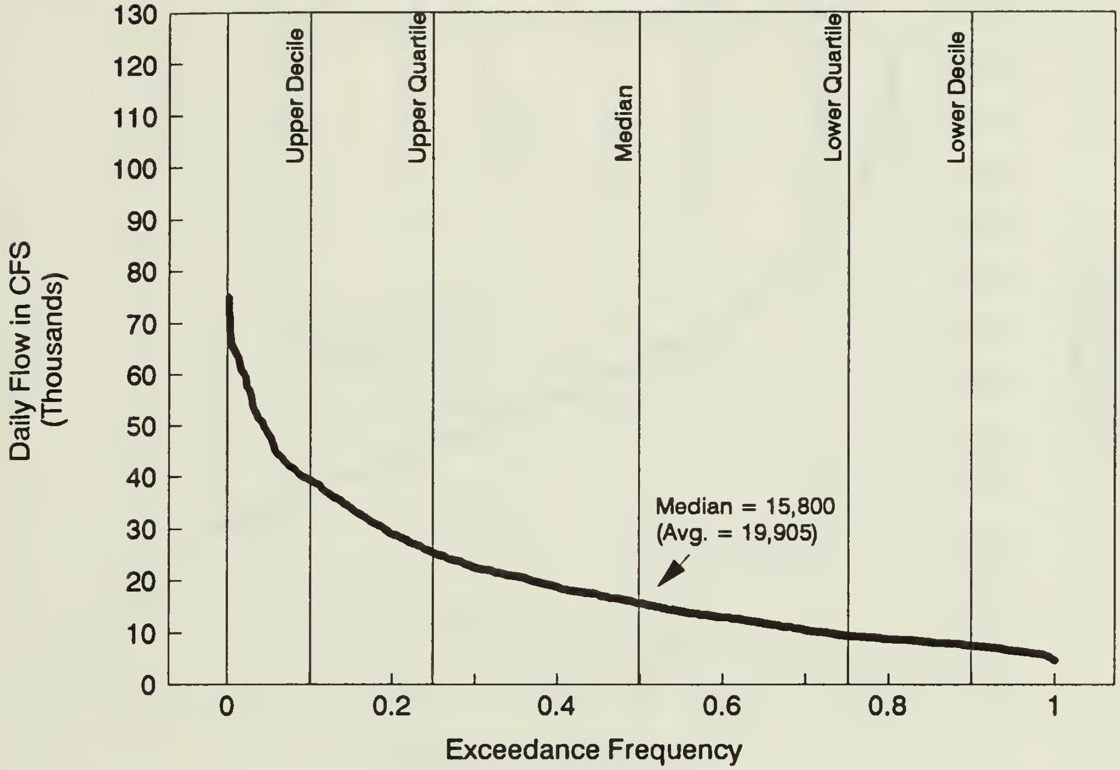
Historic February Daily Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Daily Flow in CFS (Thousands)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 6,200
(Avg. = 6,718)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

Historic March Daily Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Daily Flow in CFS (Thousands)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 8,110
(Avg. = 9,254)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

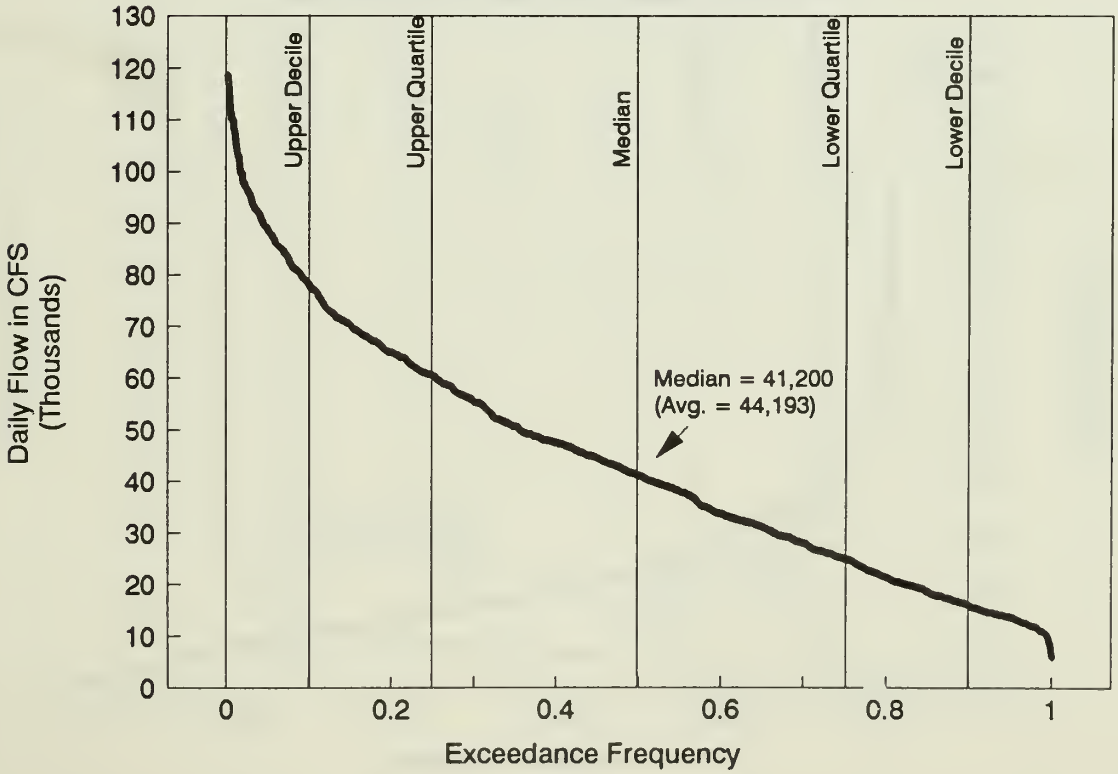
## Historic April Daily Flows at Lees Ferry

Flow Duration for Water Years 1922-1962



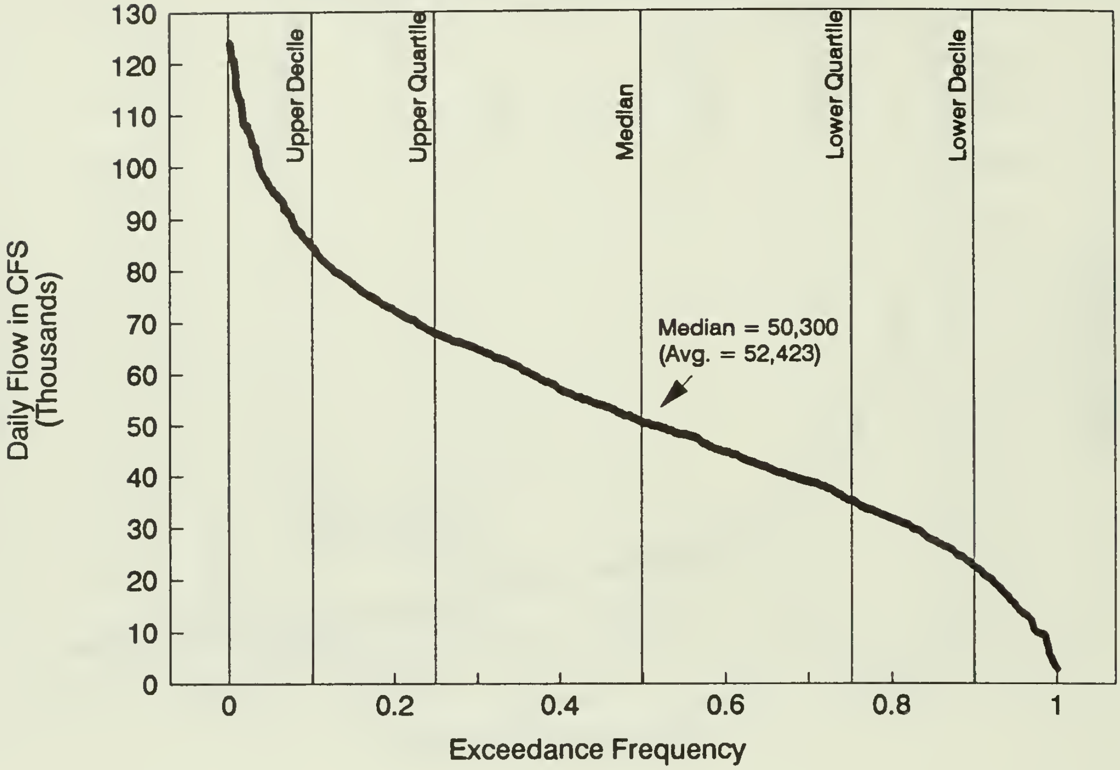

## Historic May Daily Flows at Lees Ferry

Flow Duration for Water Years 1922-1962



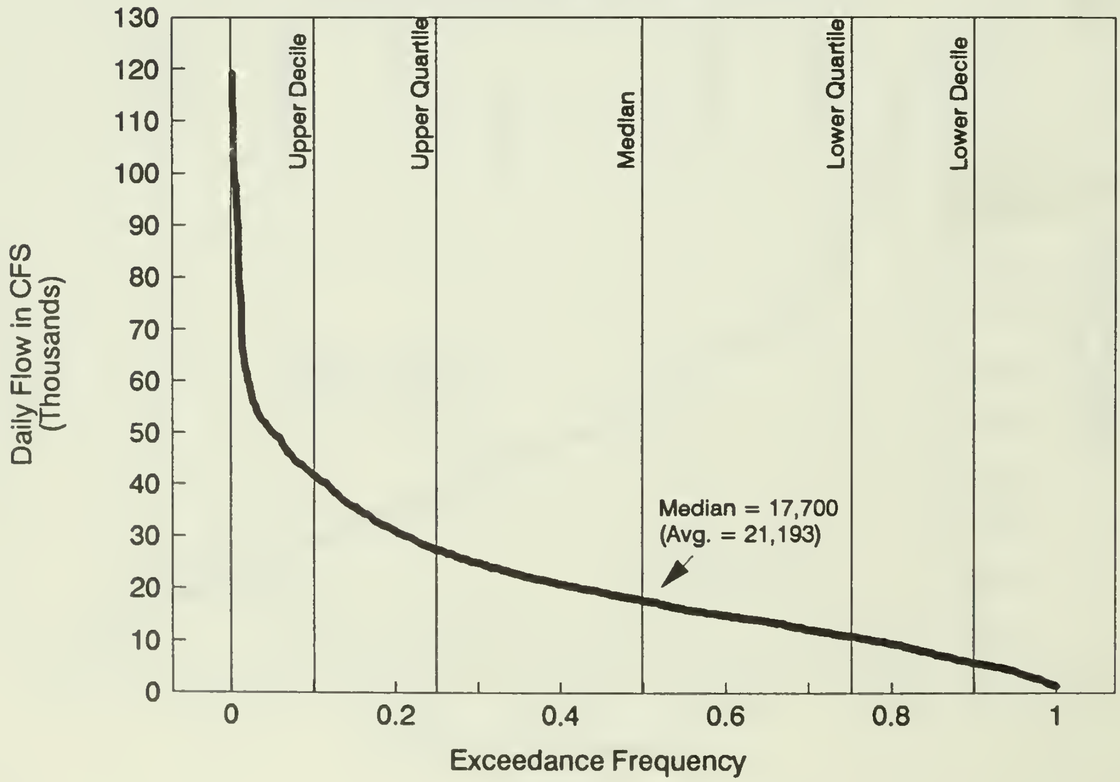
## Historic June Daily Flows at Lees Ferry

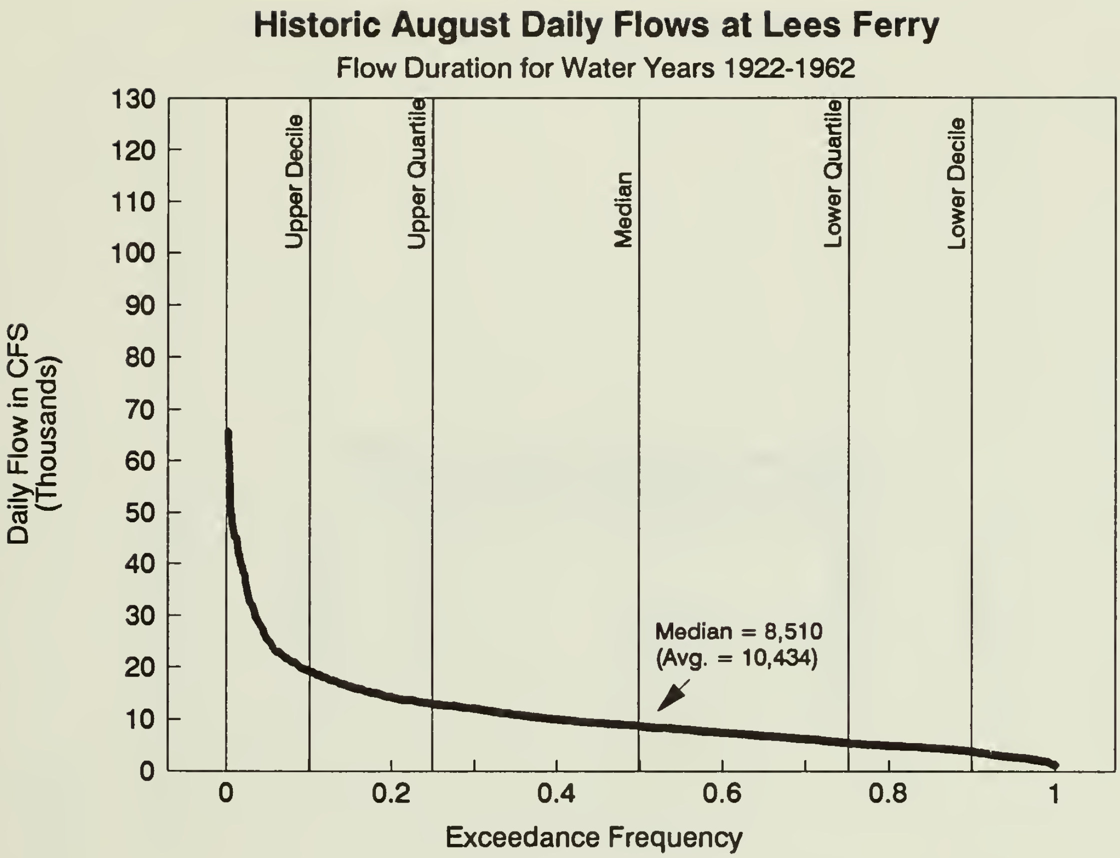
Flow Duration for Water Years 1922-1962



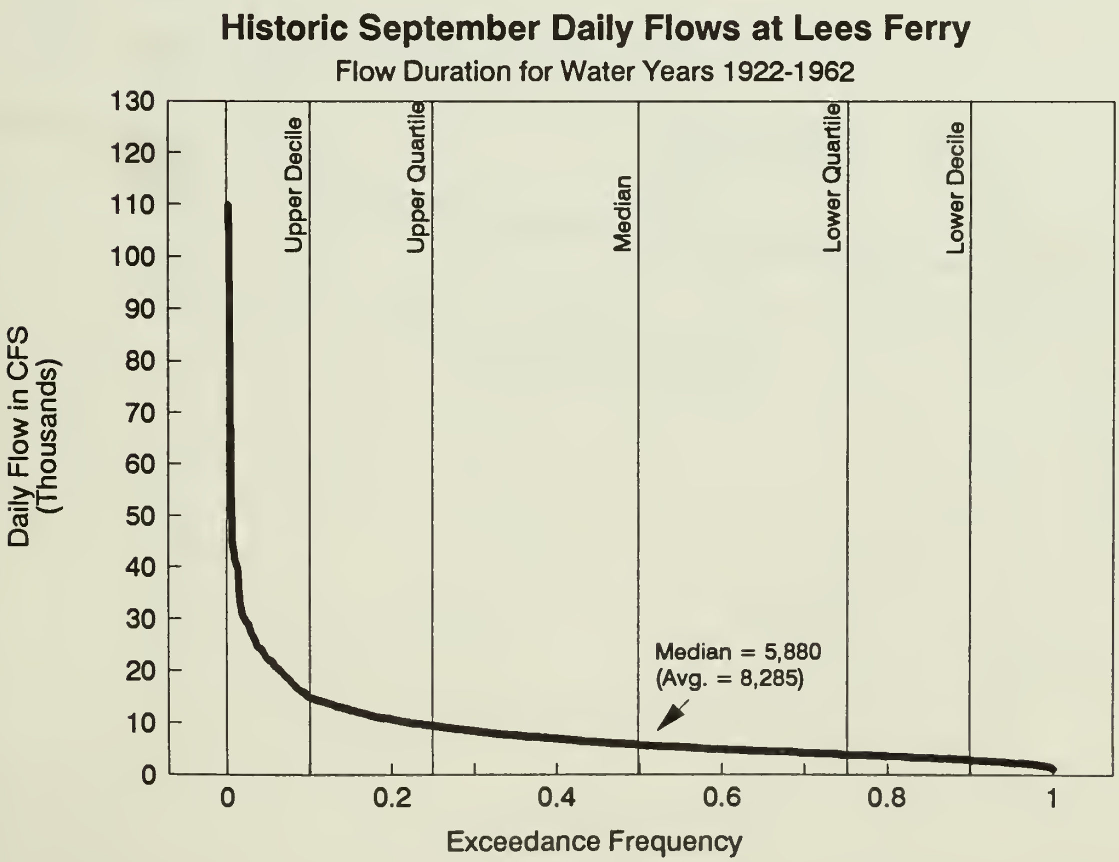

## Historic July Daily Flows at Lees Ferry

Flow Duration for Water Years 1922-1962

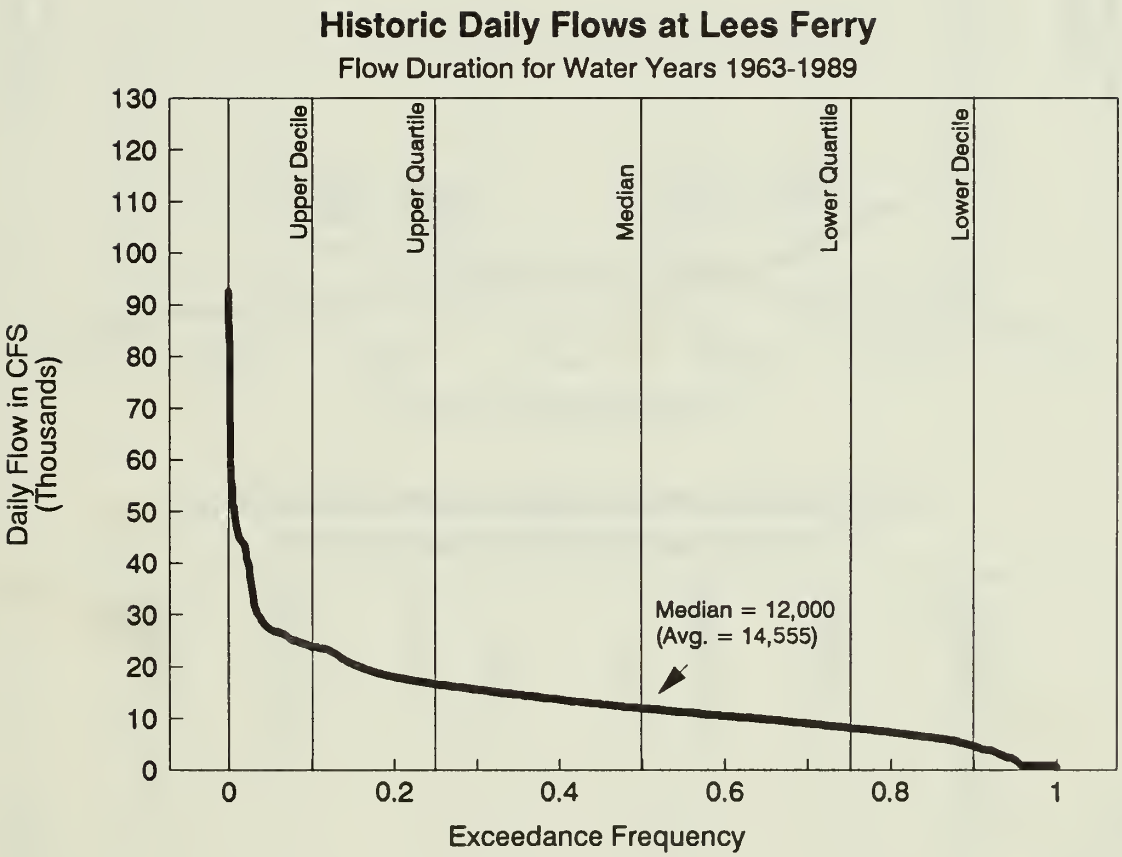




Historic August Daily Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Daily Flow in CFS (Thousands)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 8,510
(Avg. = 10,434)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

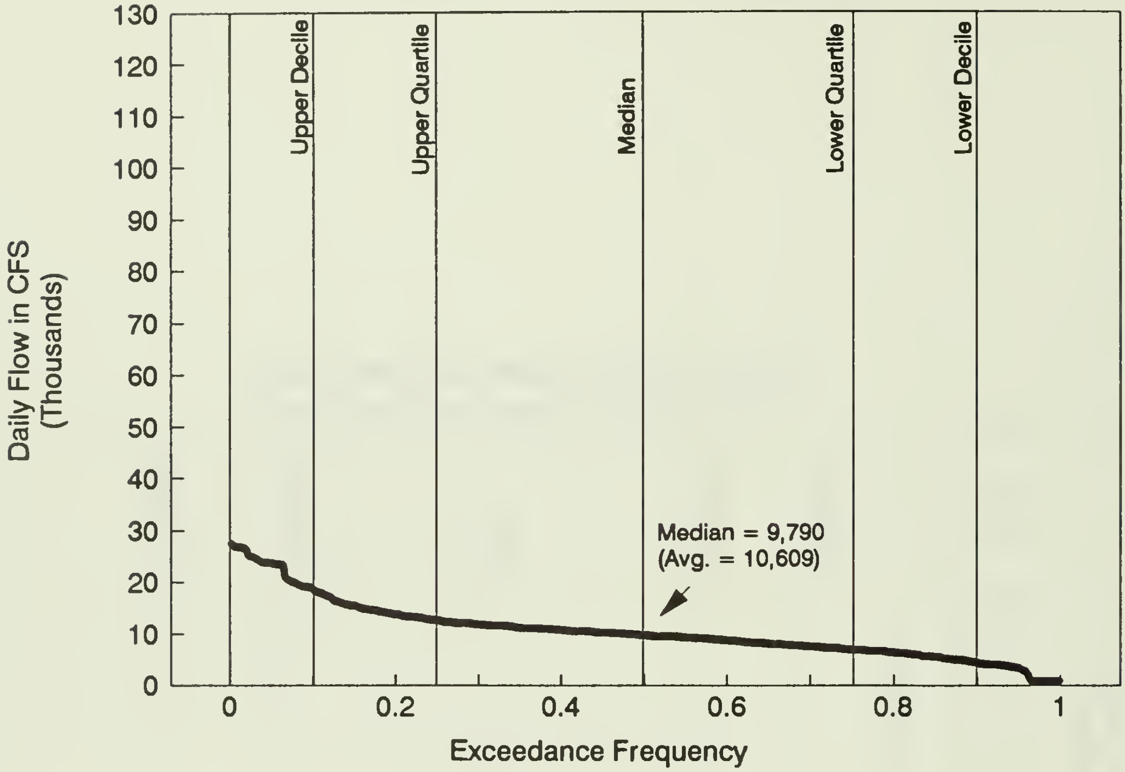



Historic September Daily Flows at Lees Ferry
Flow Duration for Water Years 1922-1962
Daily Flow in CFS (Thousands)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 5,880
(Avg. = 8,285)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency


Historic Daily Flows at Lees Ferry
Flow Duration for Water Years 1963-1989
Daily Flow in CFS (Thousands)
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 12,000
(Avg. = 14,555)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

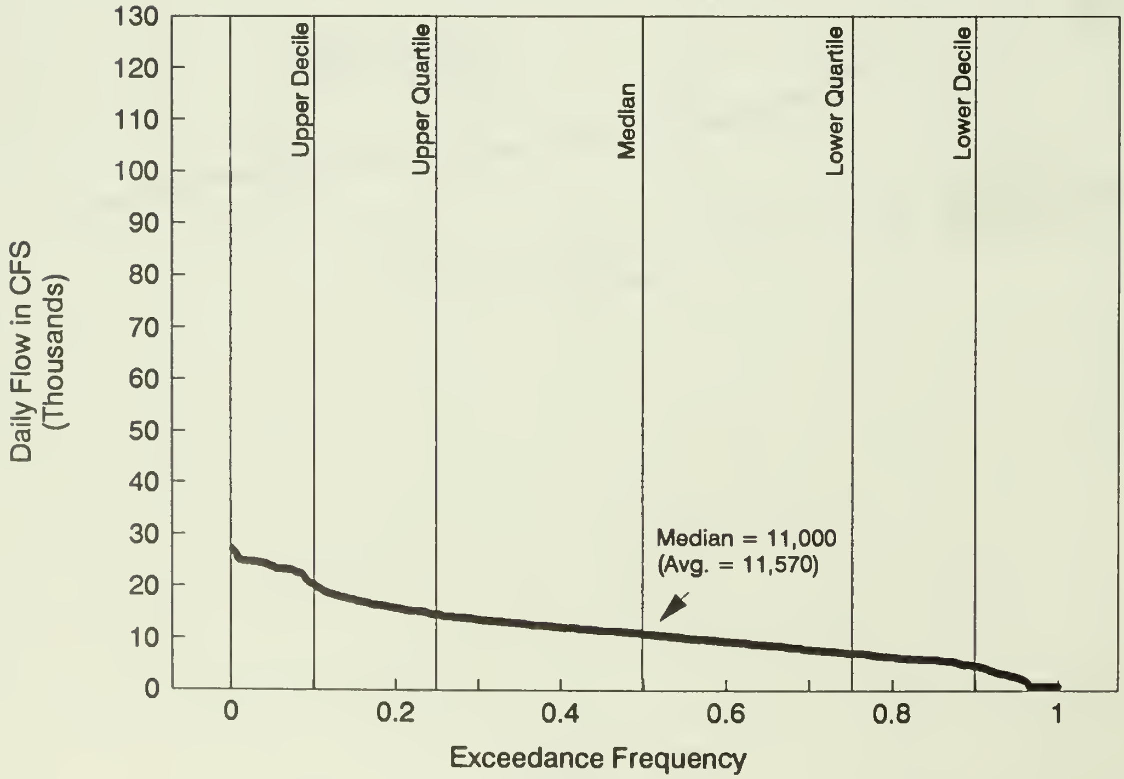
## Historic October Daily Flows at Lees Ferry

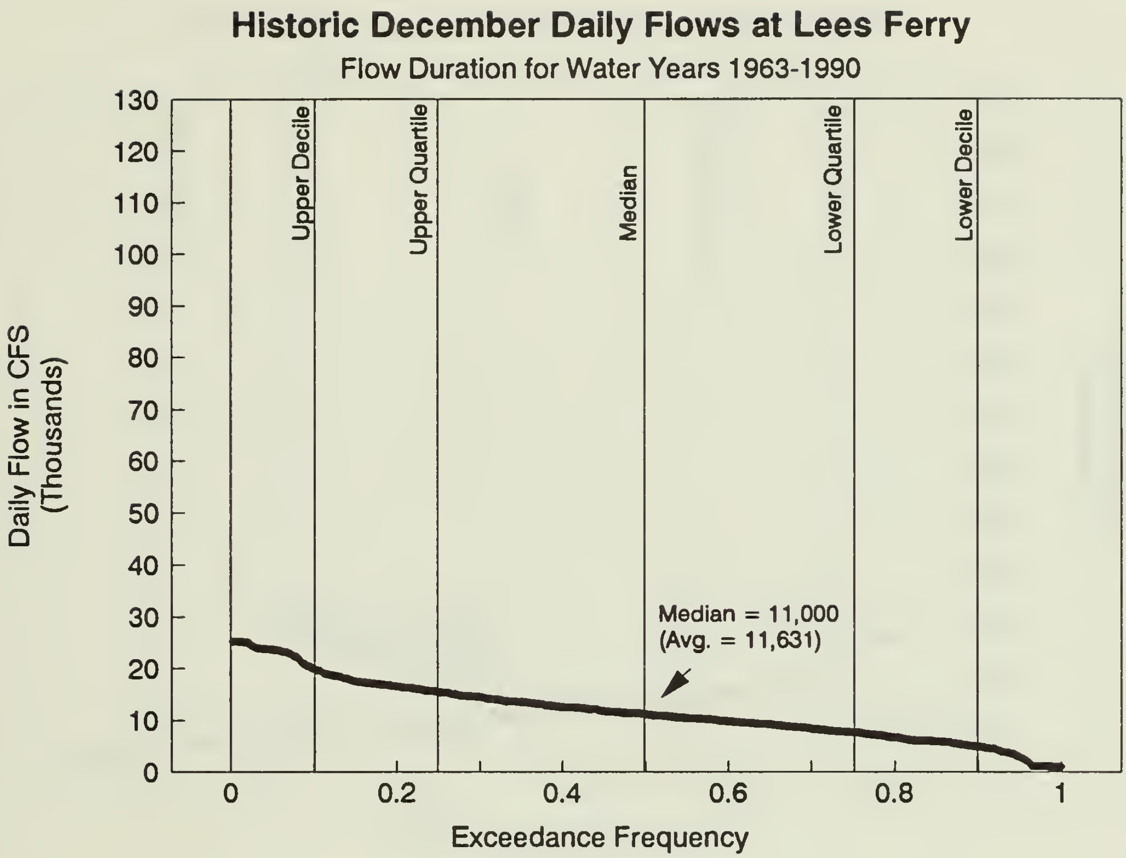
Flow Duration for Water Years 1963-1990

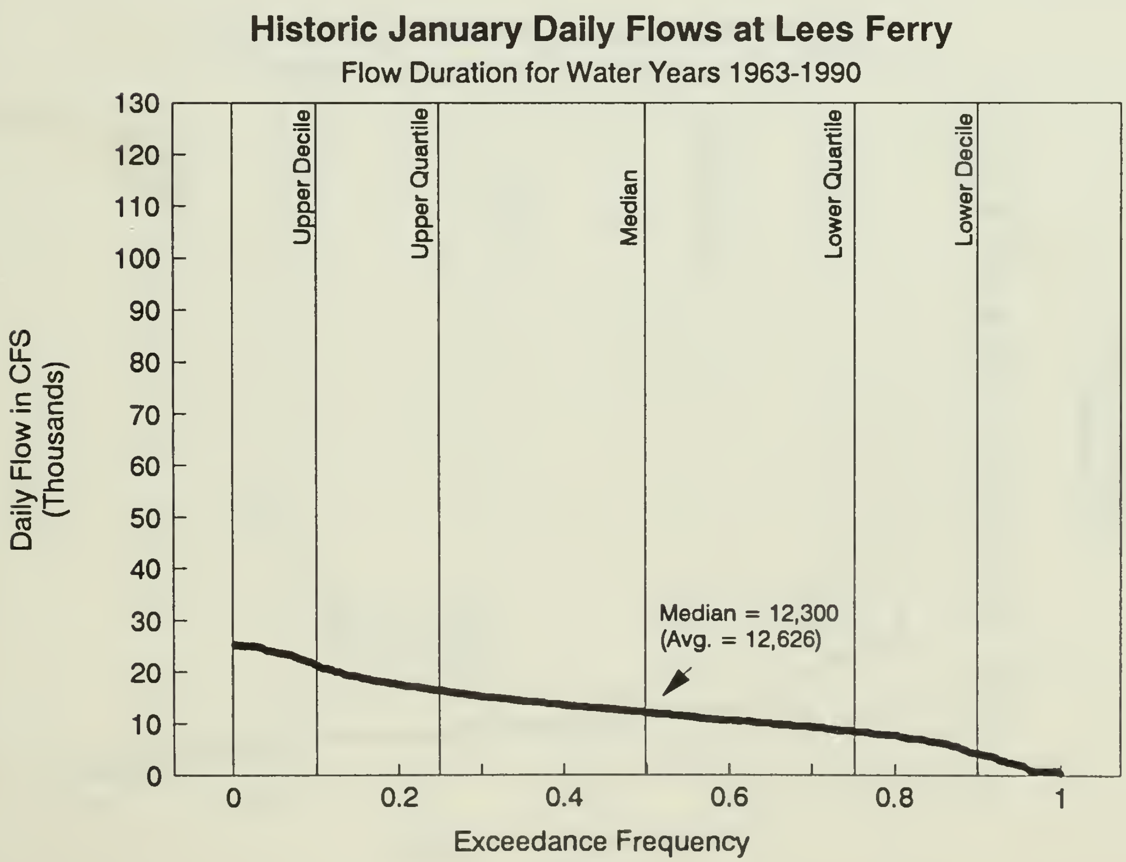


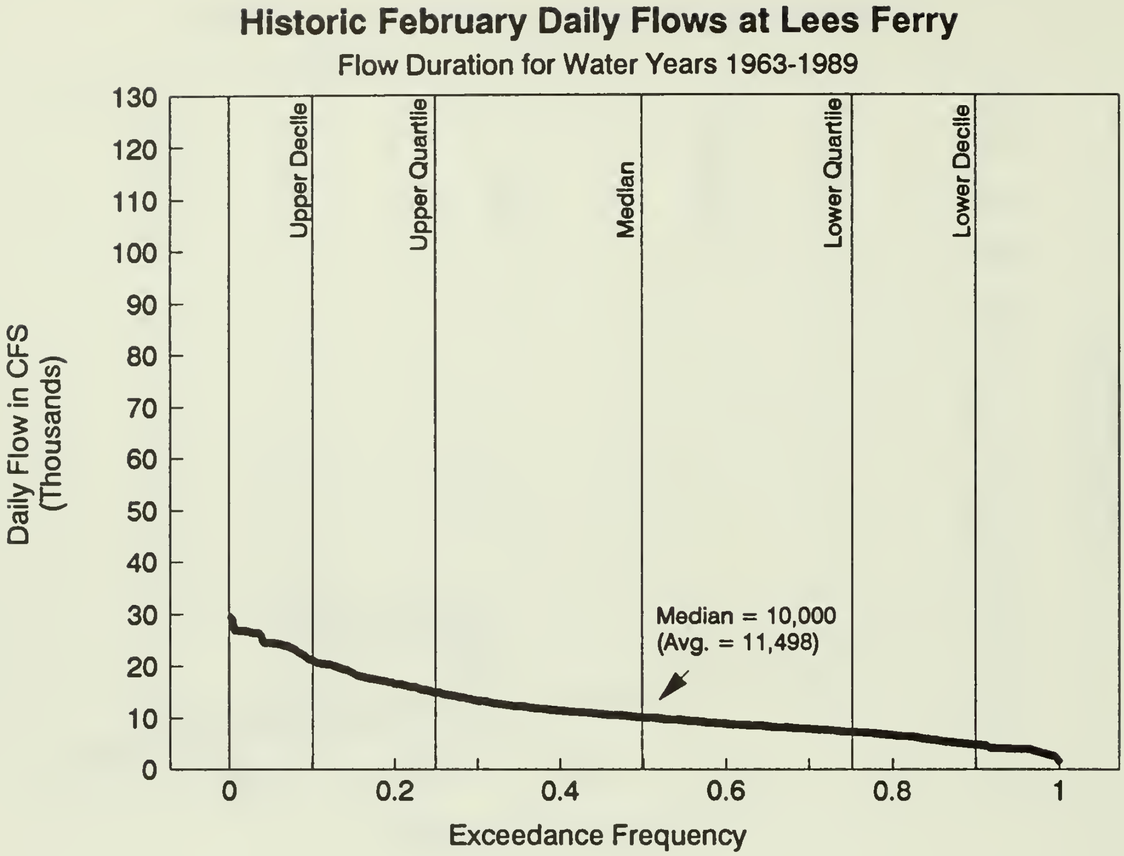

## Historic November Daily Flows at Lees Ferry

Flow Duration for Water Years 1963-1990

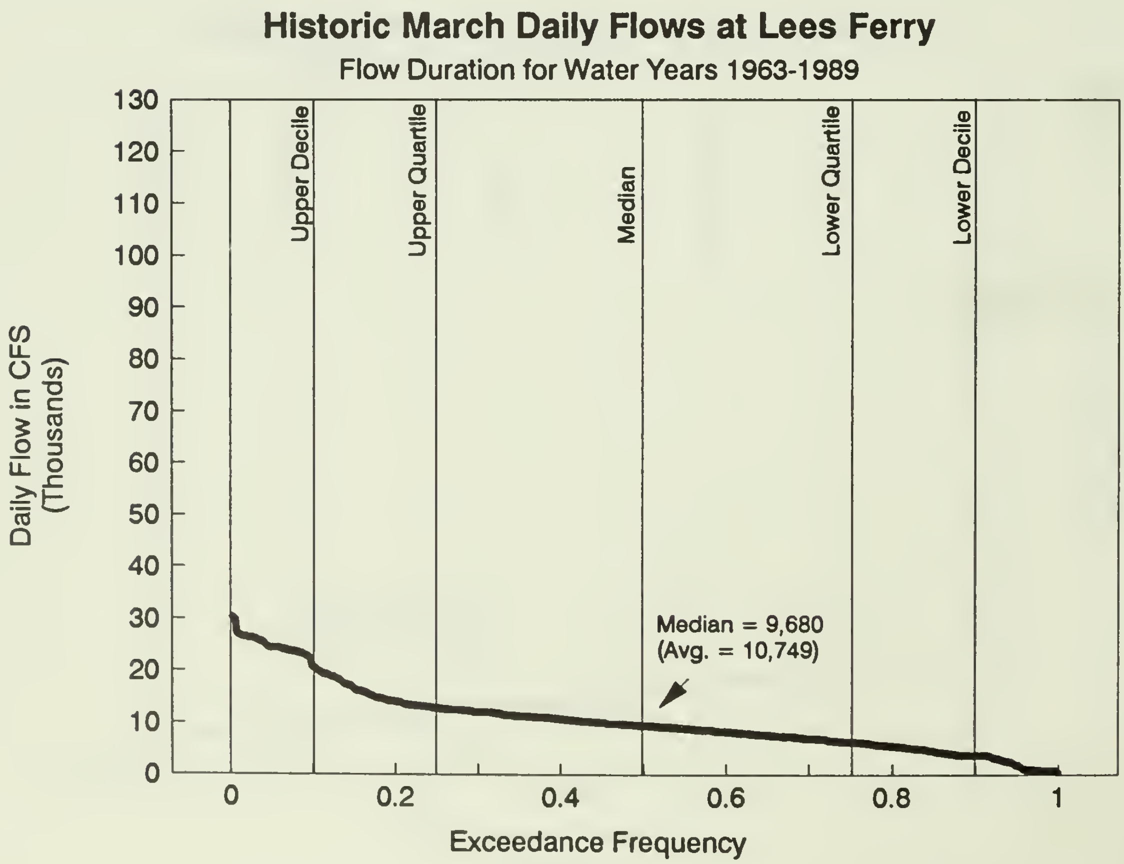



Historic December Daily Flows at Lees Ferry
Flow Duration for Water Years 1963-1990
Daily Flow in CFS (Thousands)
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 11,000
(Avg. = 11,631)
Exceedance Frequency


Historic January Daily Flows at Lees Ferry
Flow Duration for Water Years 1963-1990
Daily Flow in CFS (Thousands)
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 12,300
(Avg. = 12,626)
Exceedance Frequency



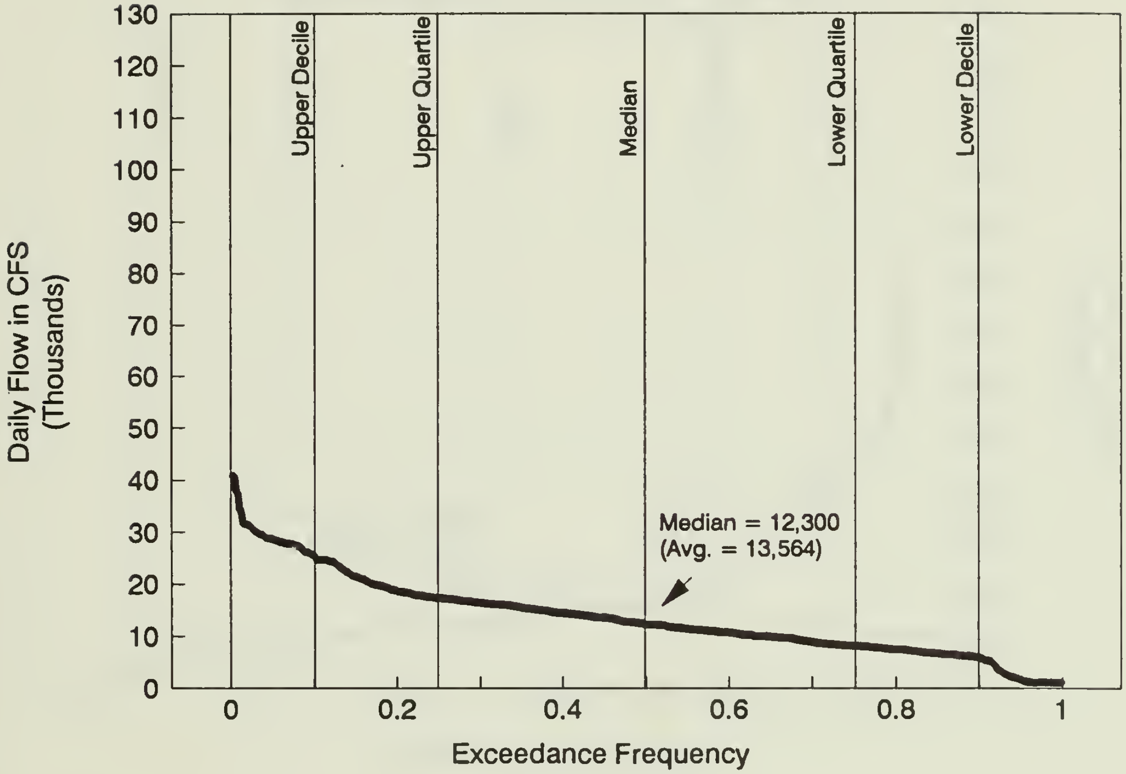
Historic February Daily Flows at Lees Ferry
Flow Duration for Water Years 1963-1989
Daily Flow in CFS
(Thousands)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 10,000
(Avg. = 11,498)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

Historic March Daily Flows at Lees Ferry
Flow Duration for Water Years 1963-1989
Daily Flow in CFS
(Thousands)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 9,680
(Avg. = 10,749)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

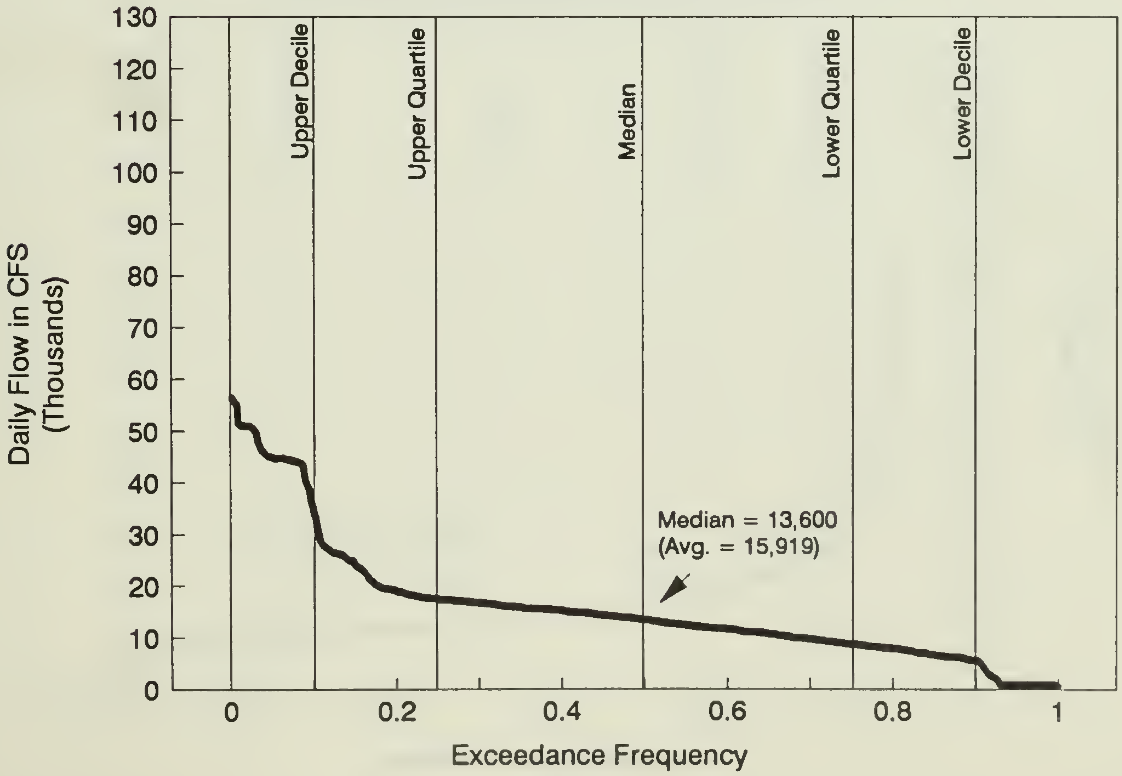
## Historic April Daily Flows at Lees Ferry

Flow Duration for Water Years 1963-1989



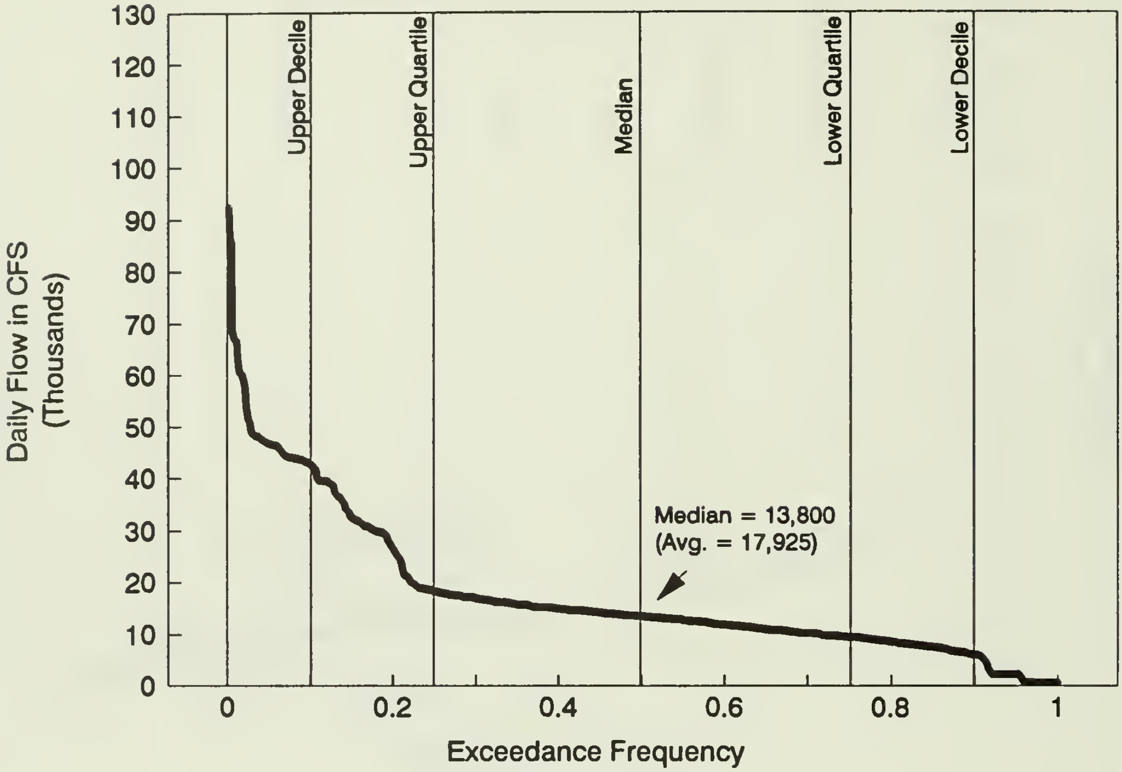

## Historic May Daily Flows at Lees Ferry

Flow Duration for Water Years 1963-1989



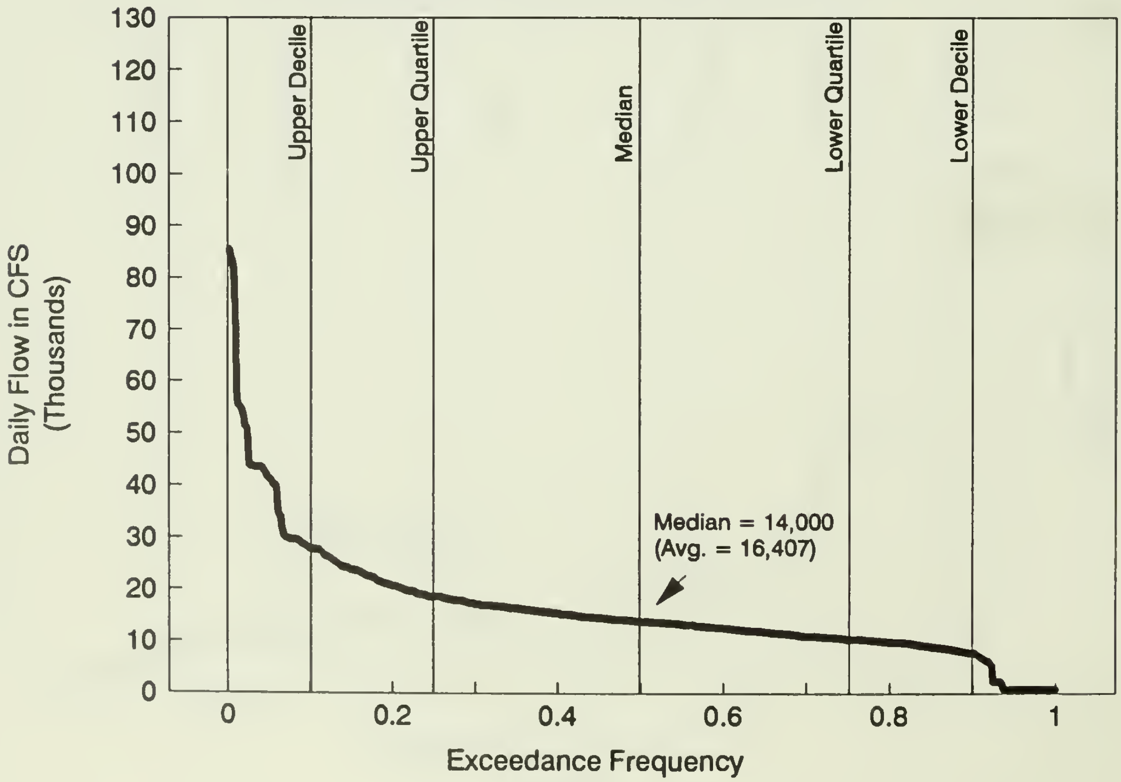
# Historic June Daily Flows at Lees Ferry

Flow Duration for Water Years 1963-1989



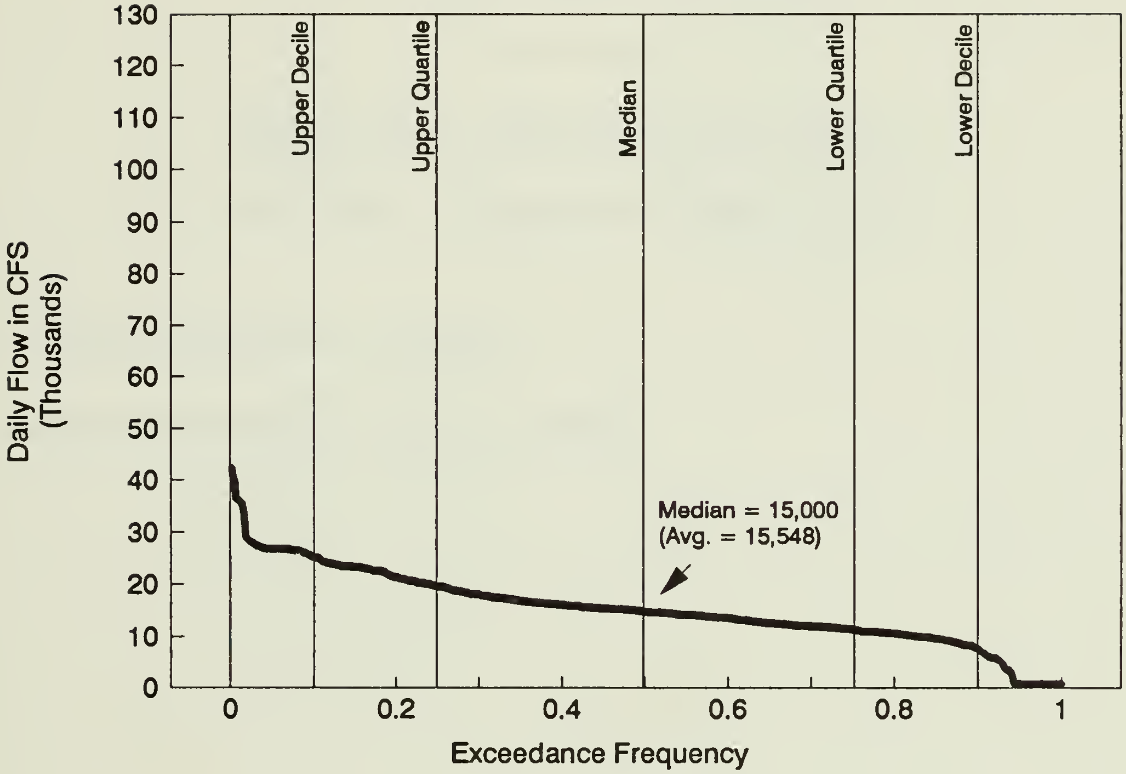

# Historic July Daily Flows at Lees Ferry

Flow Duration for Water Years 1963-1989



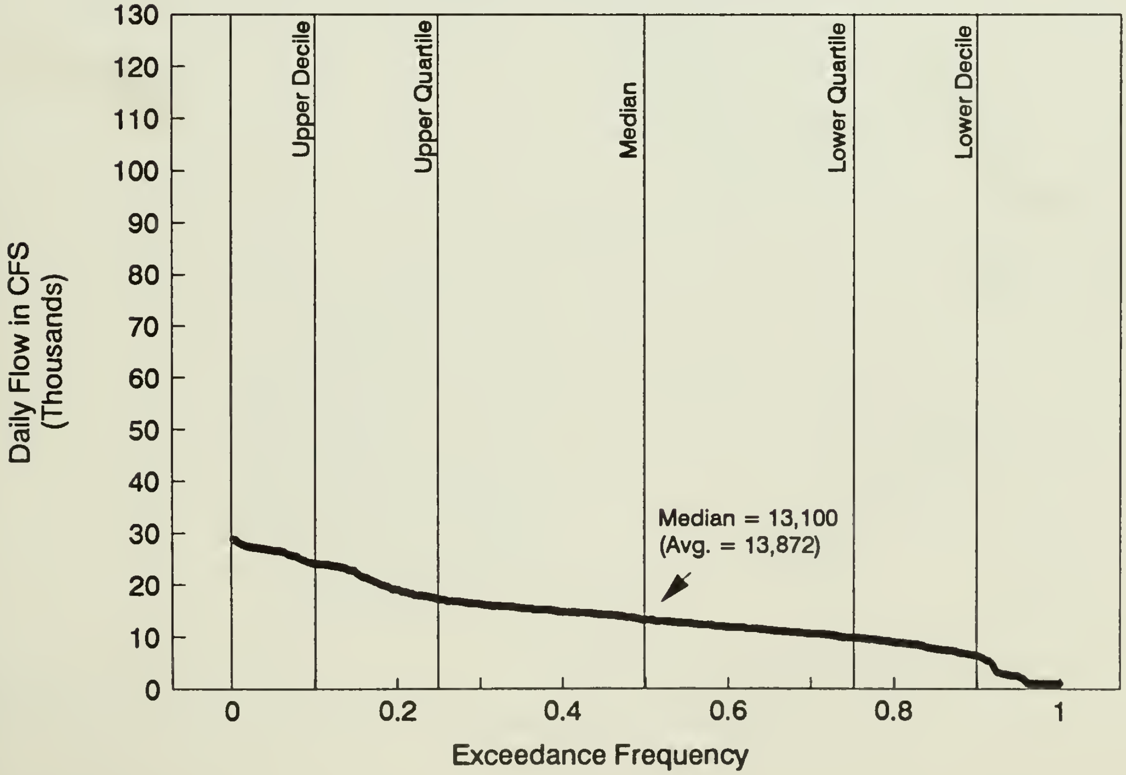
## Historic August Daily Flows at Lees Ferry

Flow Duration for Water Years 1963-1989




## Historic September Daily Flows at Lees Ferry

Flow Duration for Water Years 1963-1988

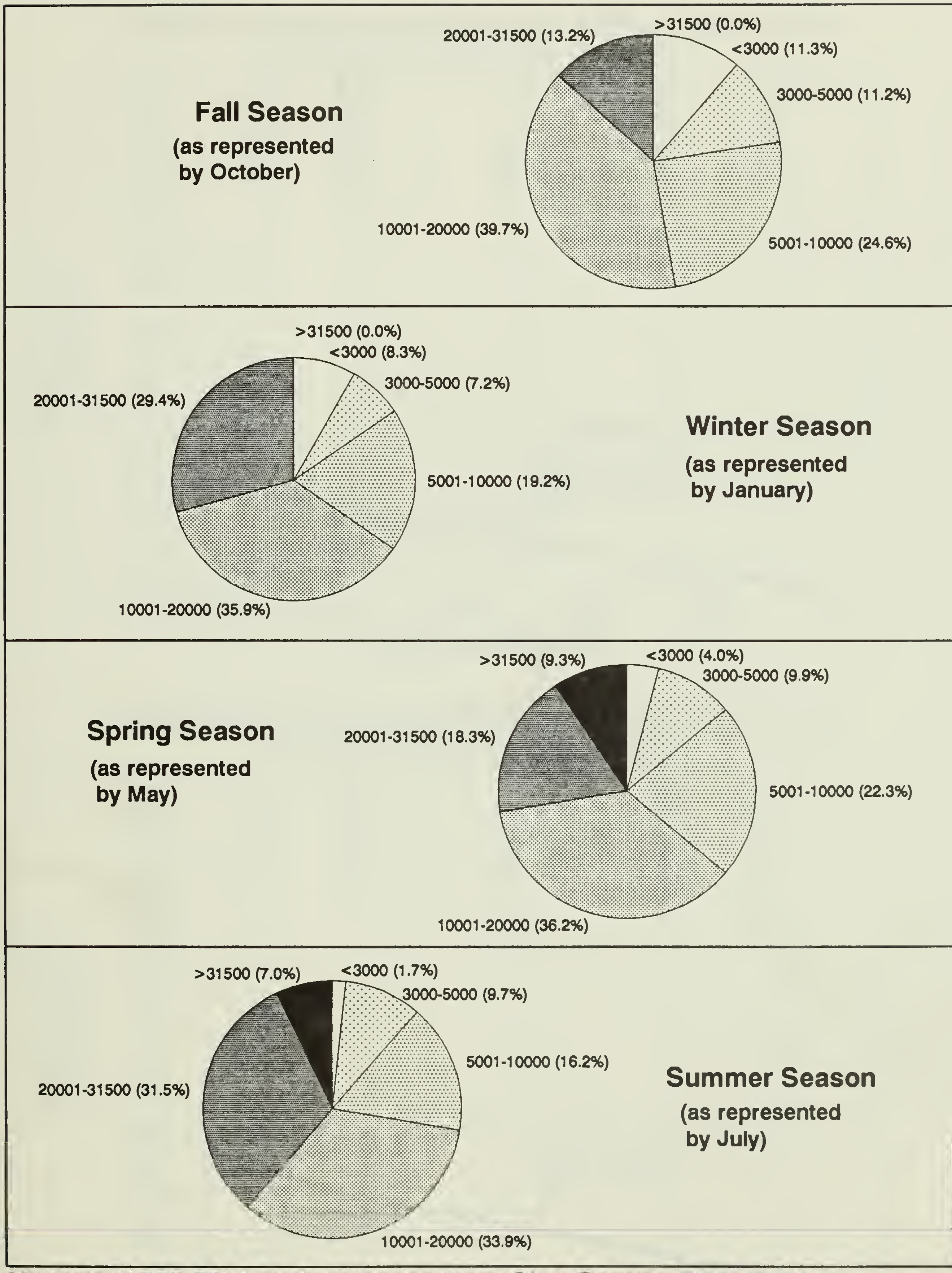


Frequencies of

# Historic Hourly Releases at Glen Canyon Dam (cfs)

A. Pie Chart Summaries by Season

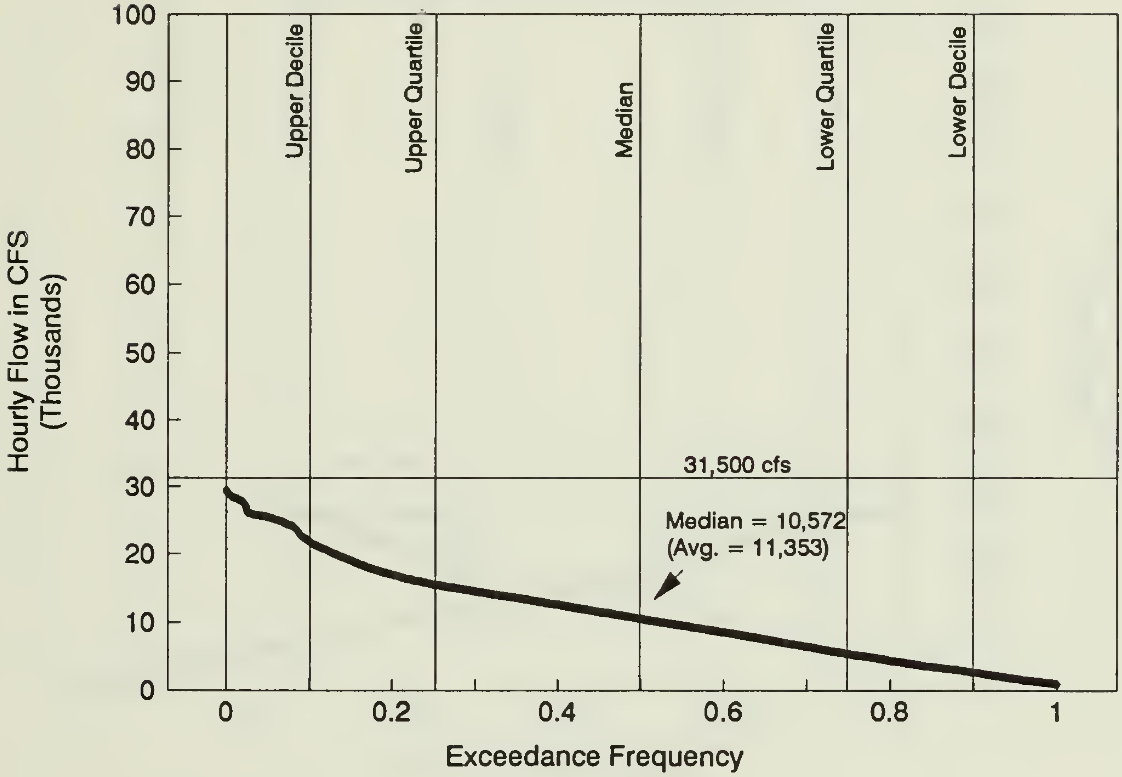
B. Individual Months (12 frequency graphs)




**Historic (1966-89) hourly releases from Glen Canyon Dam in cfs (percent of hours that the specified flows occurred)**

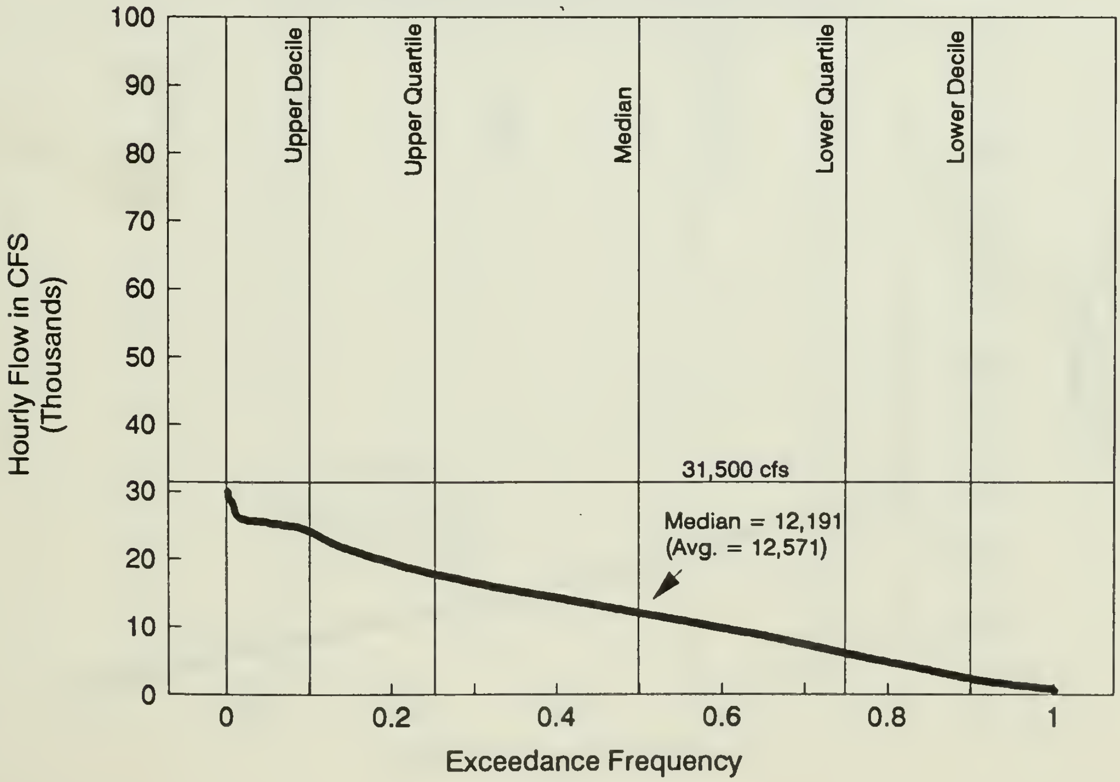
**Historic October Hourly Releases at Glen Canyon Dam**

Flow Duration for Water Years 1966-1989



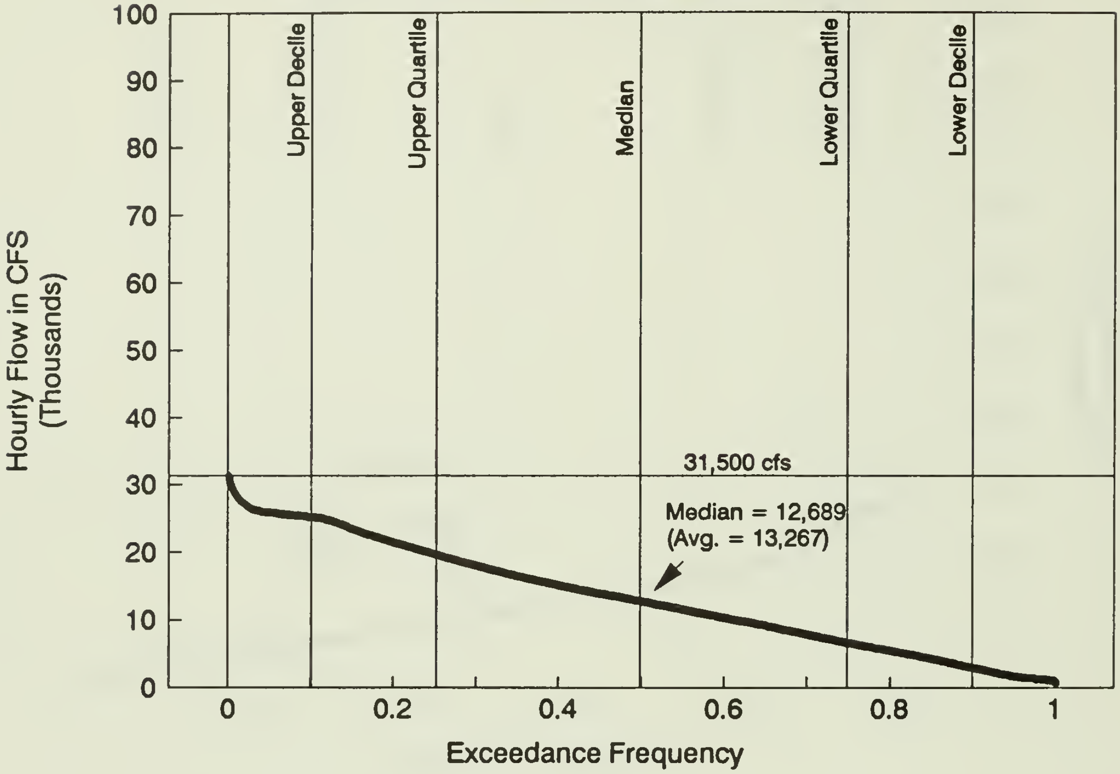

**Historic November Hourly Releases at Glen Canyon Dam**

Flow Duration for Water Years 1966-1989



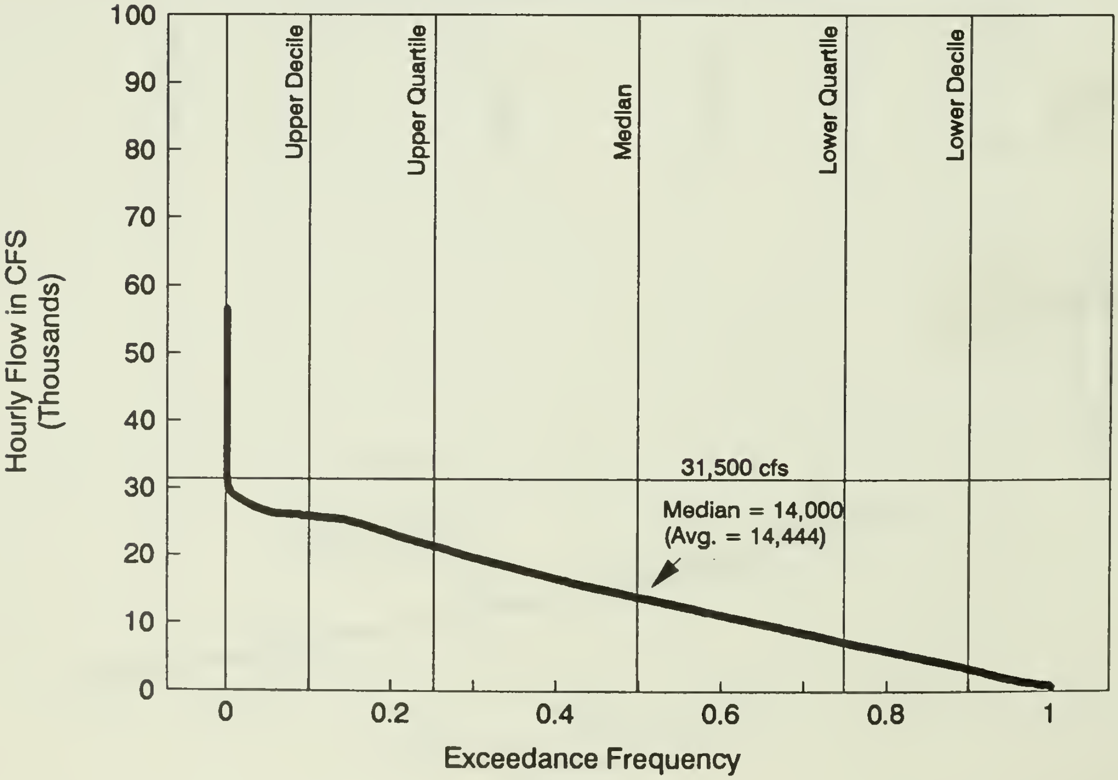
## Historic December Hourly Releases at Glen Canyon Dam

Flow Duration for Water Years 1966-1989



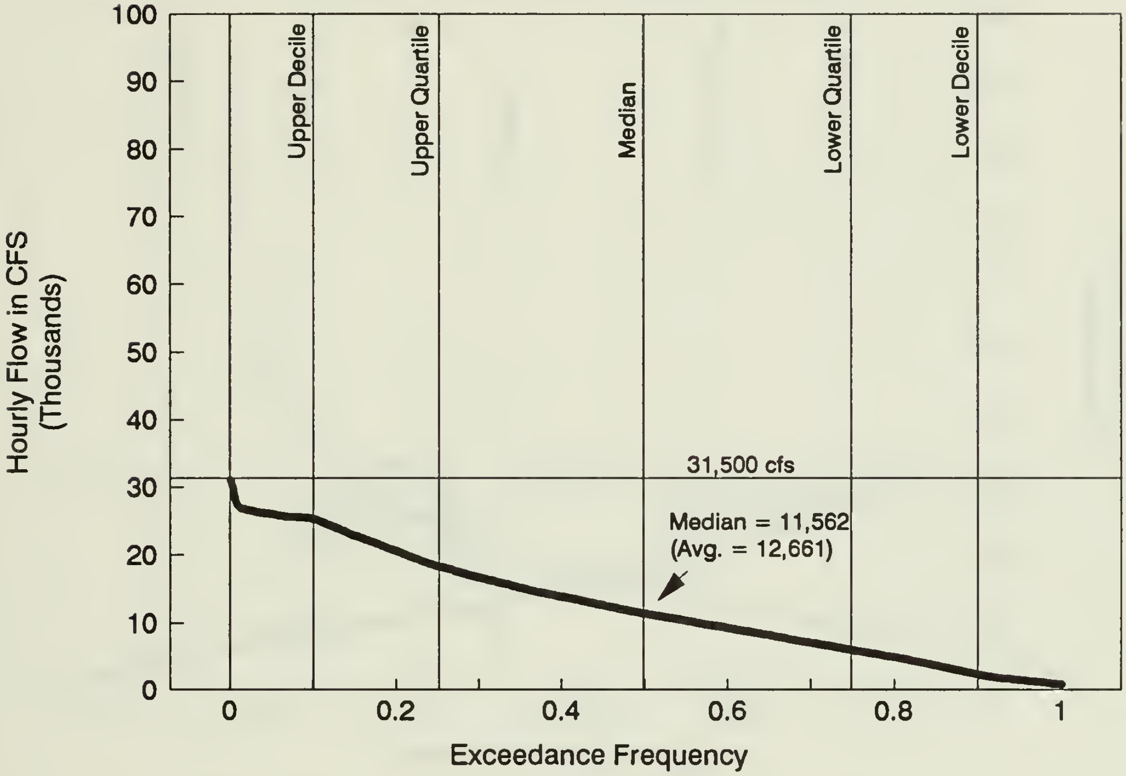

## Historic January Hourly Releases at Glen Canyon Dam

Flow Duration for Water Years 1966-1989



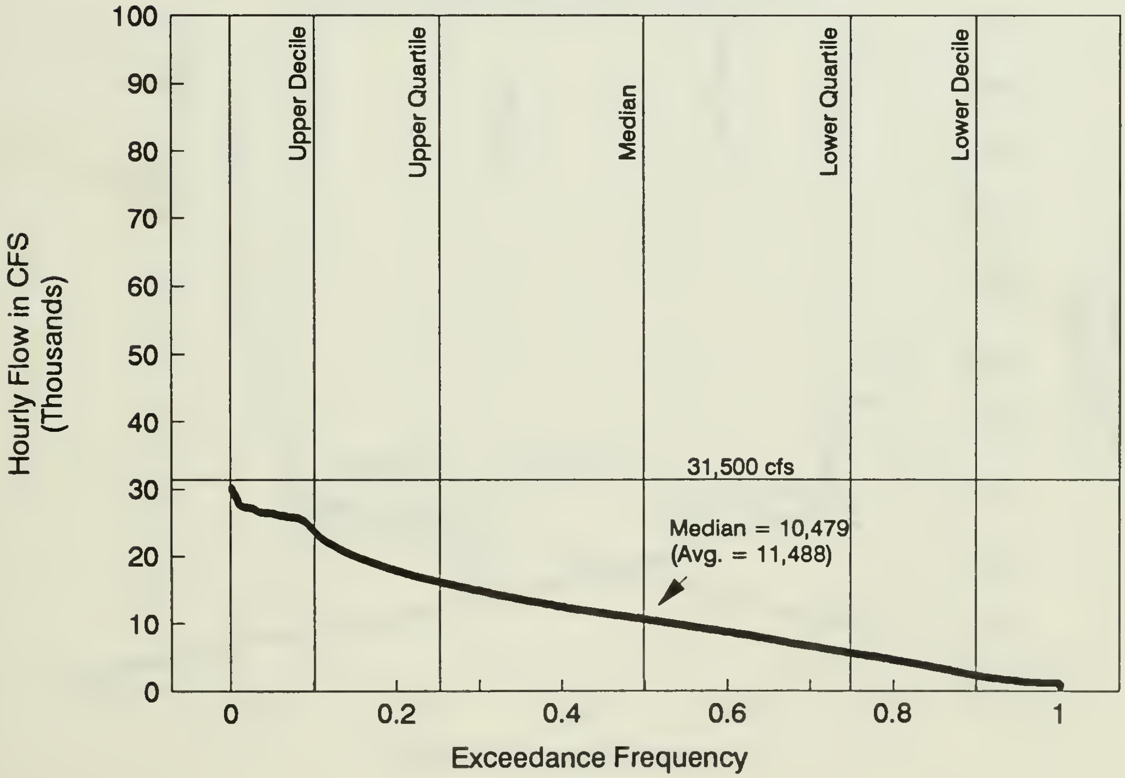
## Historic February Hourly Releases at Glen Canyon Dam

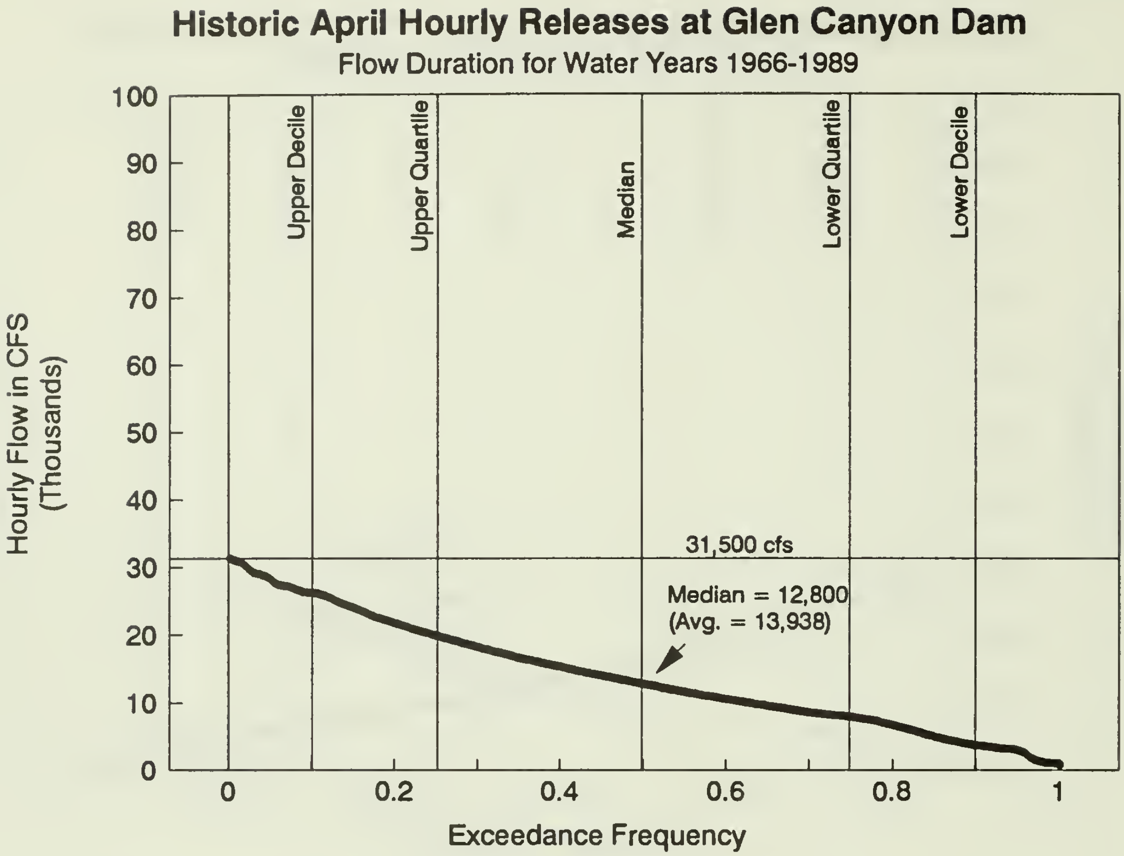
Flow Duration for Water Years 1966-1989



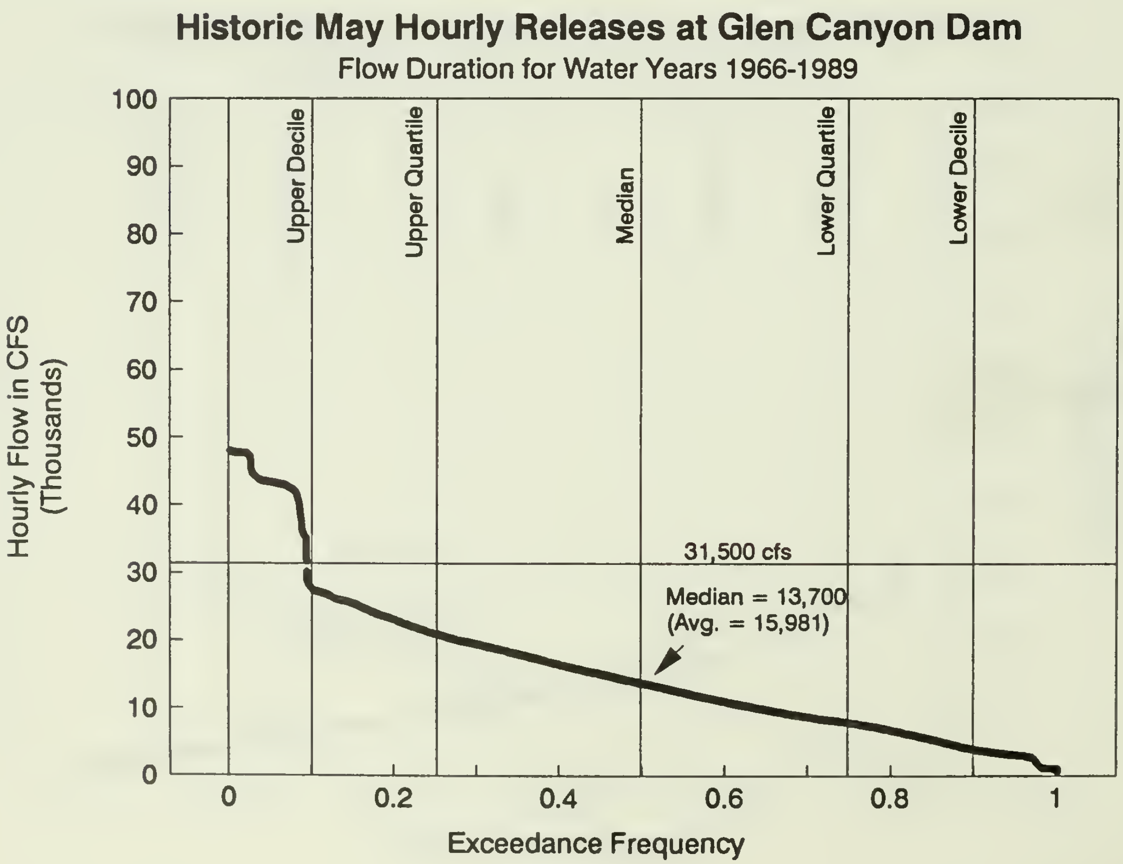

## Historic March Hourly Releases at Glen Canyon Dam

Flow Duration for Water Years 1966-1989





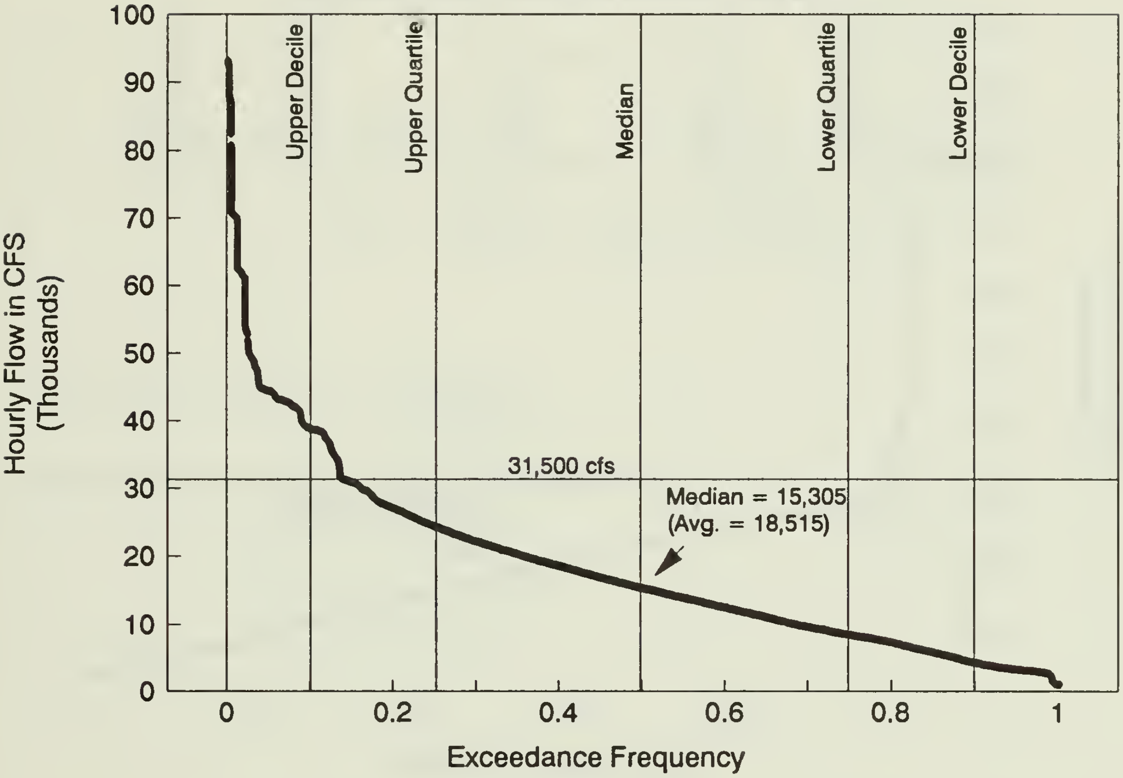
Historic April Hourly Releases at Glen Canyon Dam
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 12,800
(Avg. = 13,938)
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1

Historic May Hourly Releases at Glen Canyon Dam
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 13,700
(Avg. = 15,981)
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1

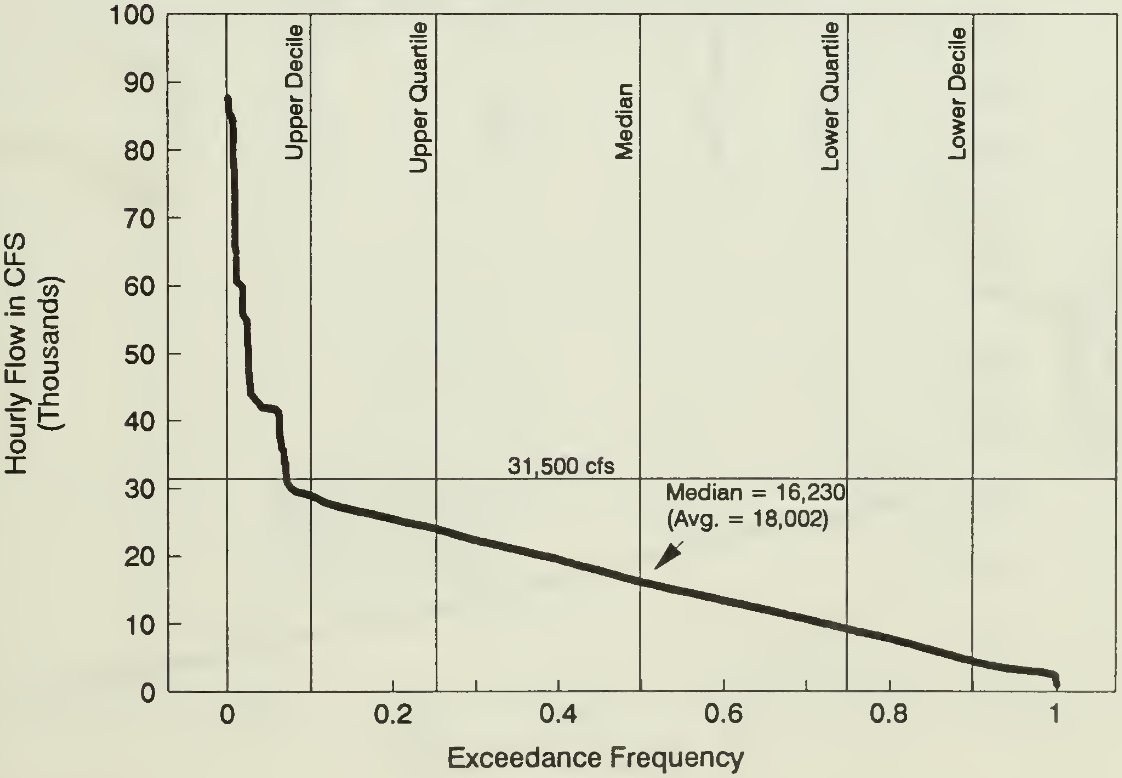
## Historic June Hourly Releases at Glen Canyon Dam

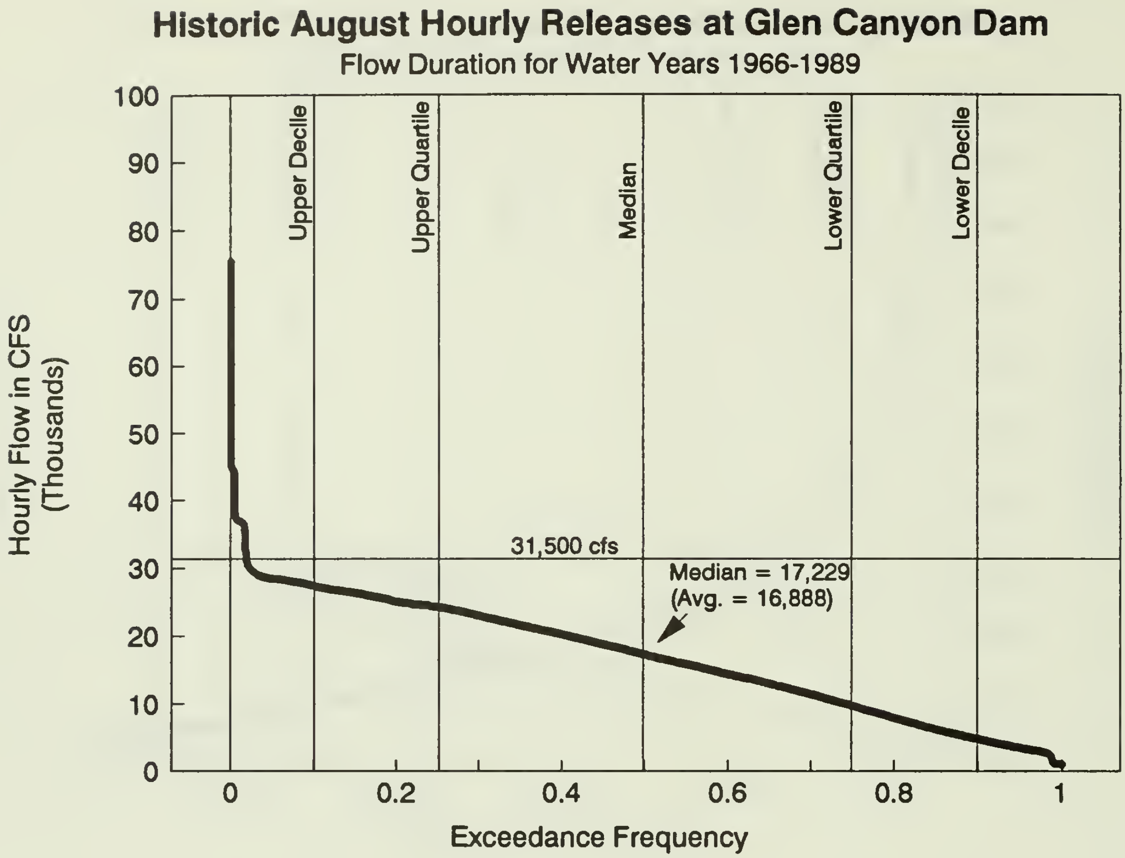
Flow Duration for Water Years 1966-1989

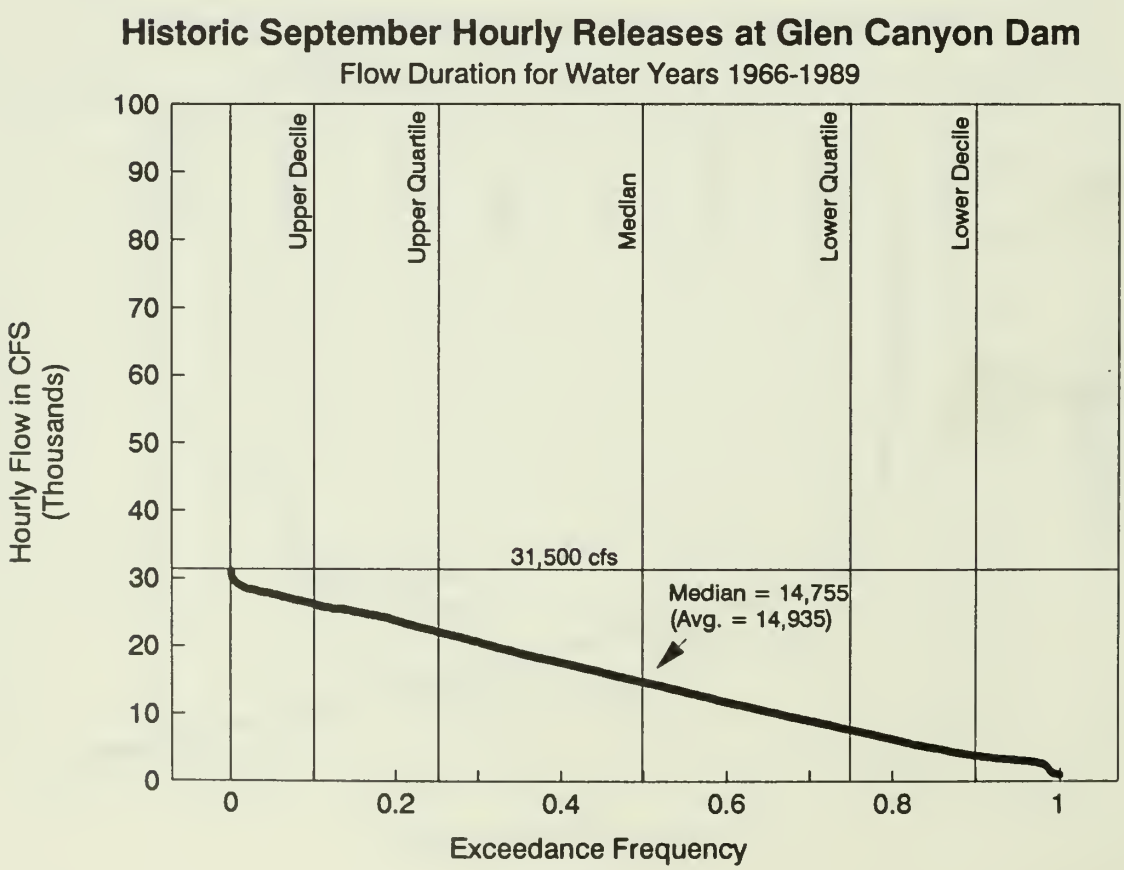



## Historic July Hourly Releases at Glen Canyon Dam

Flow Duration for Water Years 1966-1989




Historic August Hourly Releases at Glen Canyon Dam
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 17,229
(Avg. = 16,888)
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1

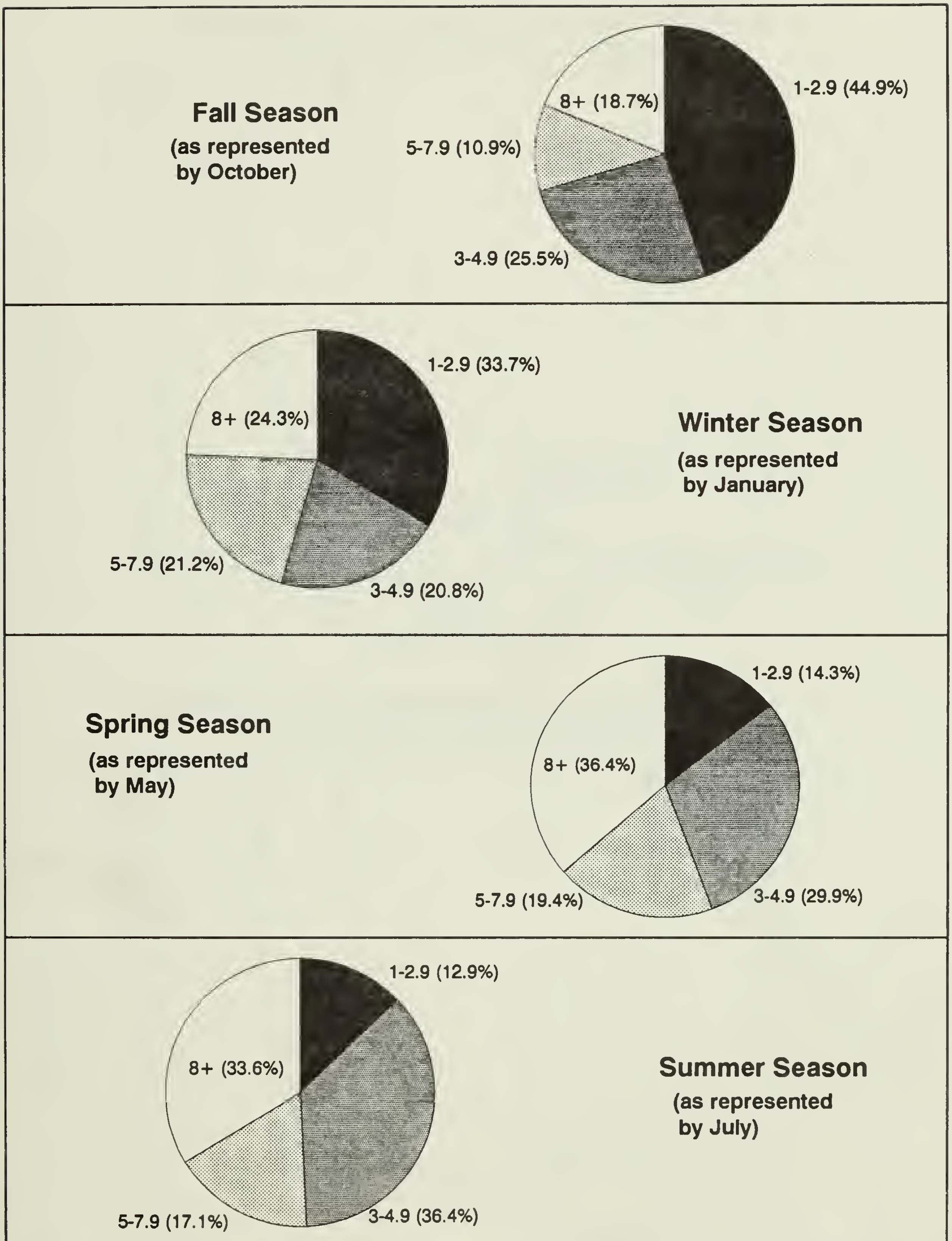

Historic September Hourly Releases at Glen Canyon Dam
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 14,755
(Avg. = 14,935)
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1

Frequencies of

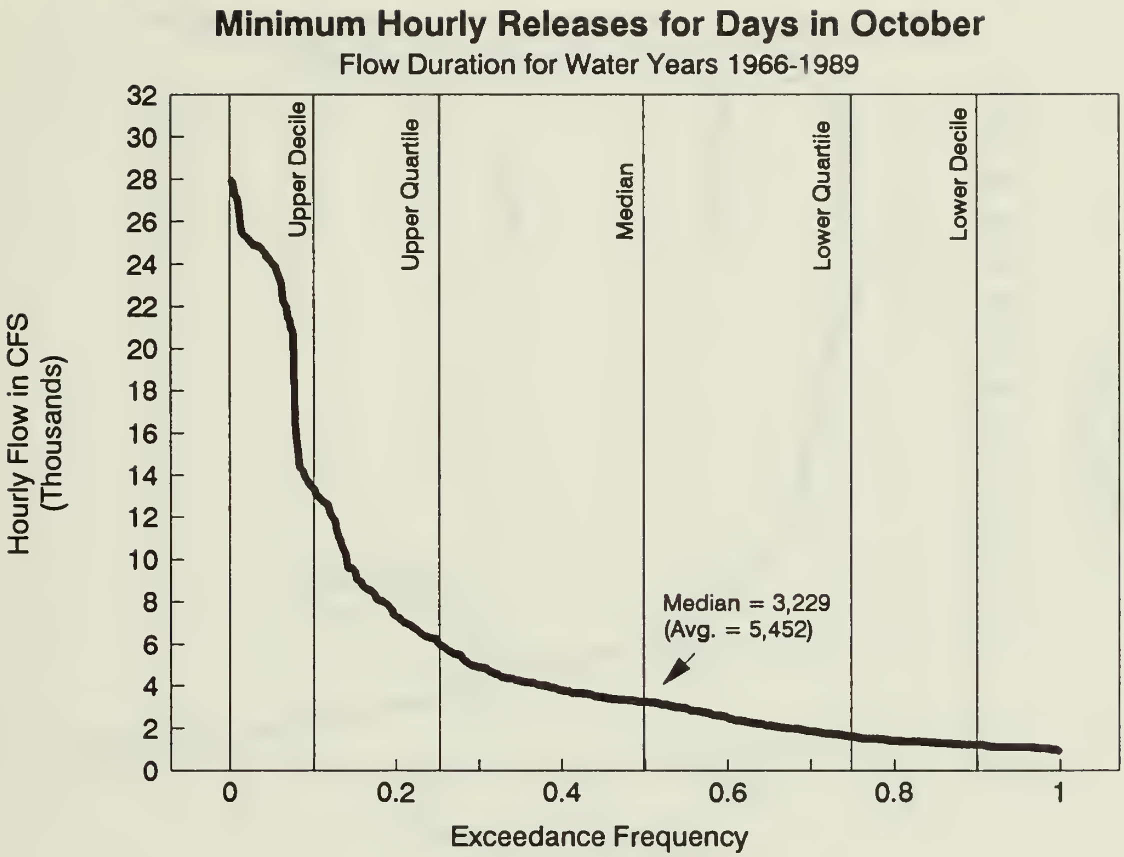
# Historic Minimum Hourly Releases for Each Day (cfs)

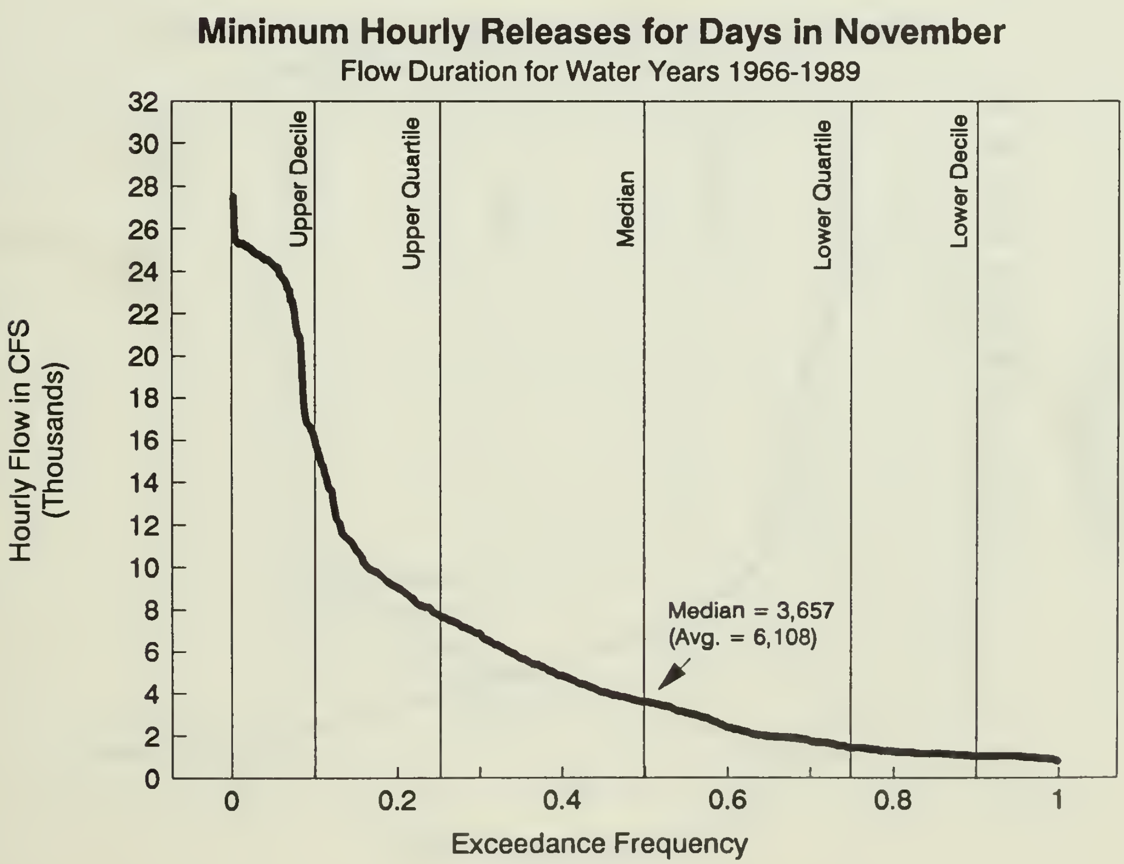
A. Pie Chart Summaries by Season

B. Individual Months (12 frequency graphs)



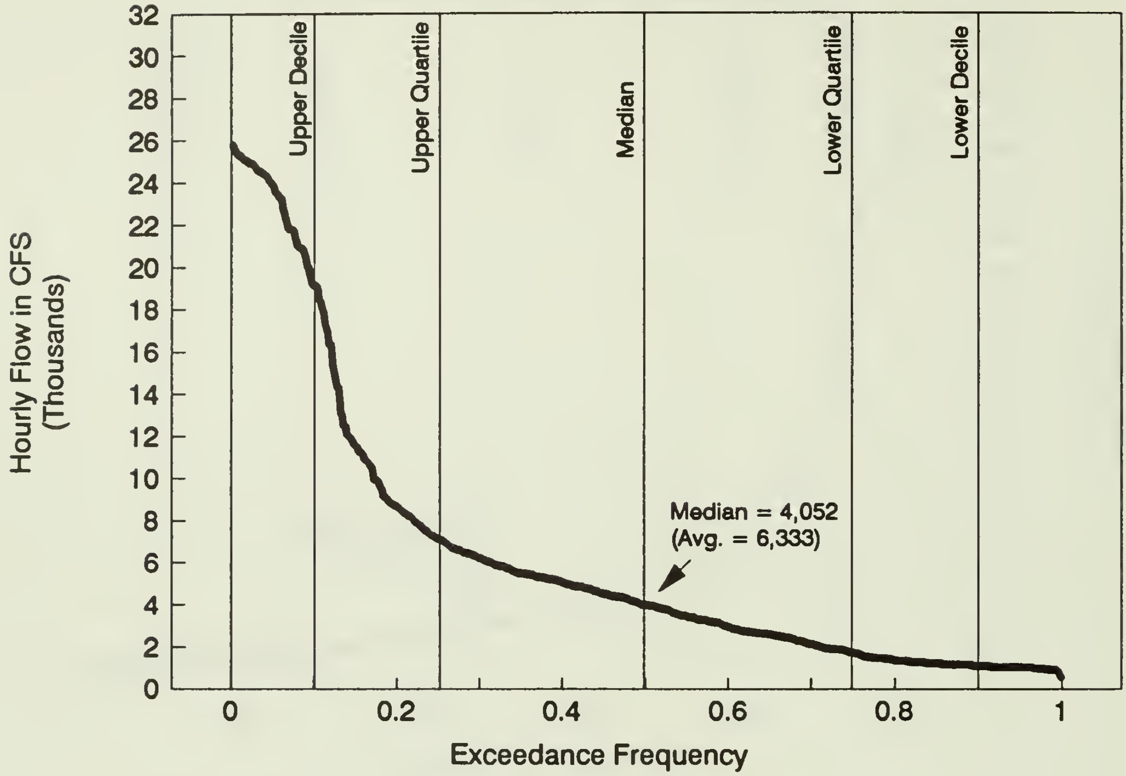

**Historic (1966-89) minimum hourly releases from Glen Canyon Dam (1000 cfs) (percent of days that the specified minimums occurred)**


Minimum Hourly Releases for Days in October
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS
(Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 3,229
(Avg. = 5,452)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency


Minimum Hourly Releases for Days in November
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS
(Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 3,657
(Avg. = 6,108)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

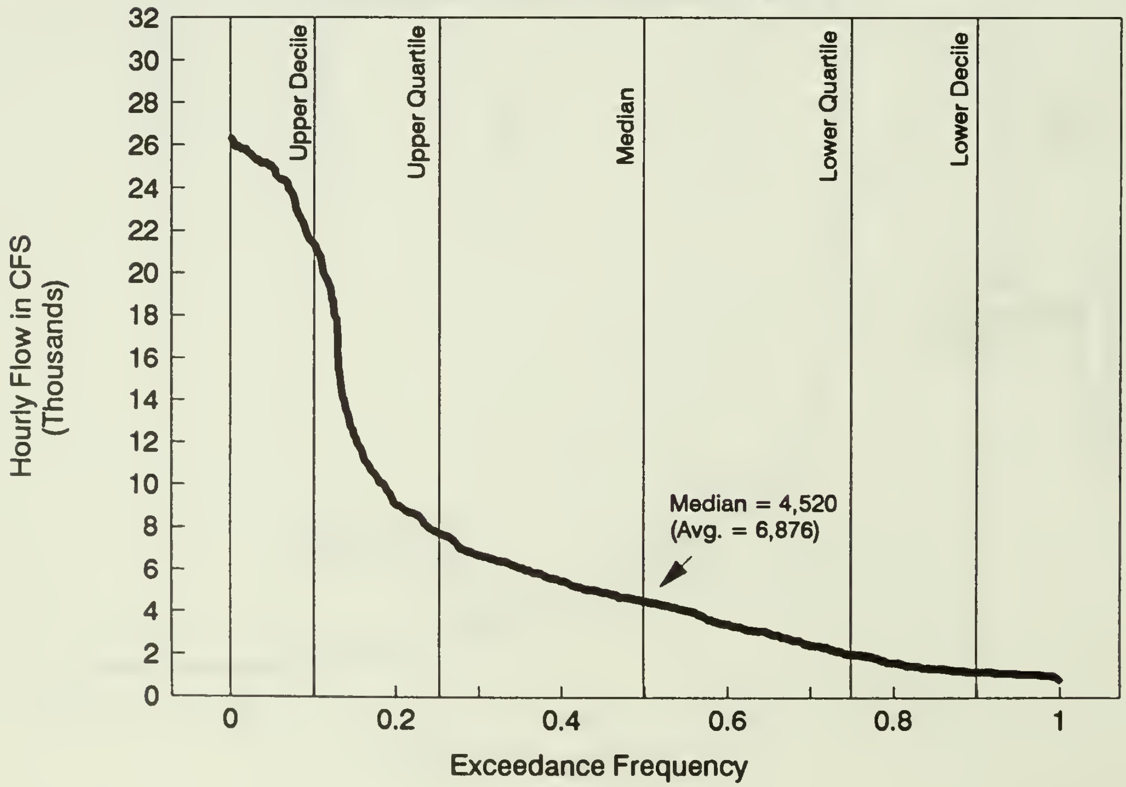
## Minimum Hourly Releases for Days in December

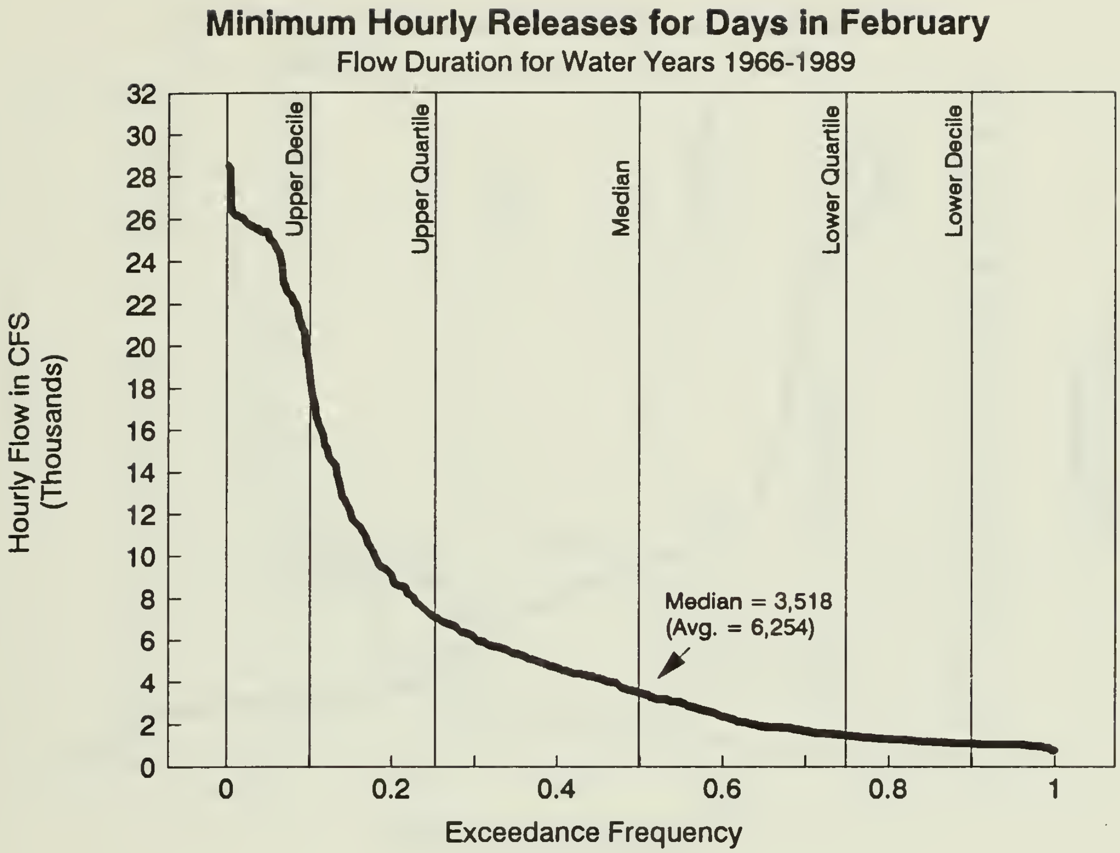
Flow Duration for Water Years 1966-1989

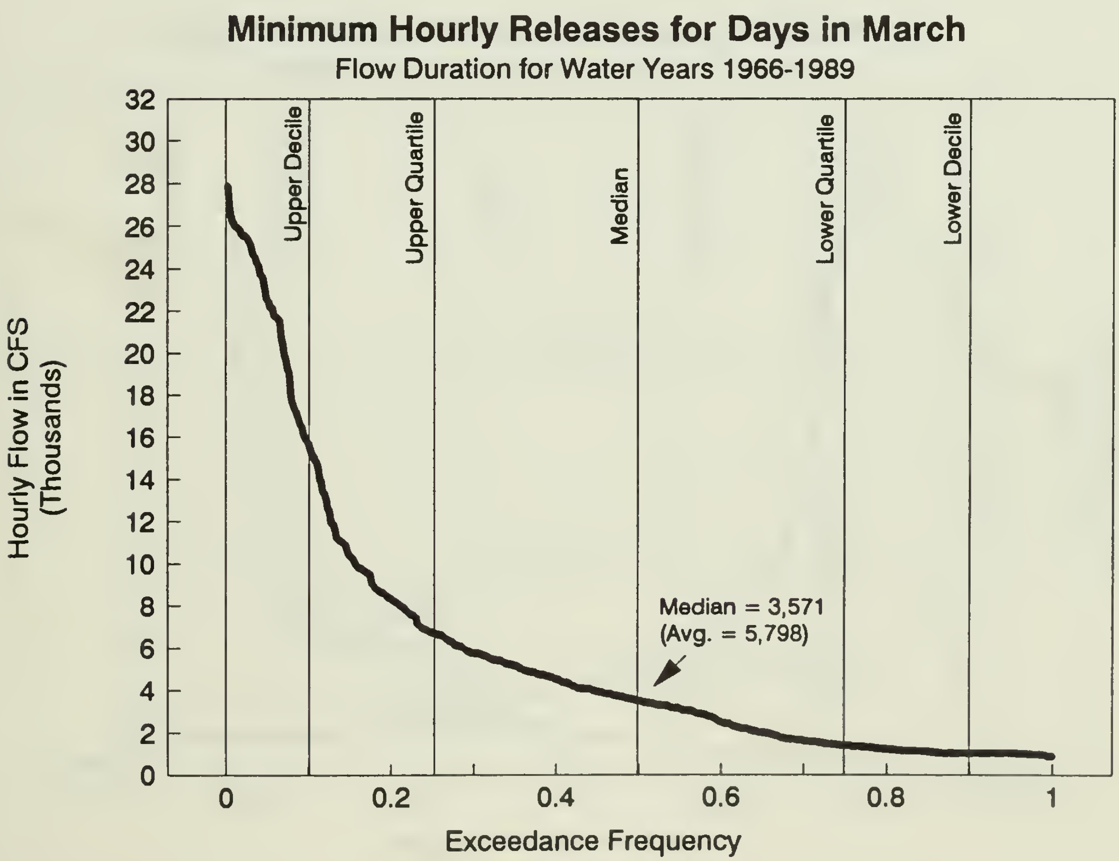


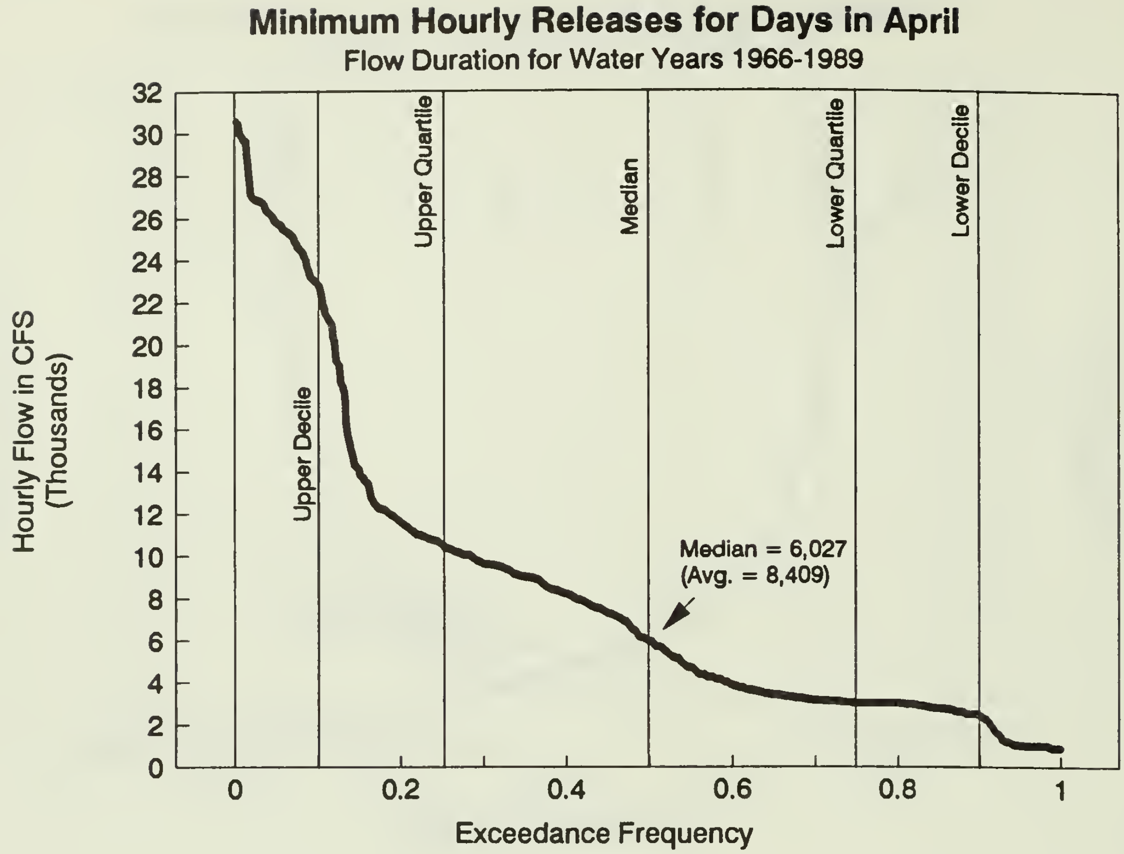

## Minimum Hourly Releases for Days In January

Flow Duration for Water Years 1966-1989

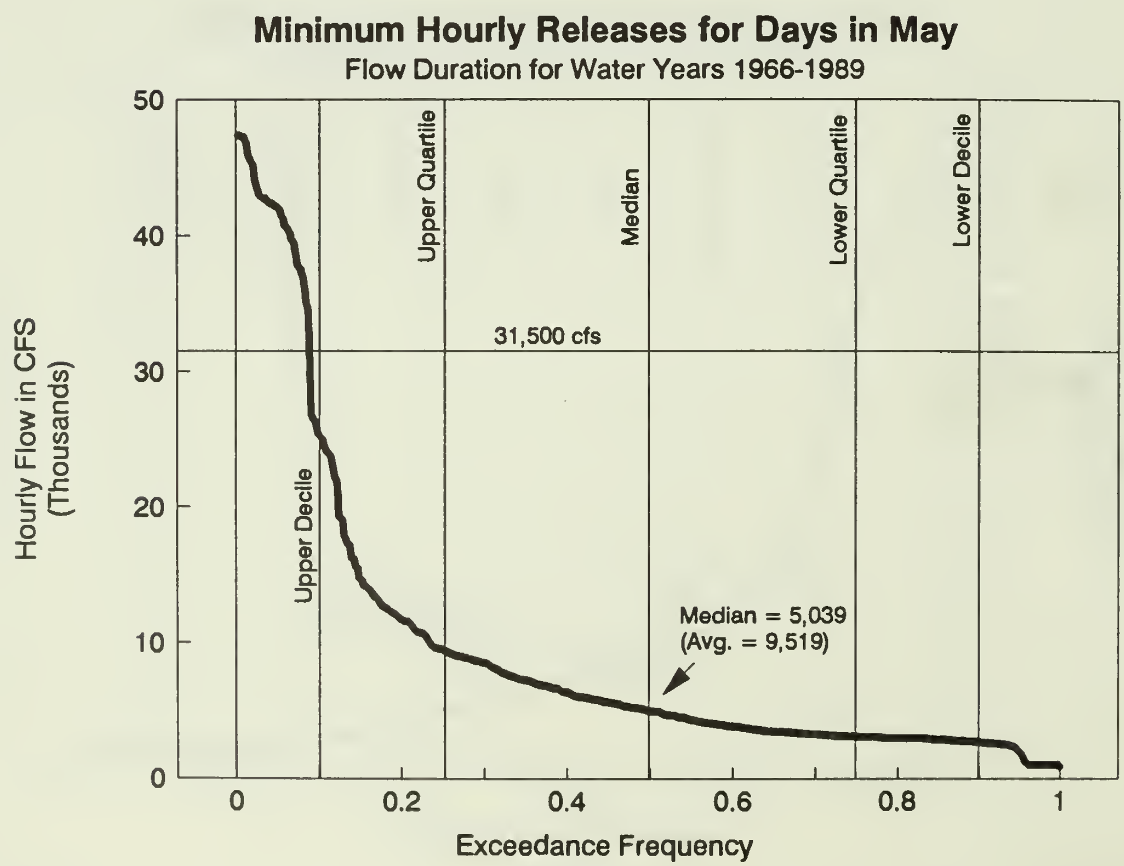



Minimum Hourly Releases for Days in February
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 3,518
(Avg. = 6,254)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
0.2
0.4
0.6
0.8
1

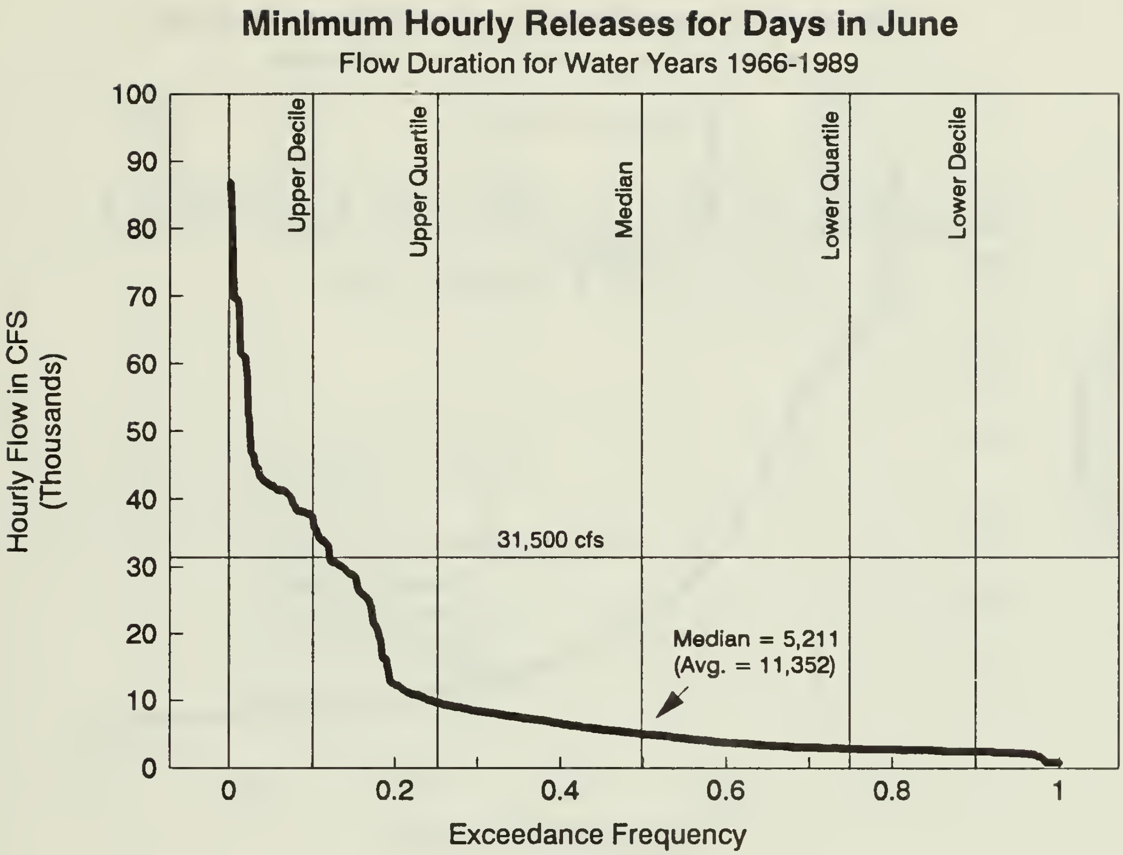

Minimum Hourly Releases for Days in March
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 3,571
(Avg. = 5,798)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
0.2
0.4
0.6
0.8
1

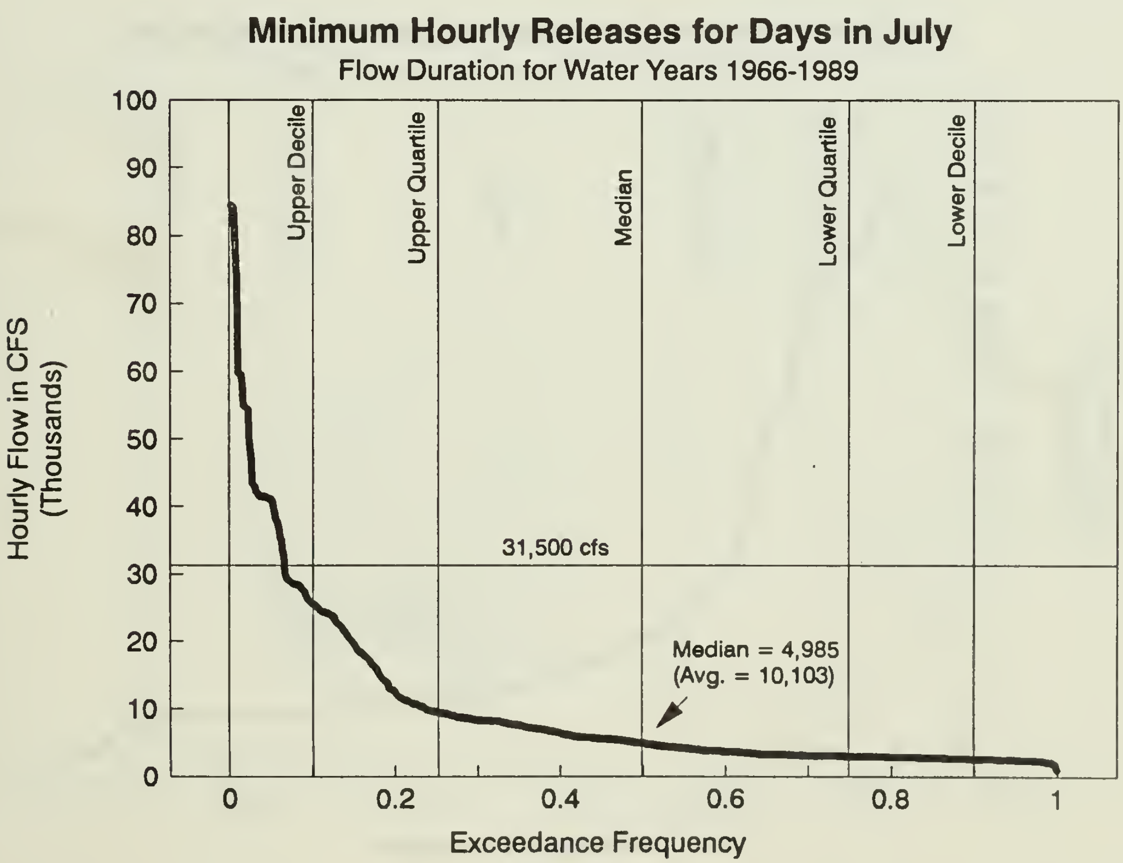


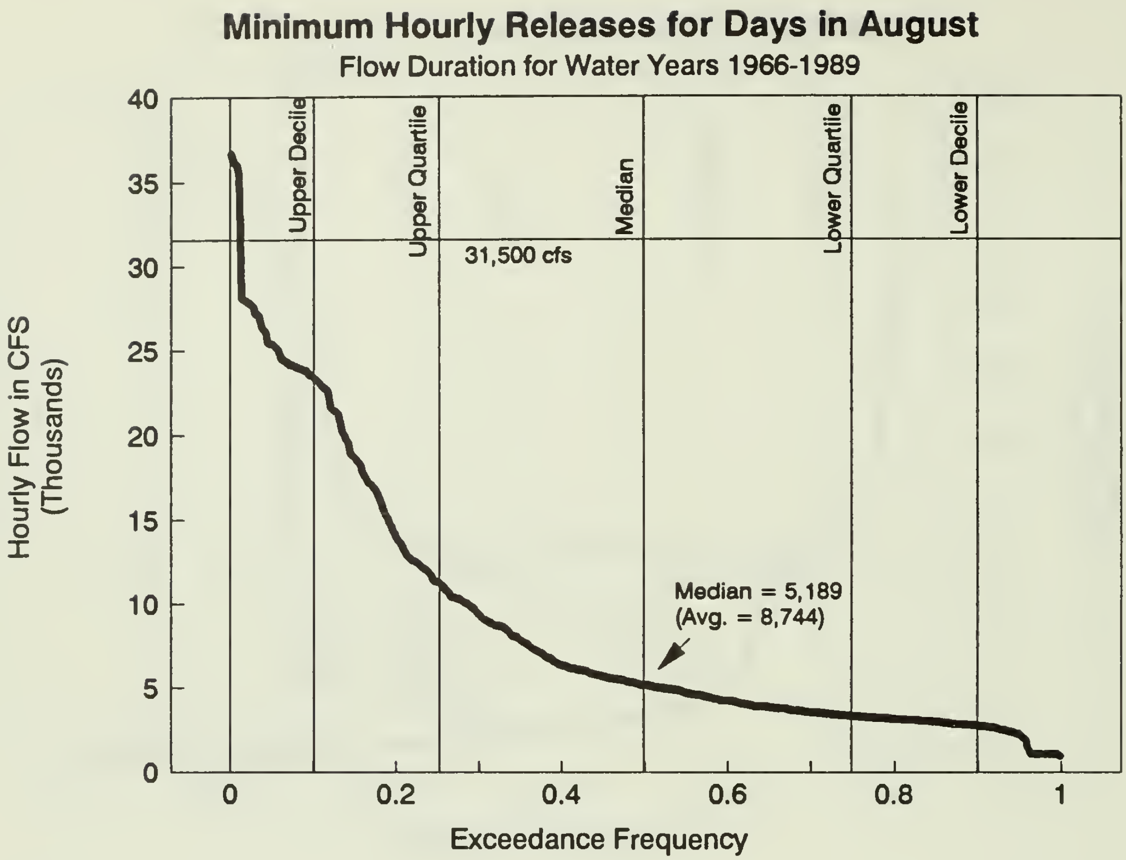
Minimum Hourly Releases for Days in April
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 6,027
(Avg. = 8,409)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0.2
0.4
0.6
0.8
1

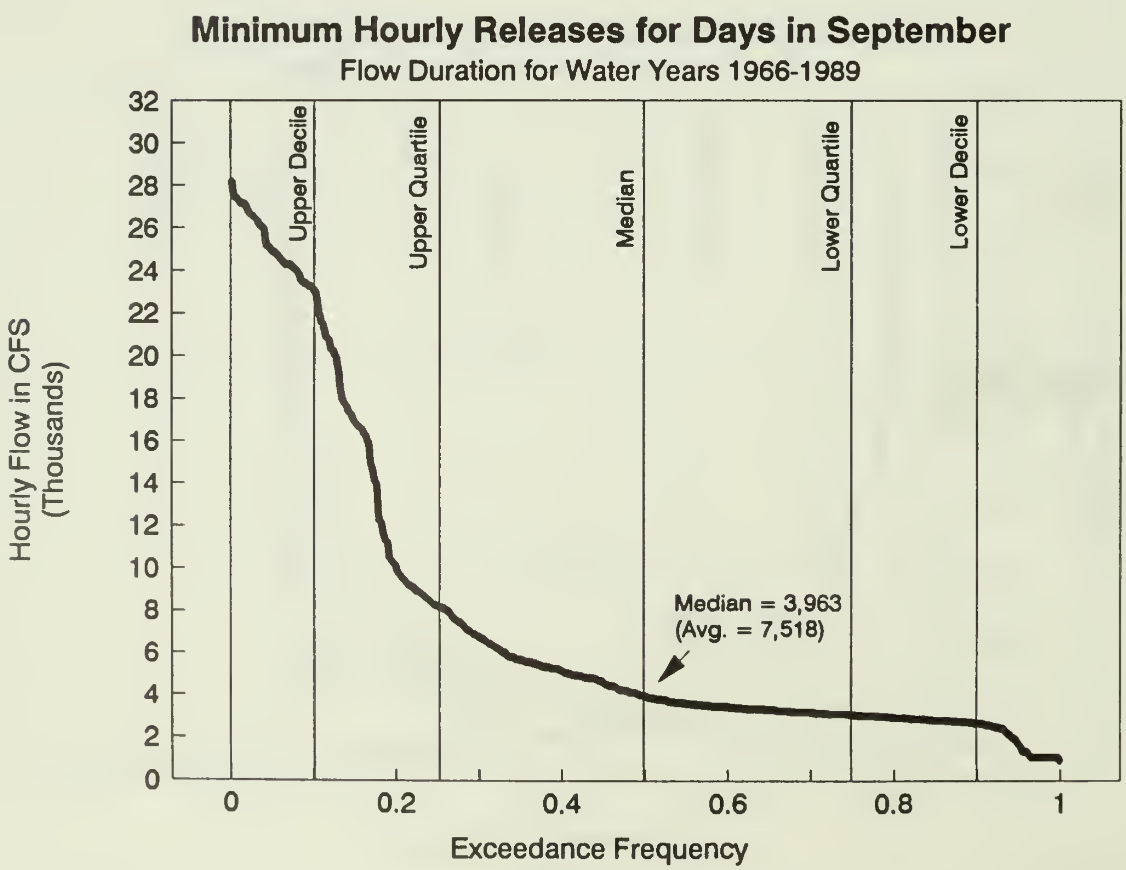
Minimum Hourly Releases for Days in May
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 5,039
(Avg. = 9,519)
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1


Minimum Hourly Releases for Days in June
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 5,211
(Avg. = 11,352)
0
10
20
30
40
50
60
70
80
90
100
0
0.2
0.4
0.6
0.8
1


Minimum Hourly Releases for Days in July
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 4,985
(Avg. = 10,103)
0
10
20
30
40
50
60
70
80
90
100
0
0.2
0.4
0.6
0.8
1



Minimum Hourly Releases for Days in August
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 5,189
(Avg. = 8,744)

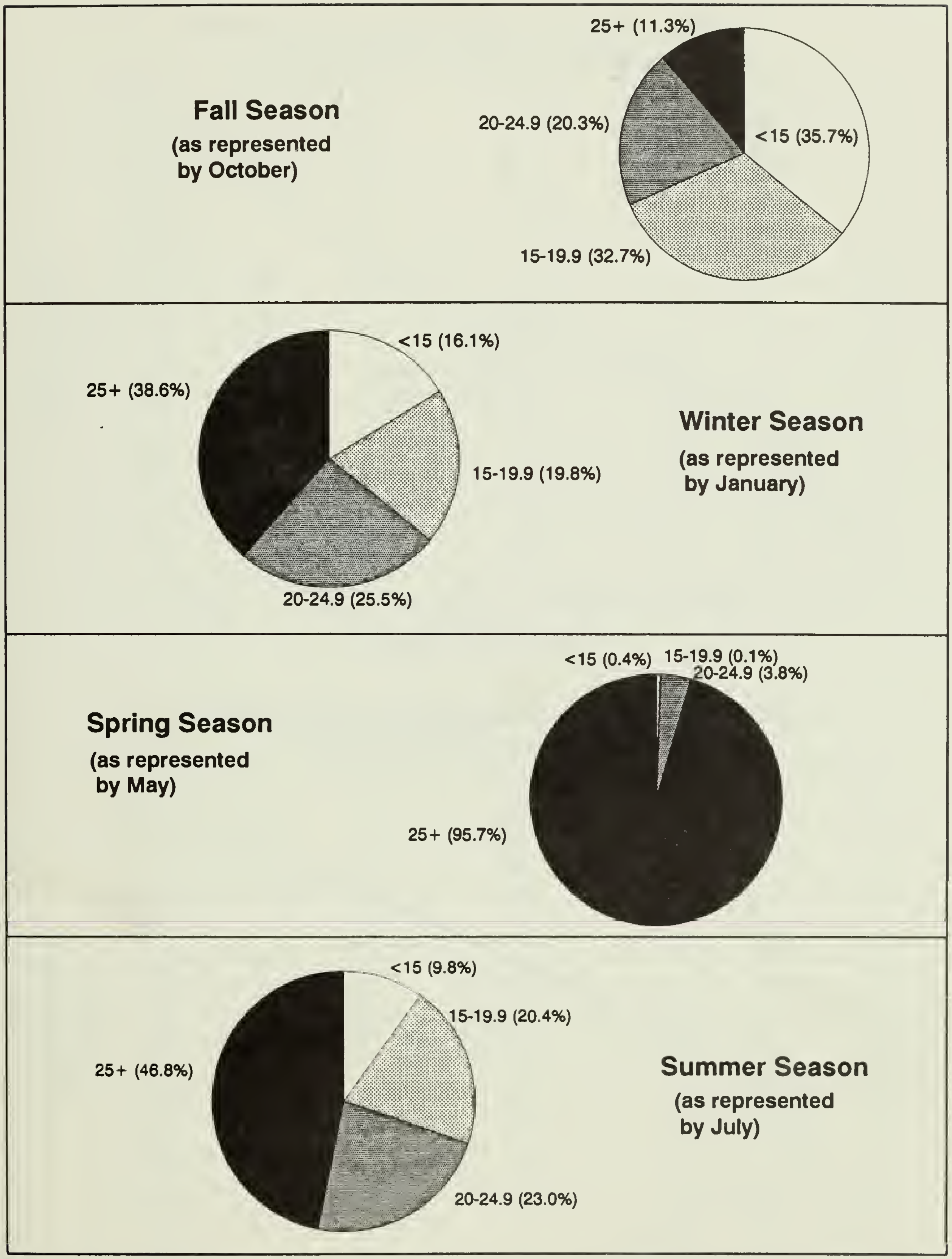
Minimum Hourly Releases for Days in September
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 3,963
(Avg. = 7,518)

Frequencies of

# Historic Maximum Hourly Releases for Each Day (cfs)

A. Pie Chart Summaries by Season

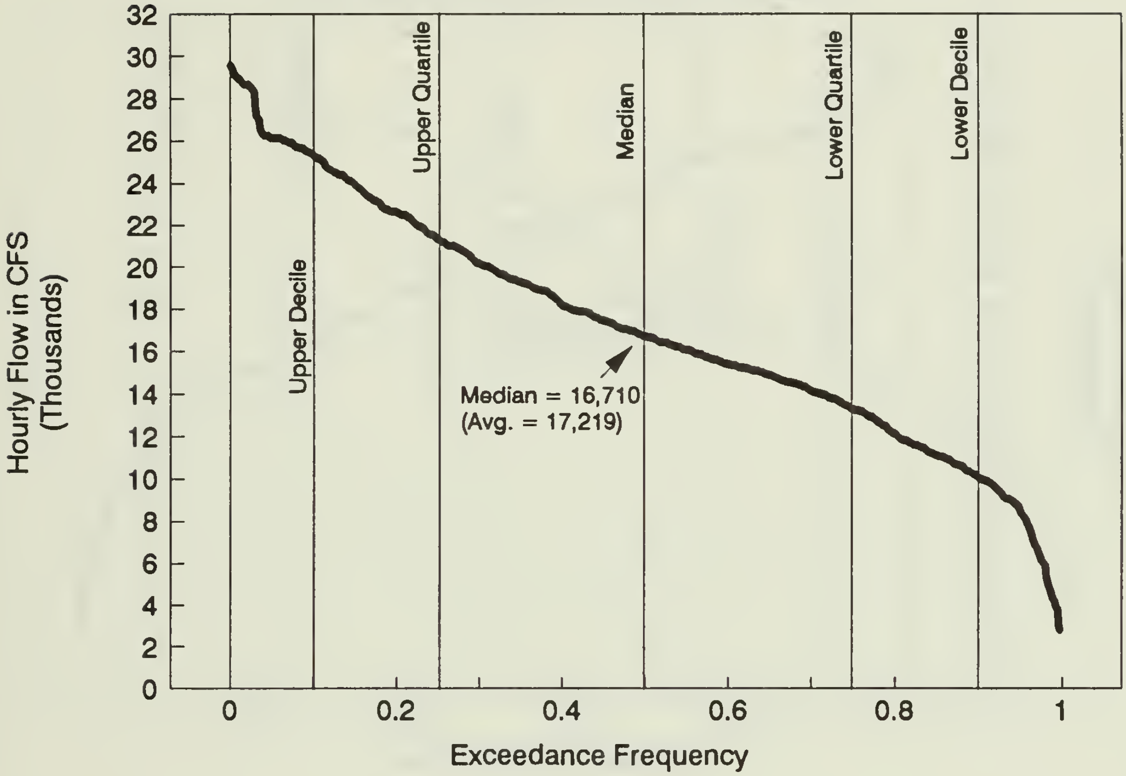
B. Individual Months (12 frequency graphs)




**Historic (1966-89) maximum hourly releases from Glen Canyon Dam (1000 cfs) (percent of days that the specified maximums occurred)**

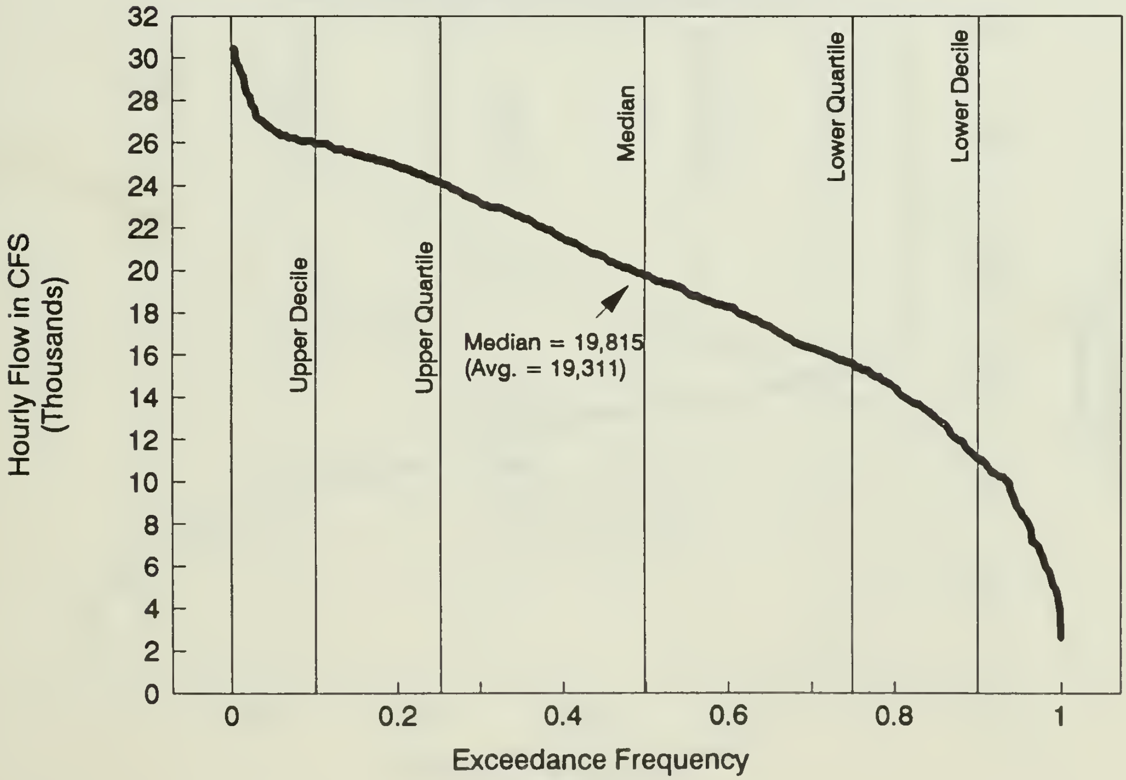
## Maximum Hourly Releases for Days in October

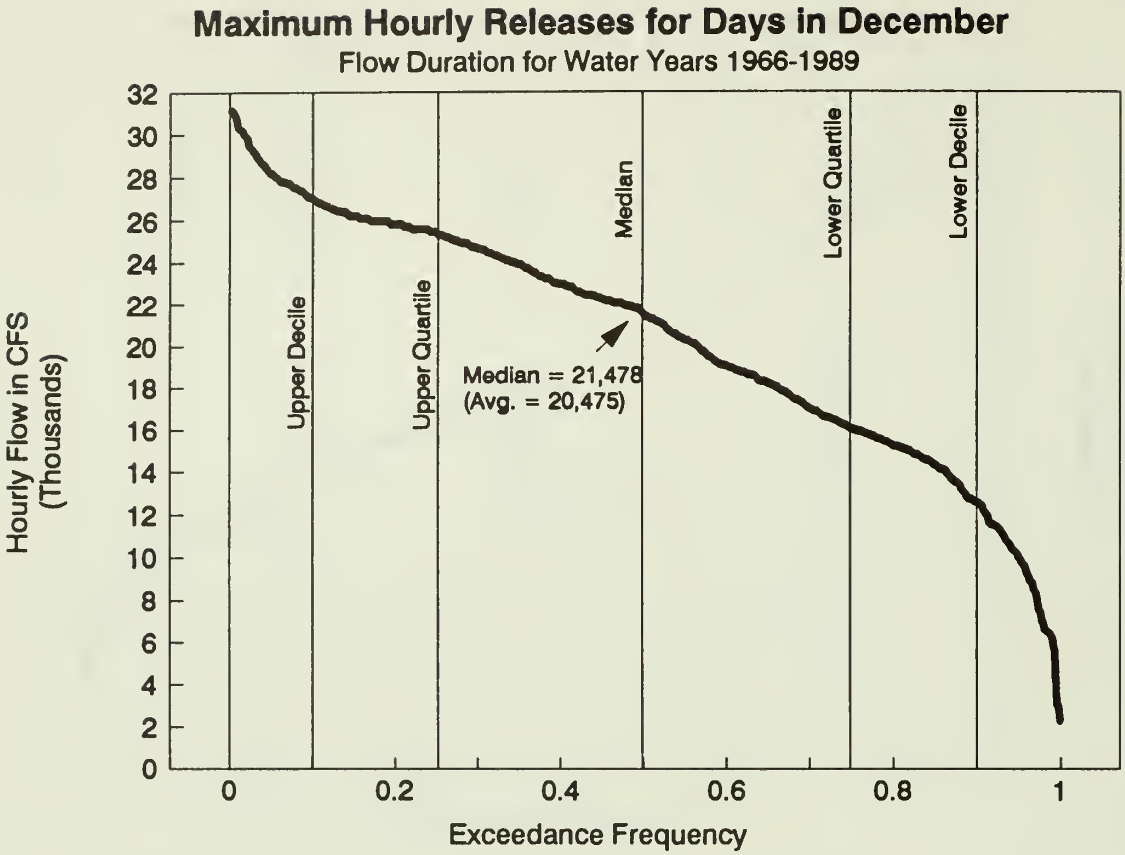
Flow Duration for Water Years 1966-1989

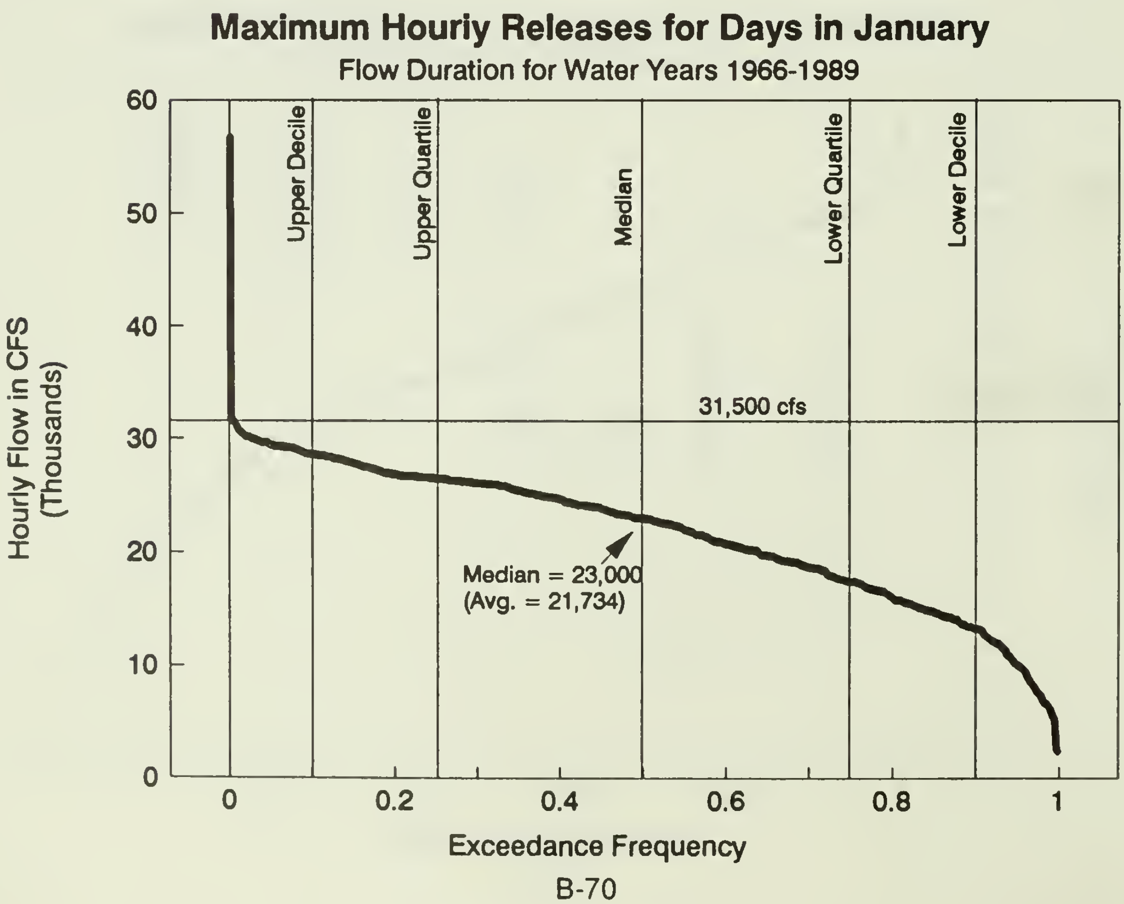



## Maximum Hourly Releases for Days in November

Flow Duration for Water Years 1966-1989

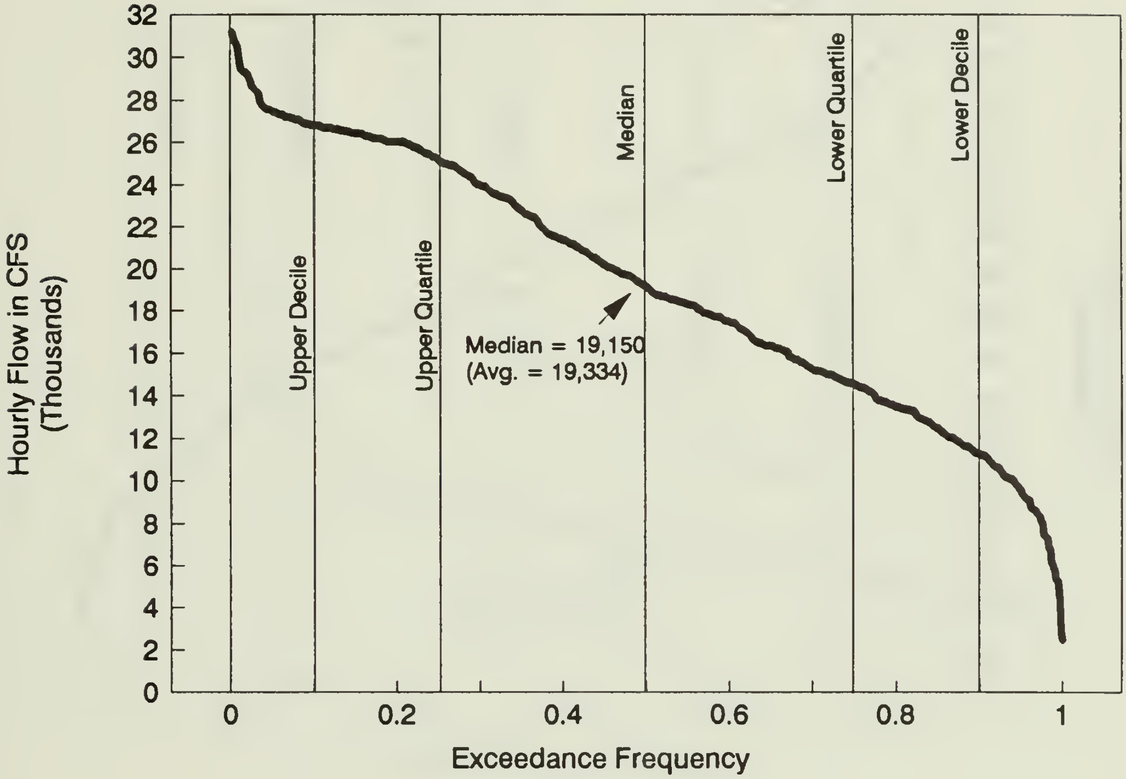



Maximum Hourly Releases for Days in December
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 21,478
(Avg. = 20,475)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
0.2
0.4
0.6
0.8
1


Maximum Hourly Releases for Days in January
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 23,000
(Avg. = 21,734)
0
10
20
30
40
50
60
0
0.2
0.4
0.6
0.8
1

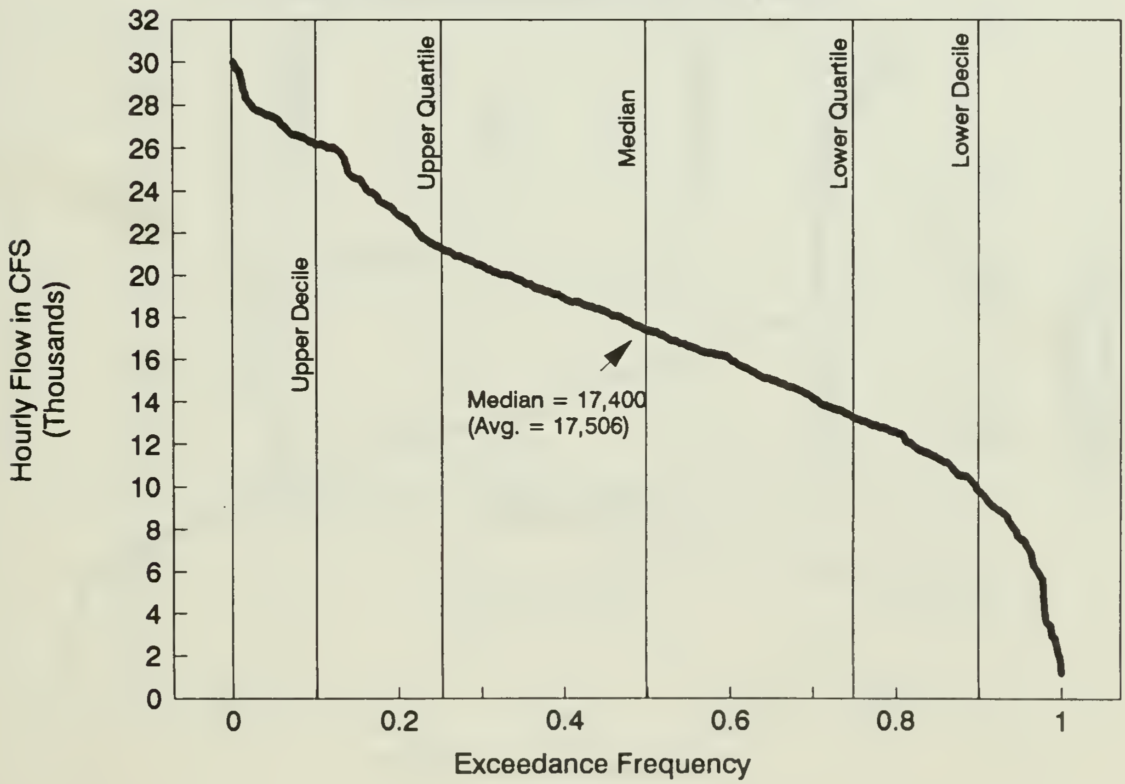
## Maximum Hourly Releases for Days in February

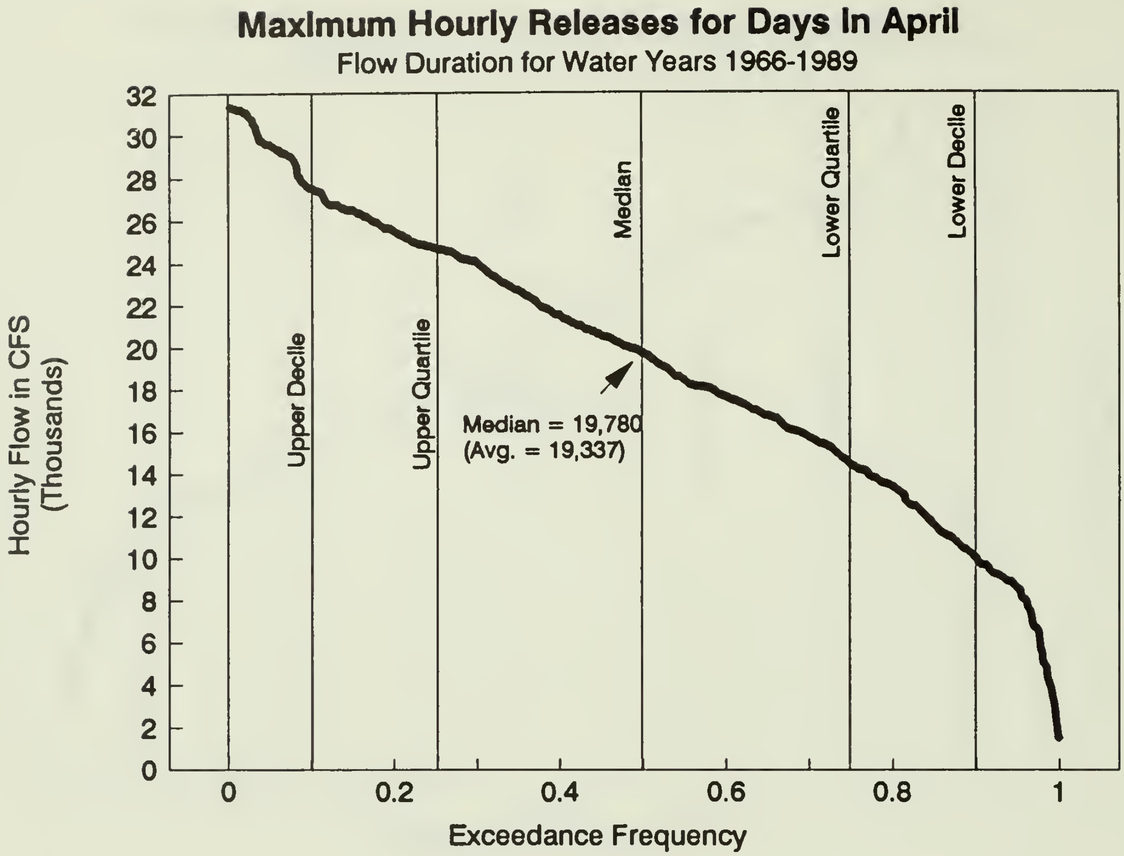
Flow Duration for Water Years 1966-1989

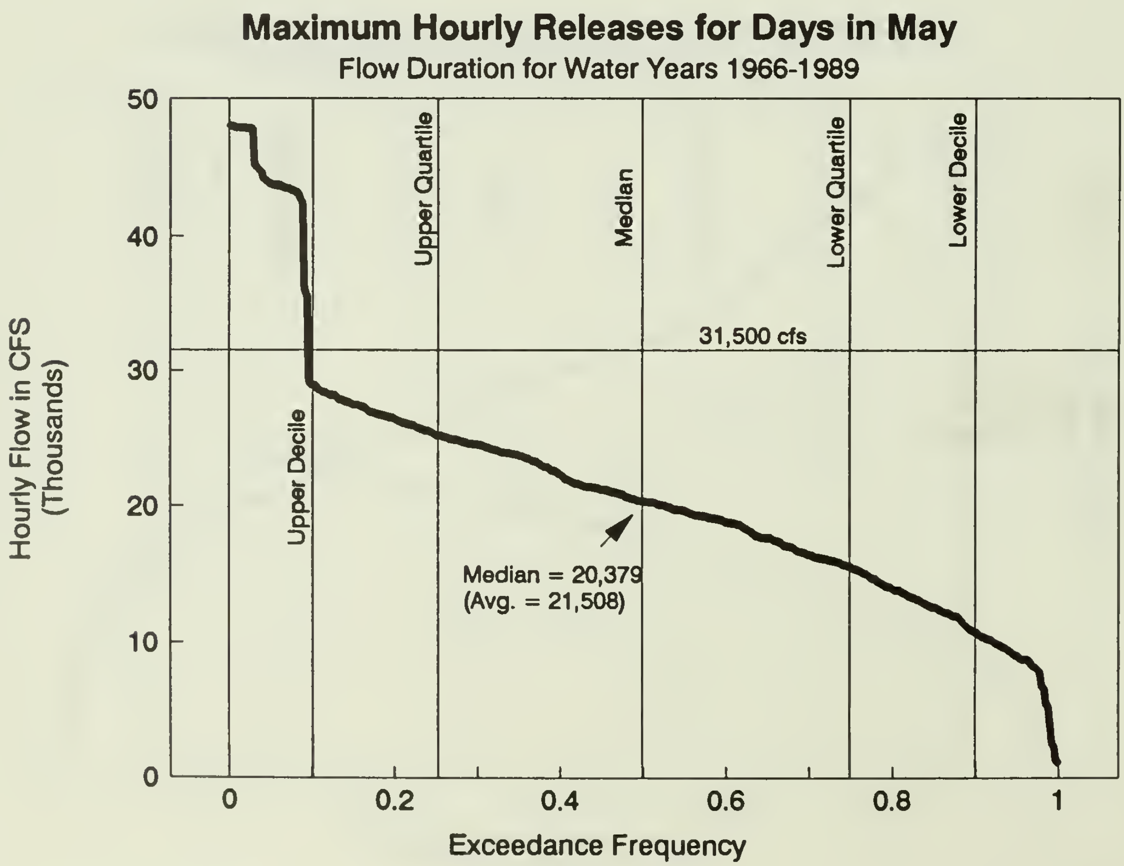



## Maximum Hourly Releases for Days in March

Flow Duration for Water Years 1966-1989

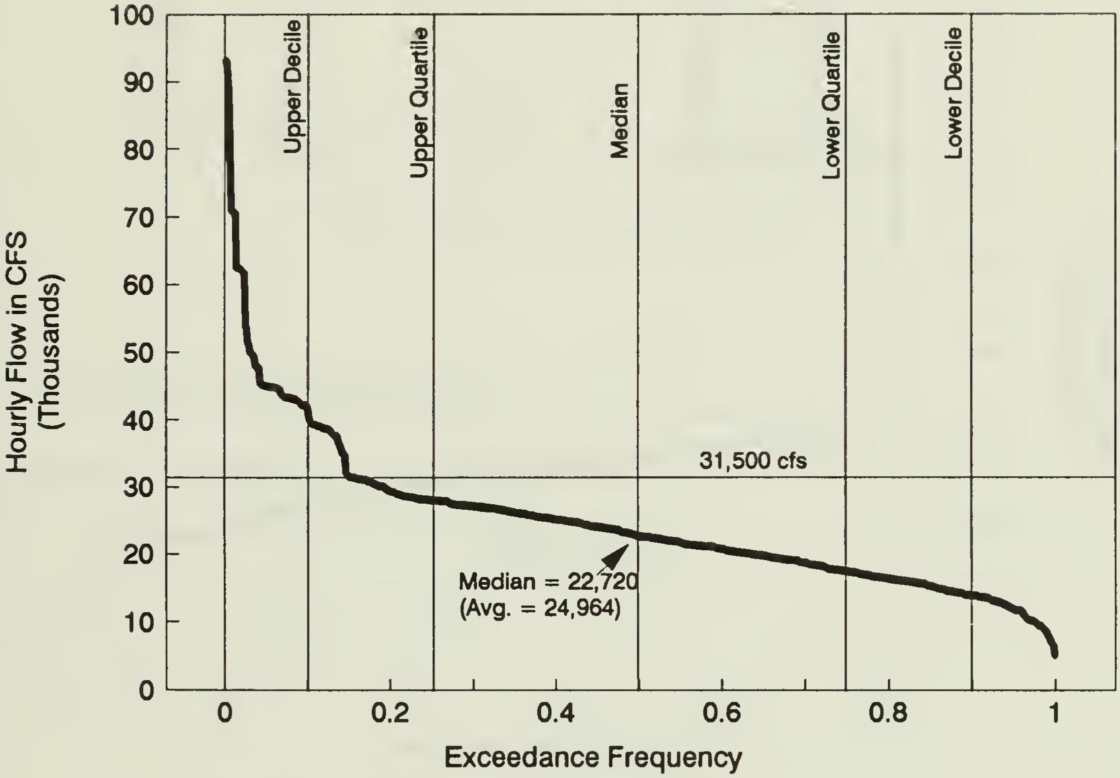



Maximum Hourly Releases for Days In April
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 19,780
(Avg. = 19,337)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency


Maximum Hourly Releases for Days in May
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
50
40
30
20
10
0
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 20,379
(Avg. = 21,508)
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

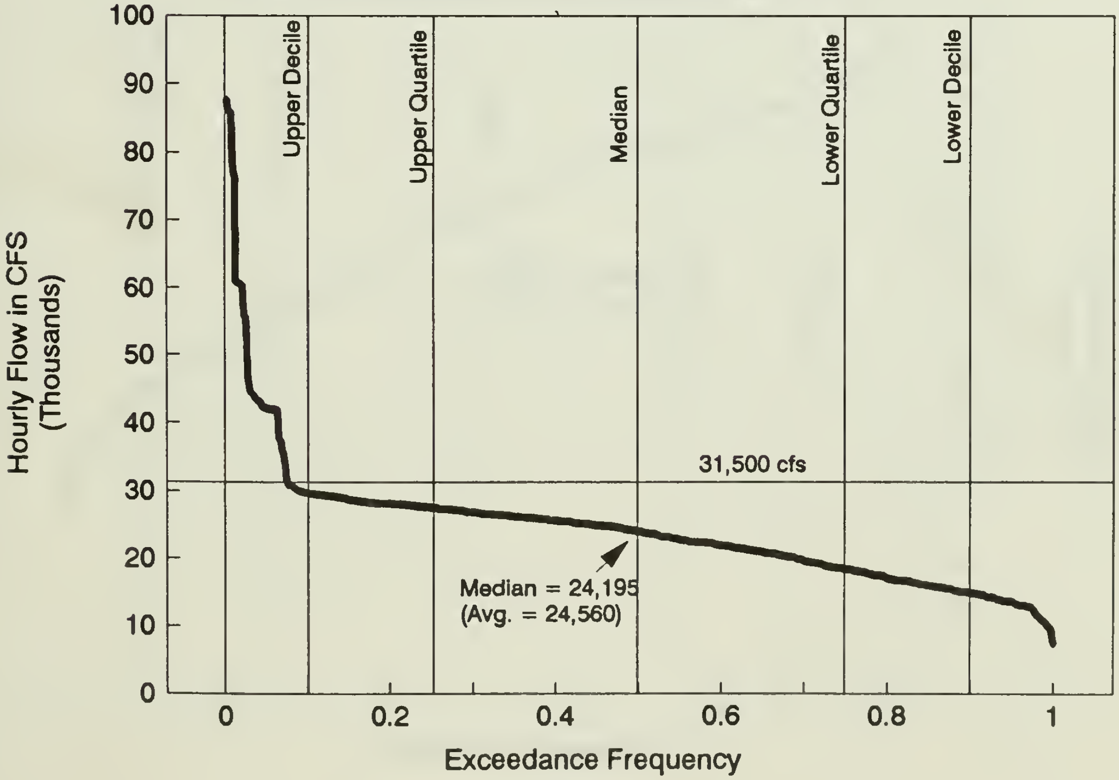
## Maximum Hourly Releases for Days in June

Flow Duration for Water Years 1966-1989



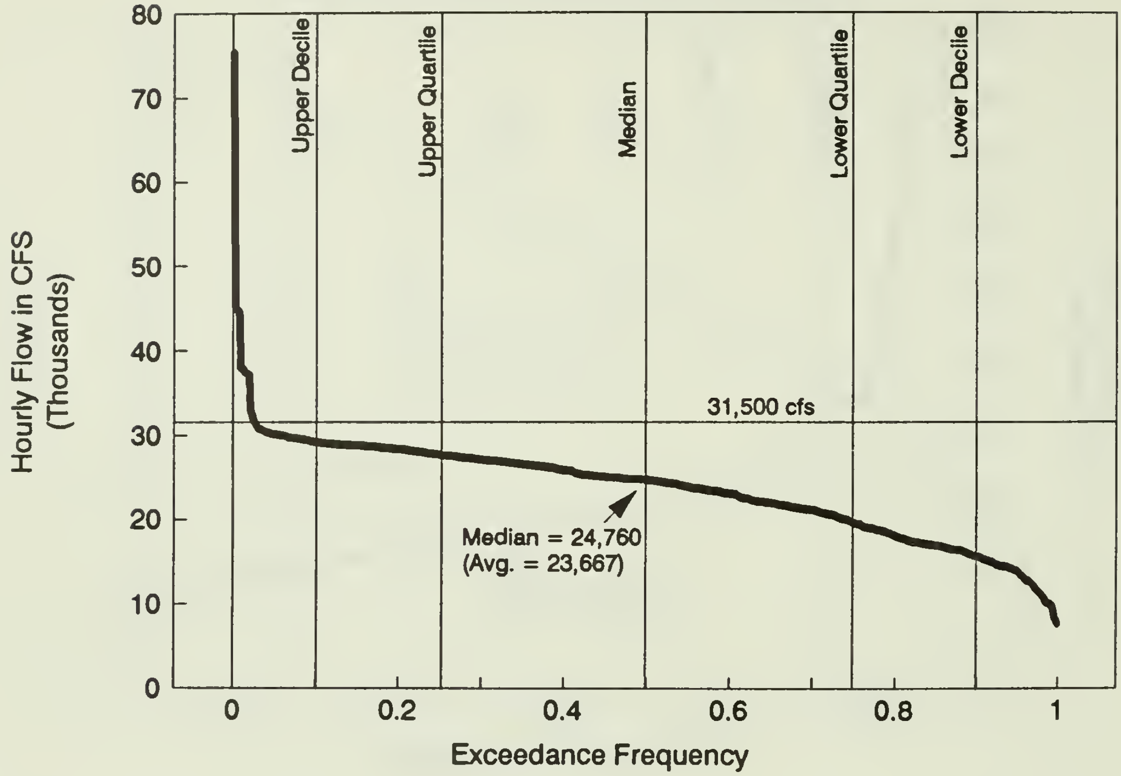

## Maximum Hourly Releases for Days in July

Flow Duration for Water Years 1966-1989



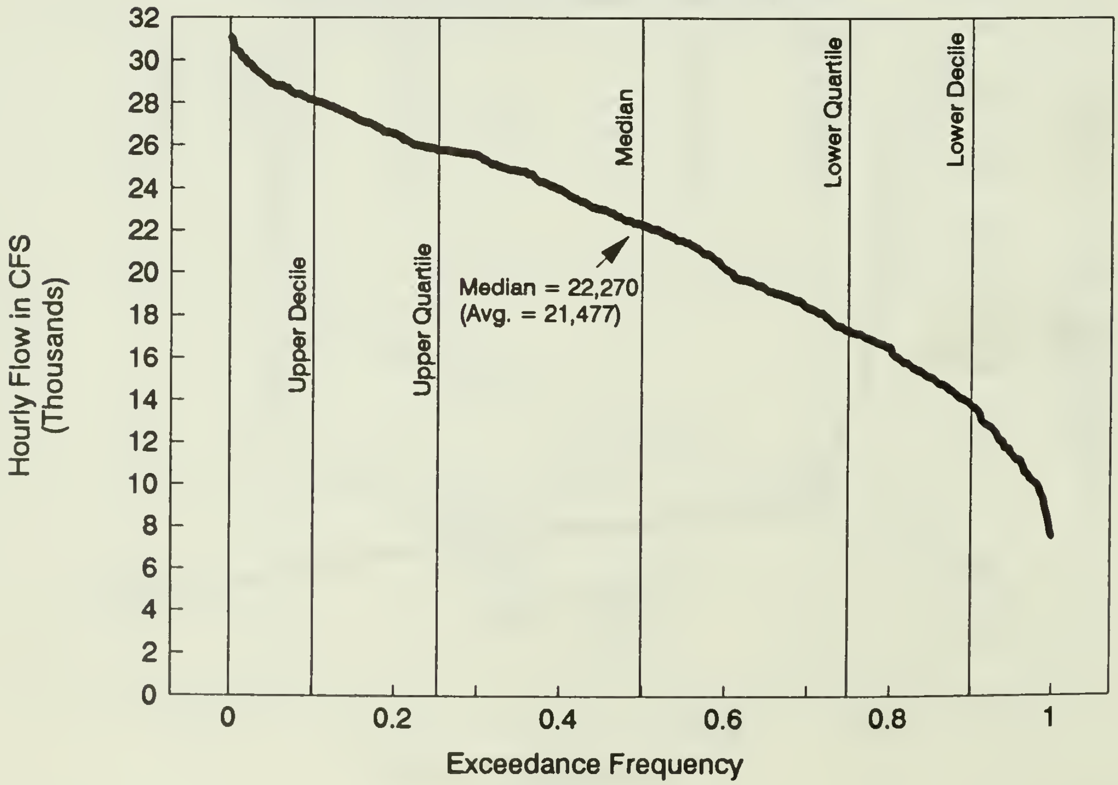
## Maximum Hourly Releases for Days in August

Flow Duration for Water Years 1966-1989




## Maximum Hourly Releases for Days in September

Flow Duration for Water Years 1966-1989

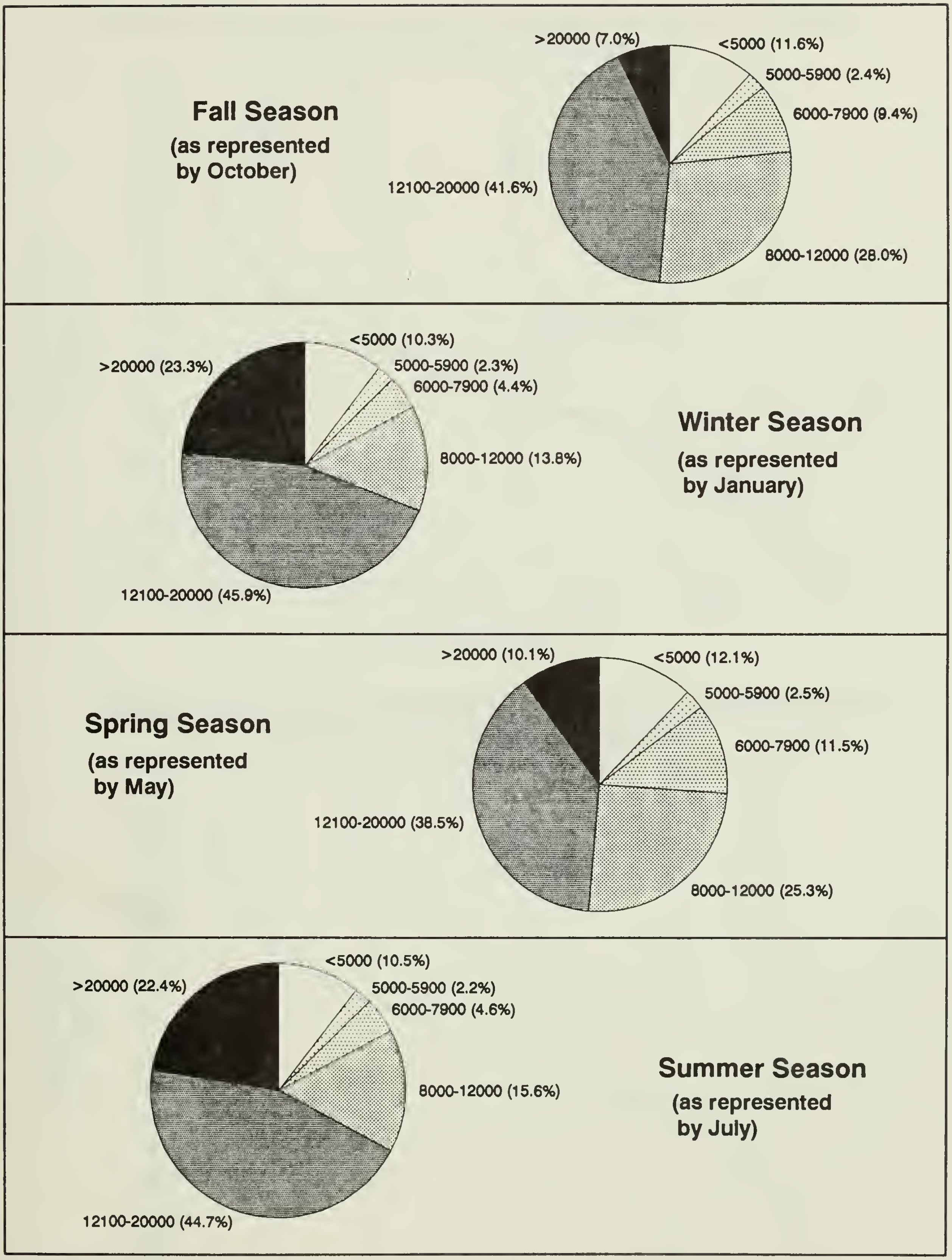


Frequencies of

# Historic Daily Fluctuations in Releases (cfs)

A. Pie Chart Summaries by Season

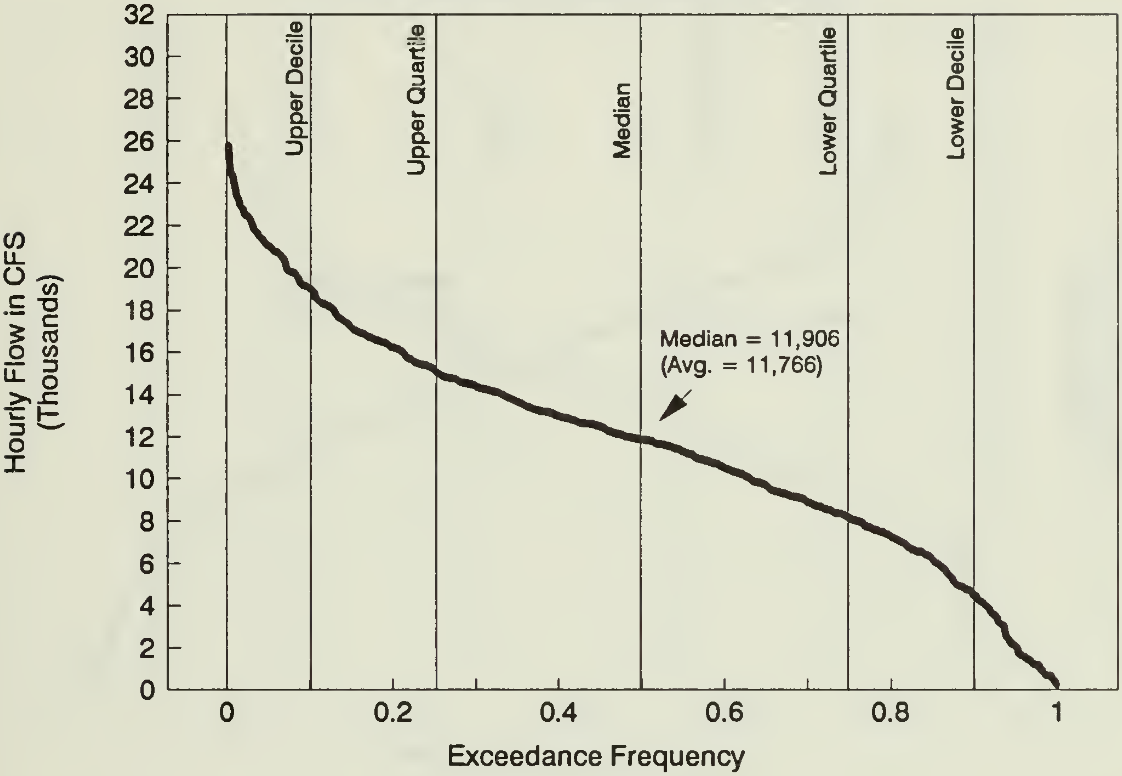
B. Individual Months (12 frequency graphs)




**Historic (1966-89) daily fluctuations in releases from Glen Canyon Dam in cfs (percent of days that the specified fluctuations occurred)**

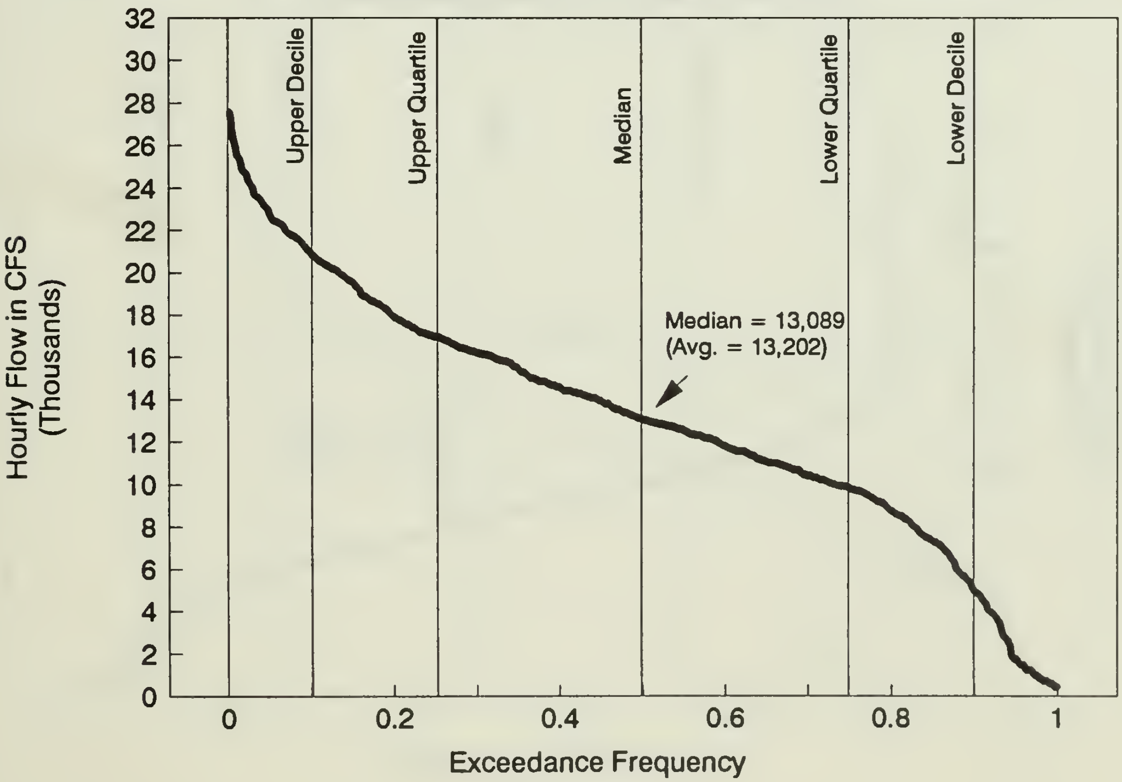
## Historic Fluctuations in Hourly Releases for Days in October

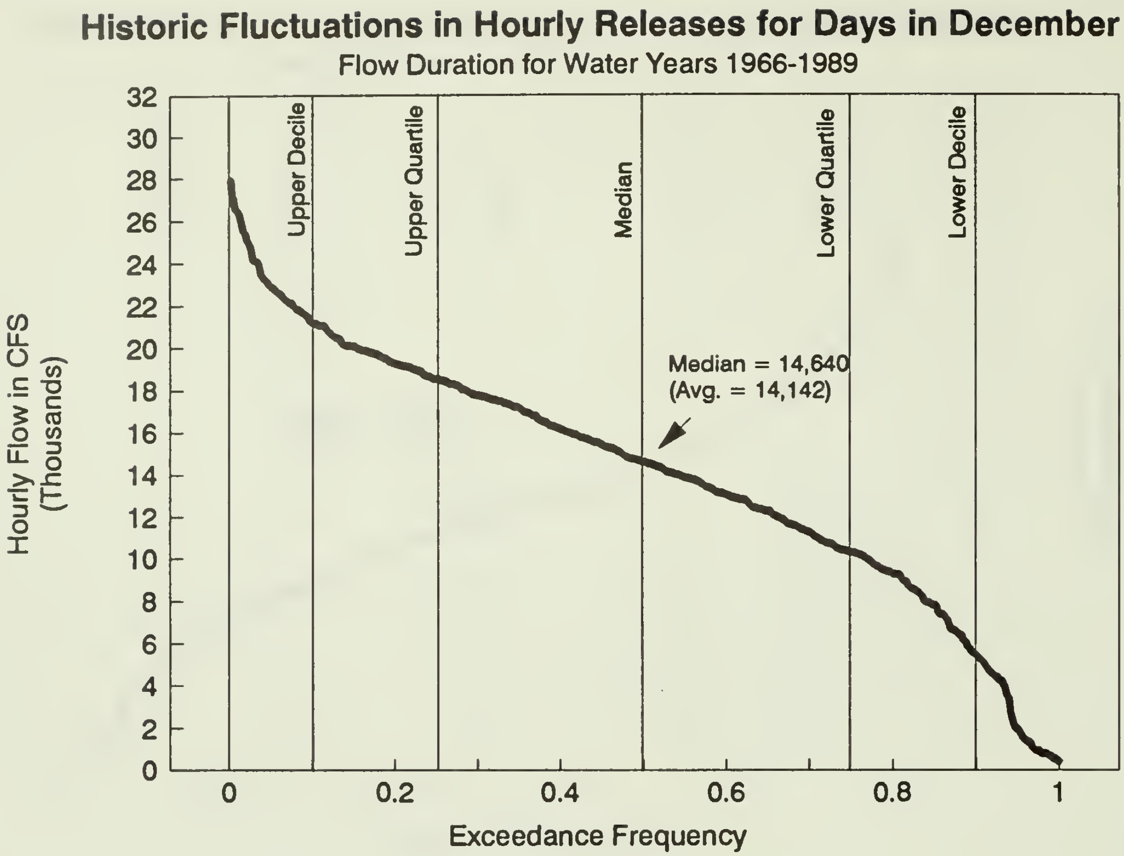
Flow Duration for Water Years 1966-1989

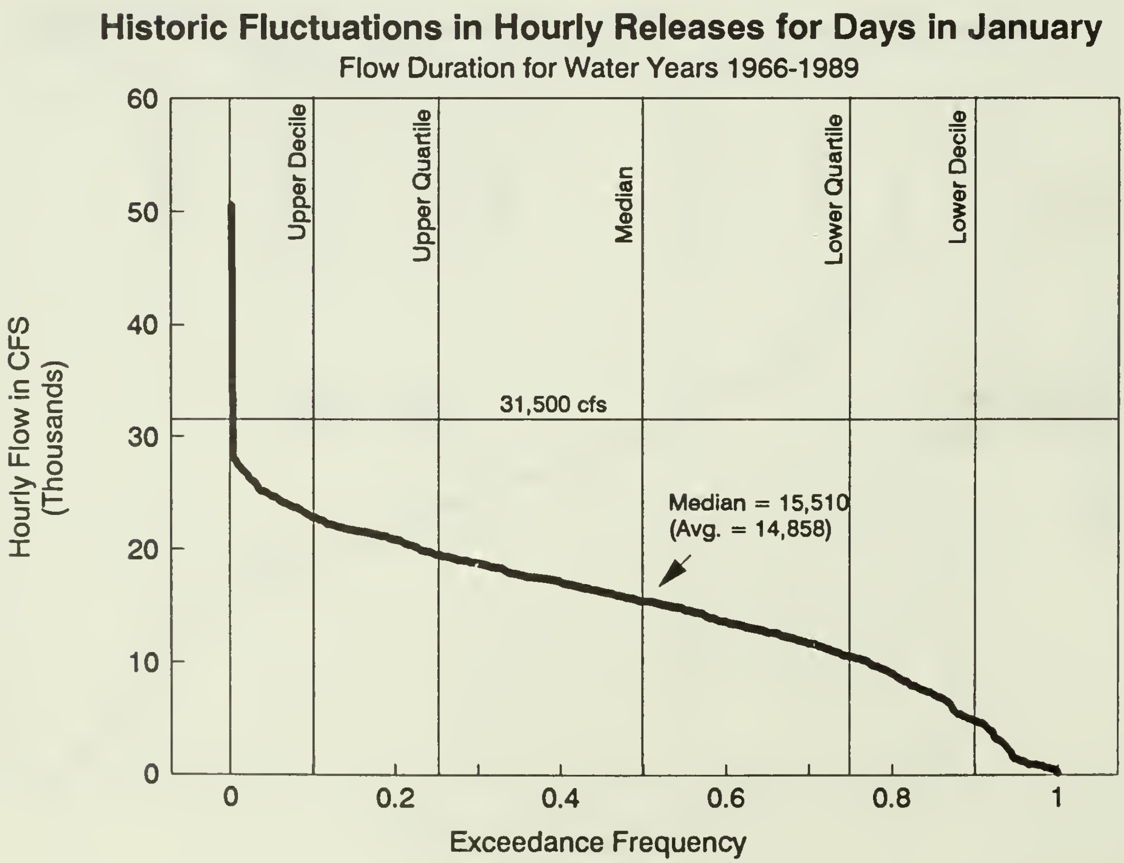



## Historic Fluctuations in Hourly Releases for Days in November

Flow Duration for Water Years 1966-1989

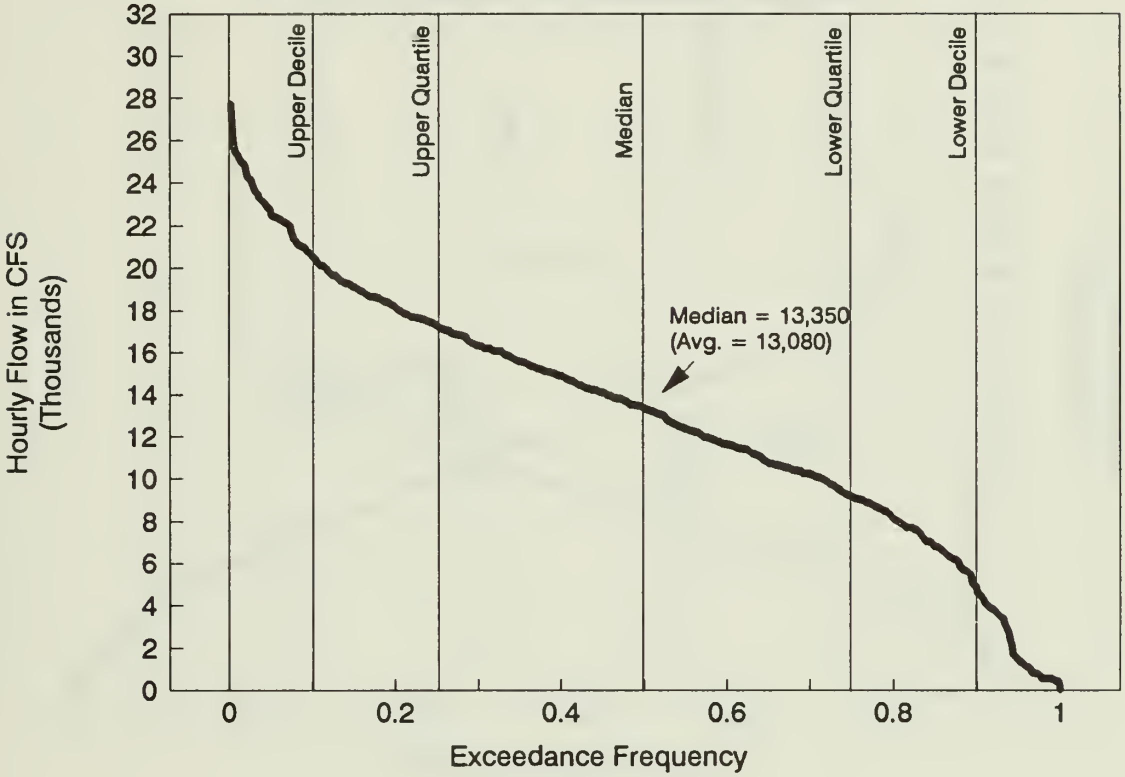



Historic Fluctuations in Hourly Releases for Days in December
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
Median = 14,640
(Avg. = 14,142)
Exceedance Frequency
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
0.2
0.4
0.6
0.8
1


Historic Fluctuations in Hourly Releases for Days in January
Flow Duration for Water Years 1966-1989
Hourly Flow in CFS (Thousands)
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
31,500 cfs
Median = 15,510
(Avg. = 14,858)
Exceedance Frequency
0
10
20
30
40
50
60
0
0.2
0.4
0.6
0.8
1

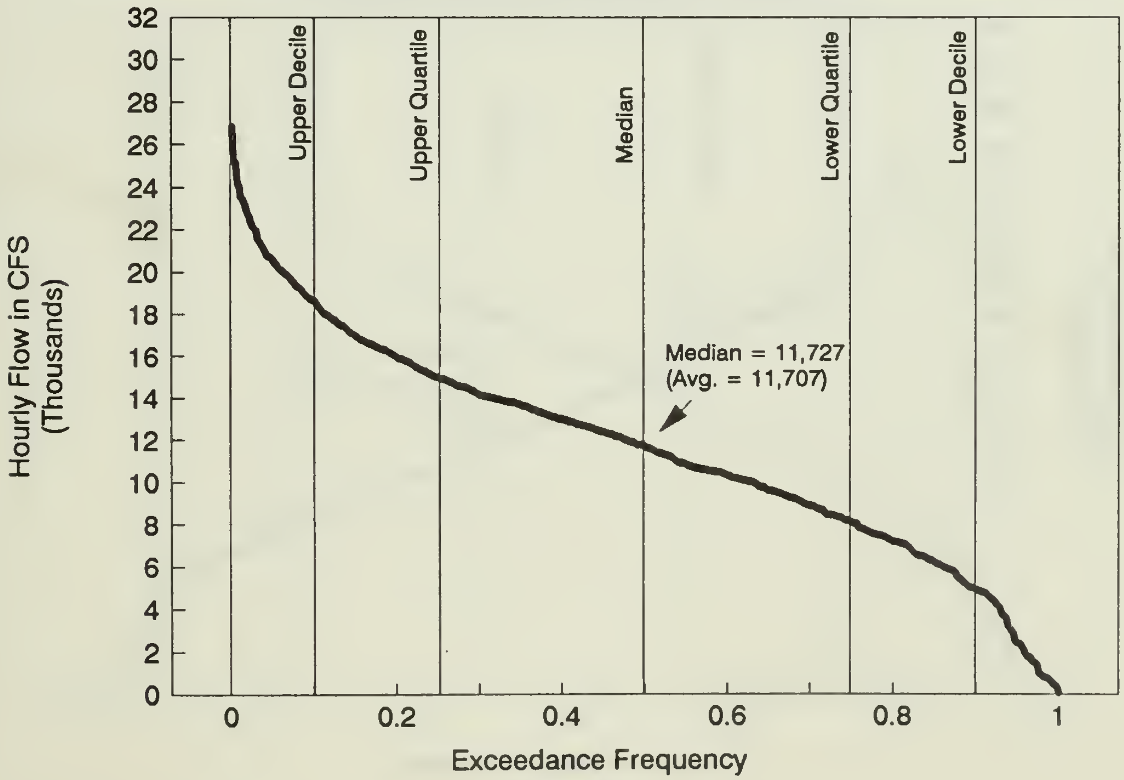
## Historic Fluctuations in Hourly Releases for Days in February

Flow Duration for Water Years 1966-1989



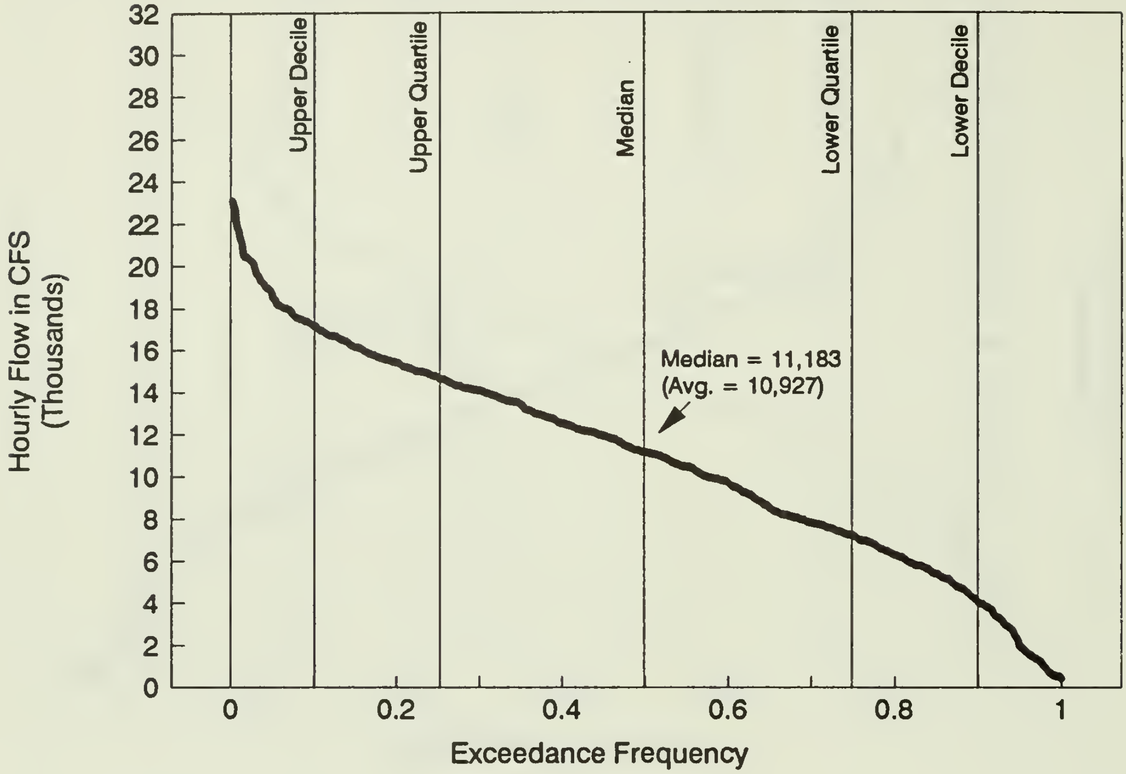

## Historic Fluctuations in Hourly Releases for Days in March

Flow Duration for Water Years 1966-1989



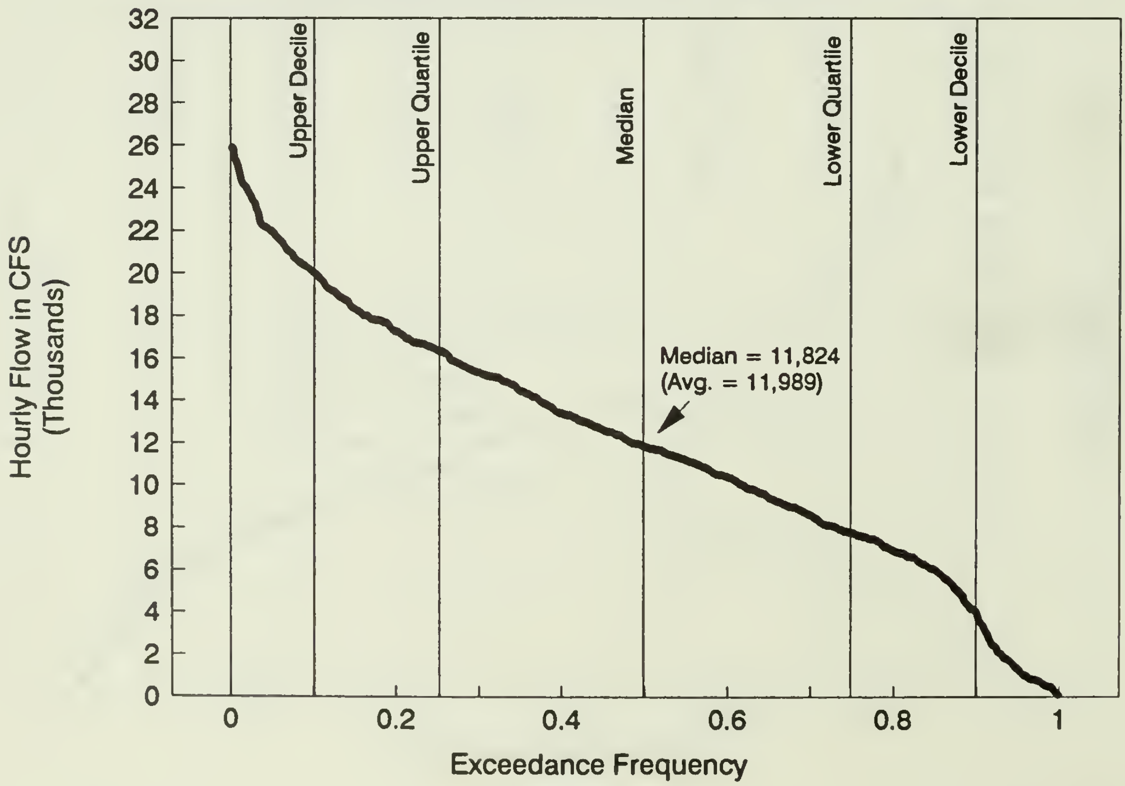
## Historic Fluctuations in Hourly Releases for Days in April

Flow Duration for Water Years 1966-1989



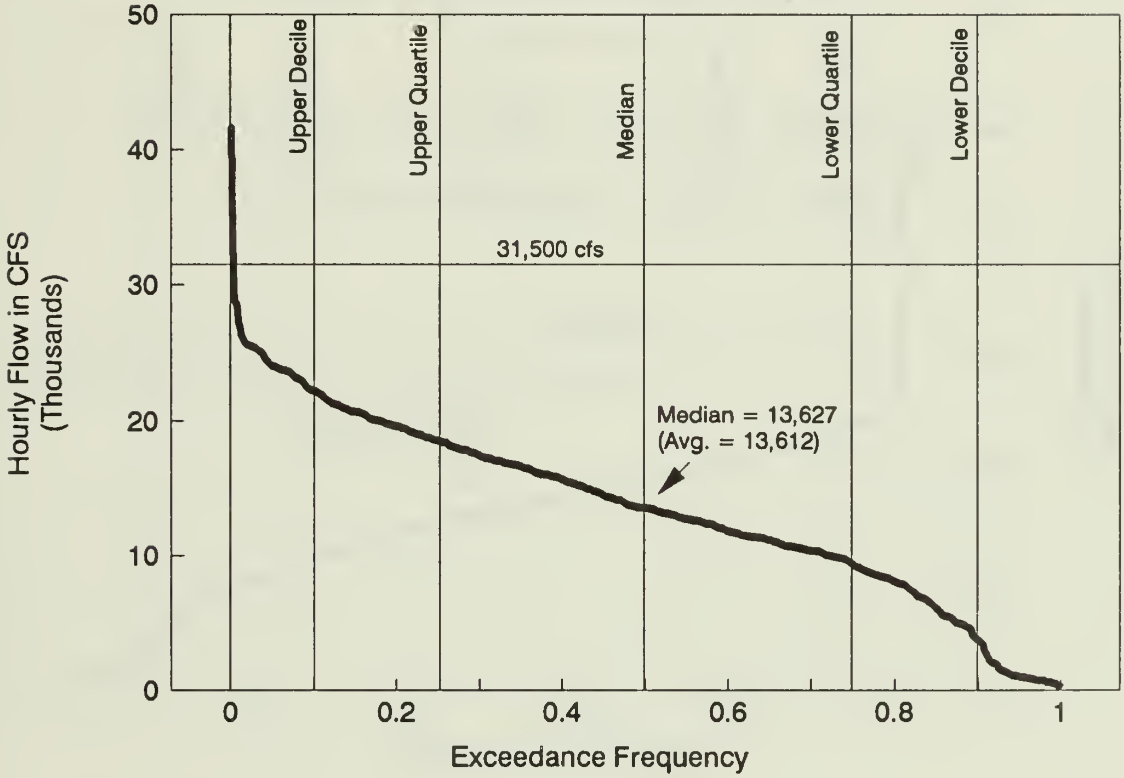

## Historic Fluctuations in Hourly Releases for Days in May

Flow Duration for Water Years 1966-1989



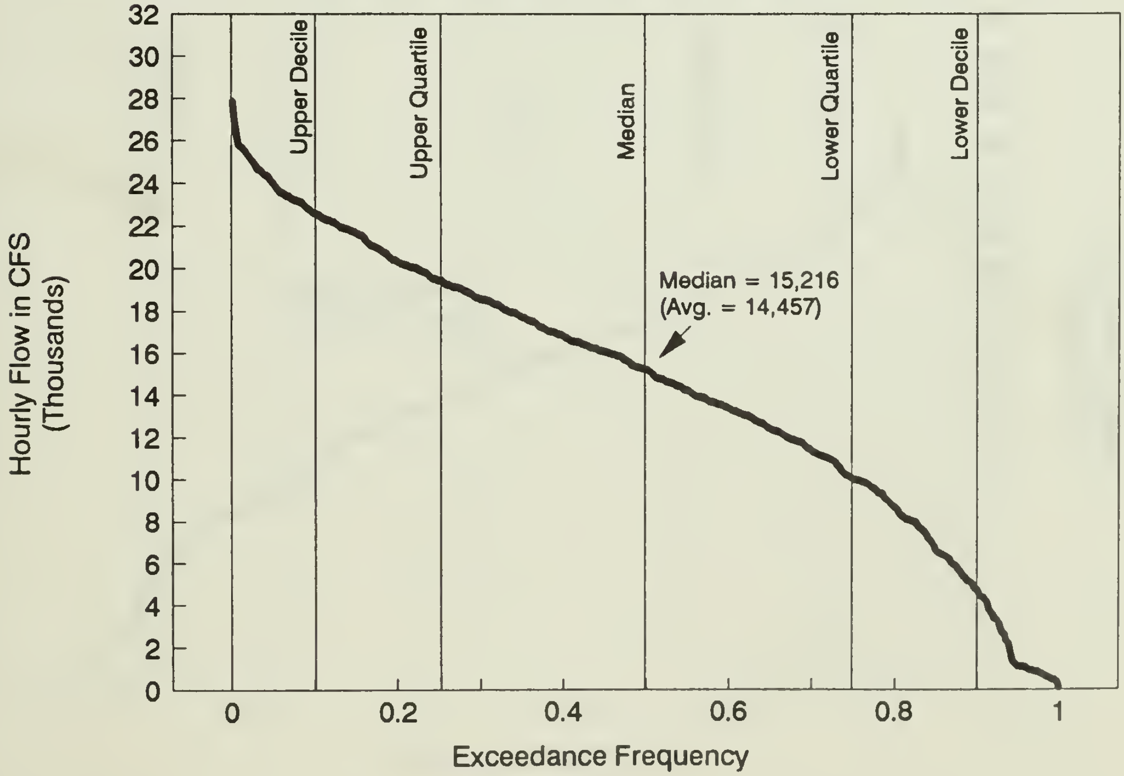
## Historic Fluctuations in Hourly Releases for Days in June

Flow Duration for Water Years 1966-1989



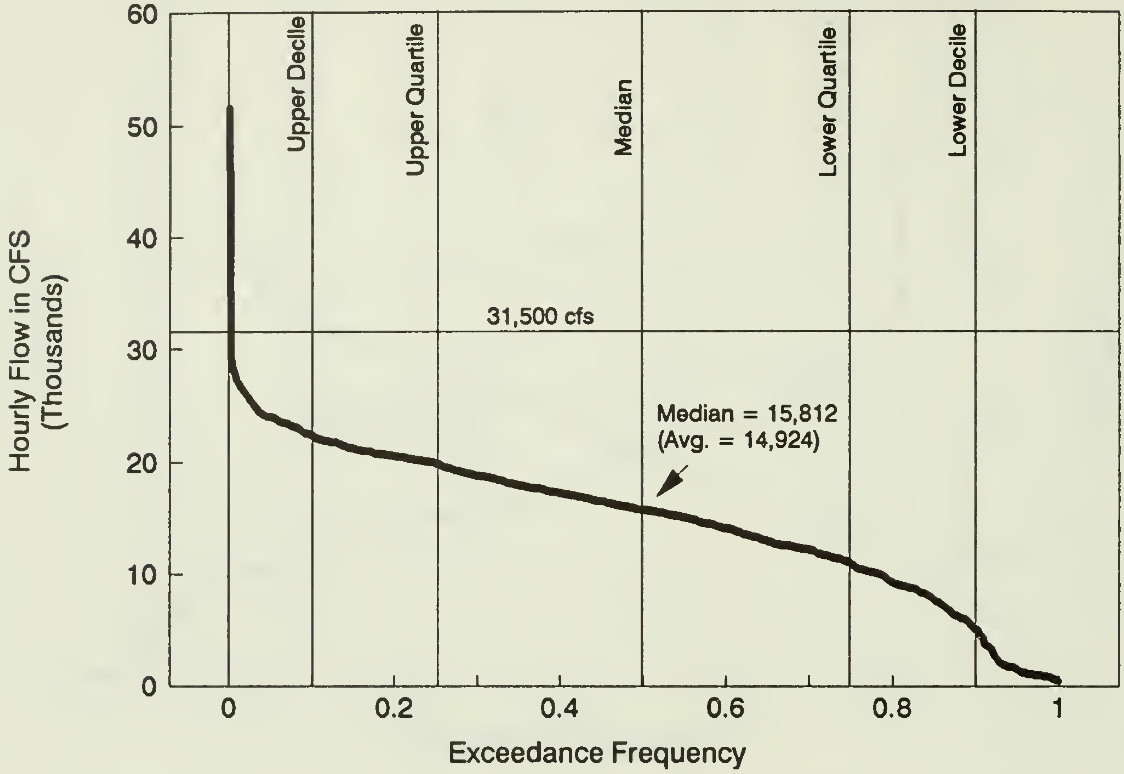

## Historic Fluctuations in Hourly Releases for Days in July

Flow Duration for Water Years 1966-1989



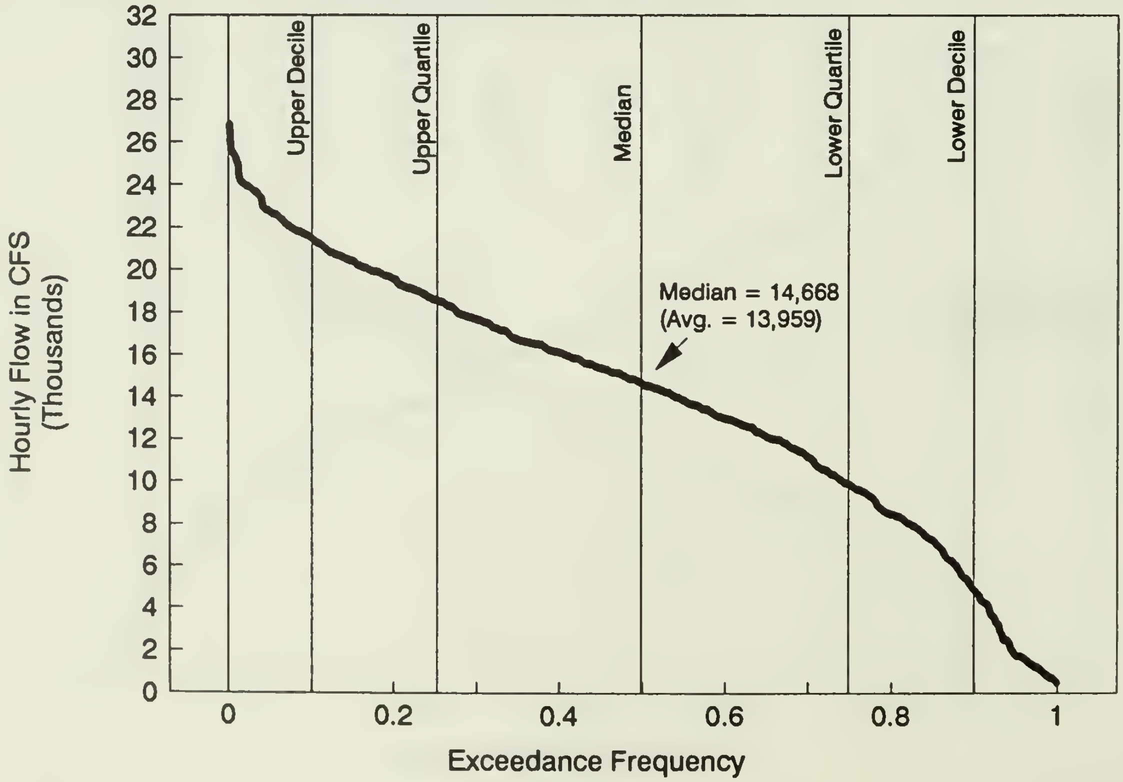
## Historic Fluctuations In Hourly Releases for Days in August

Flow Duration for Water Years 1966-1989




## Historic Fluctuations in Hourly Releases for Days in September

Flow Duration for Water Years 1966-1989



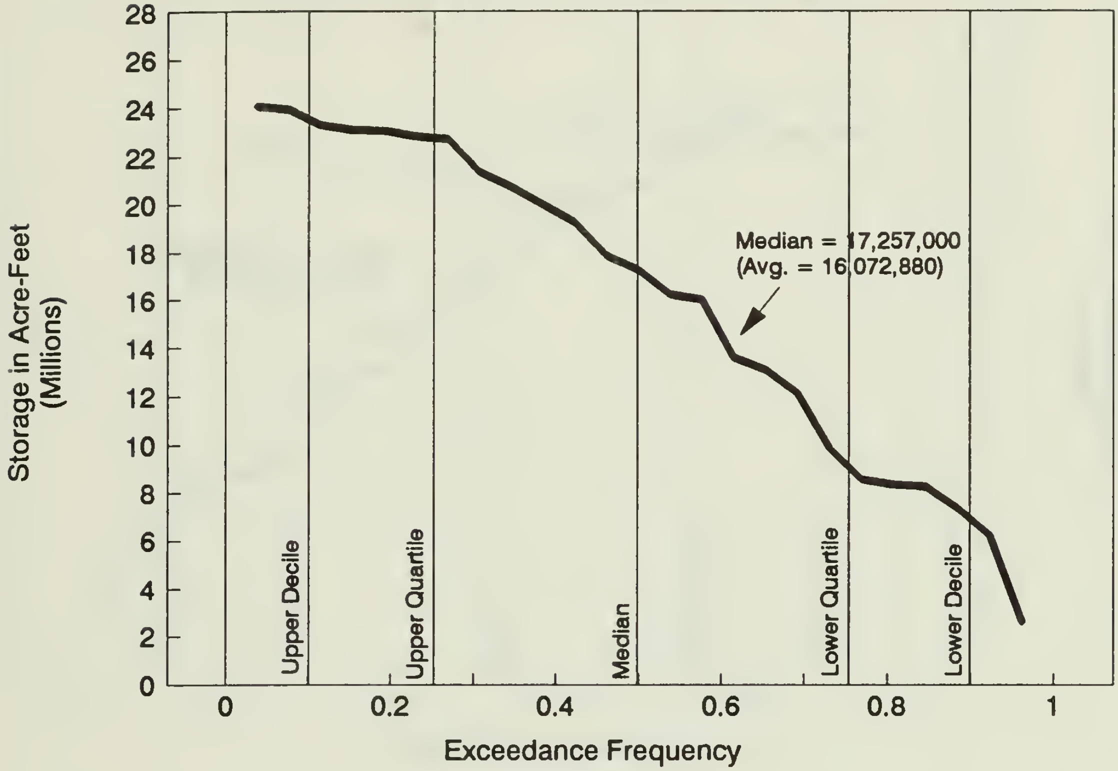
Frequencies of

# Historic End-of-Month Storage in Lake Powell (acre-feet)

- Individual Months (12 frequency graphs)

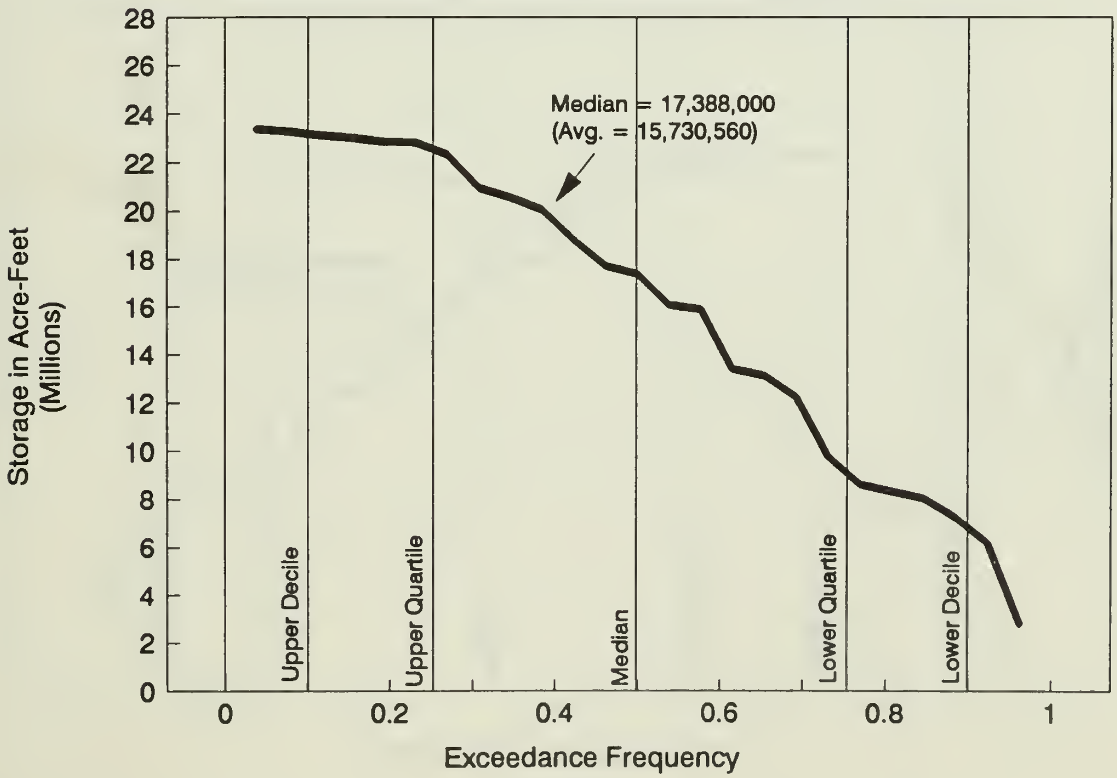
## Historic October End of Month Storage in Lake Powell

Exceedance Levels for Water Years 1963-1988



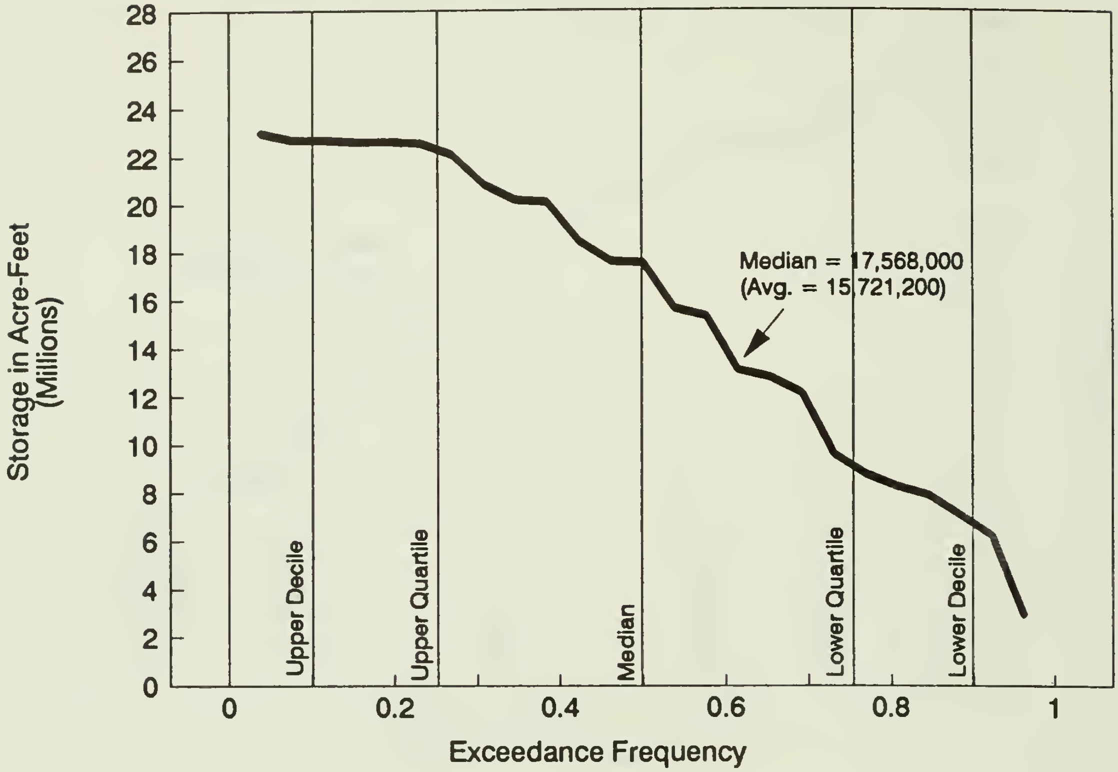

## Historic November End of Month Storage in Lake Powell

Exceedance Levels for Water Years 1963-1988



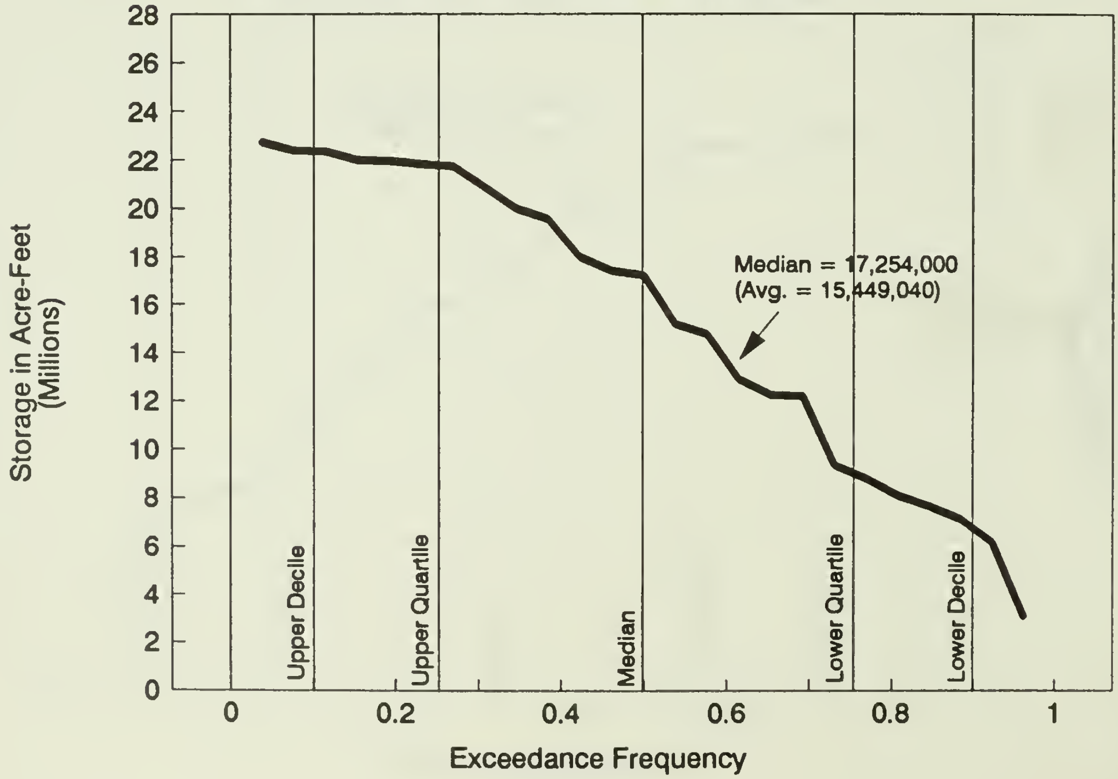
## Historic December End of Month Storage in Lake Powell

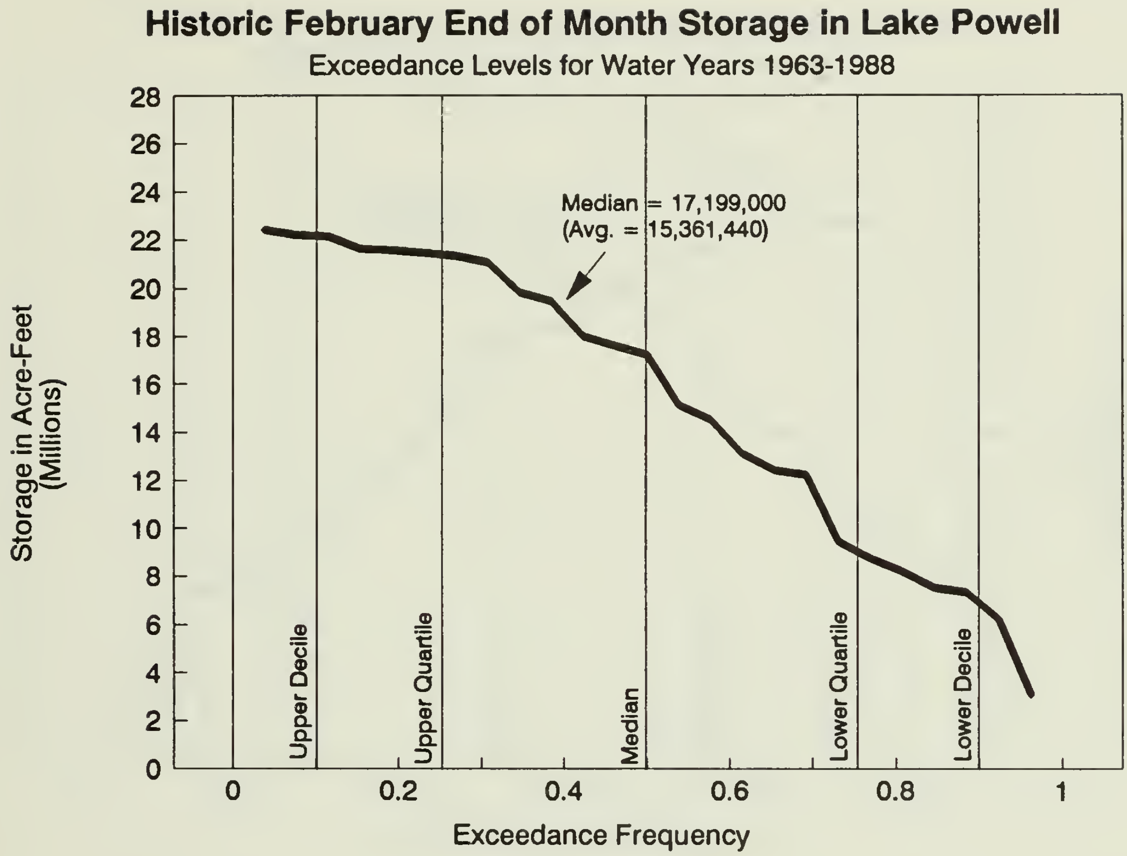
Exceedance Levels for Water Years 1963-1988

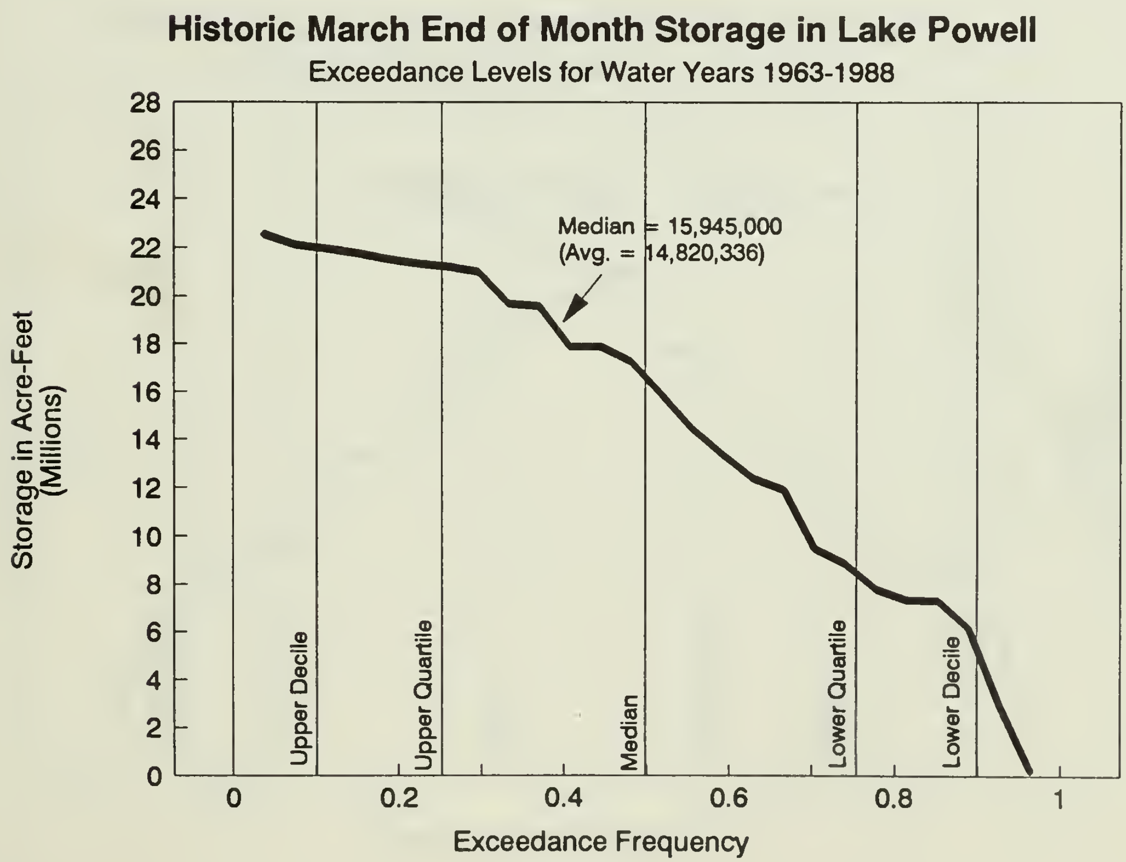



## Historic January End of Month Storage in Lake Powell

Exceedance Levels for Water Years 1963-1988

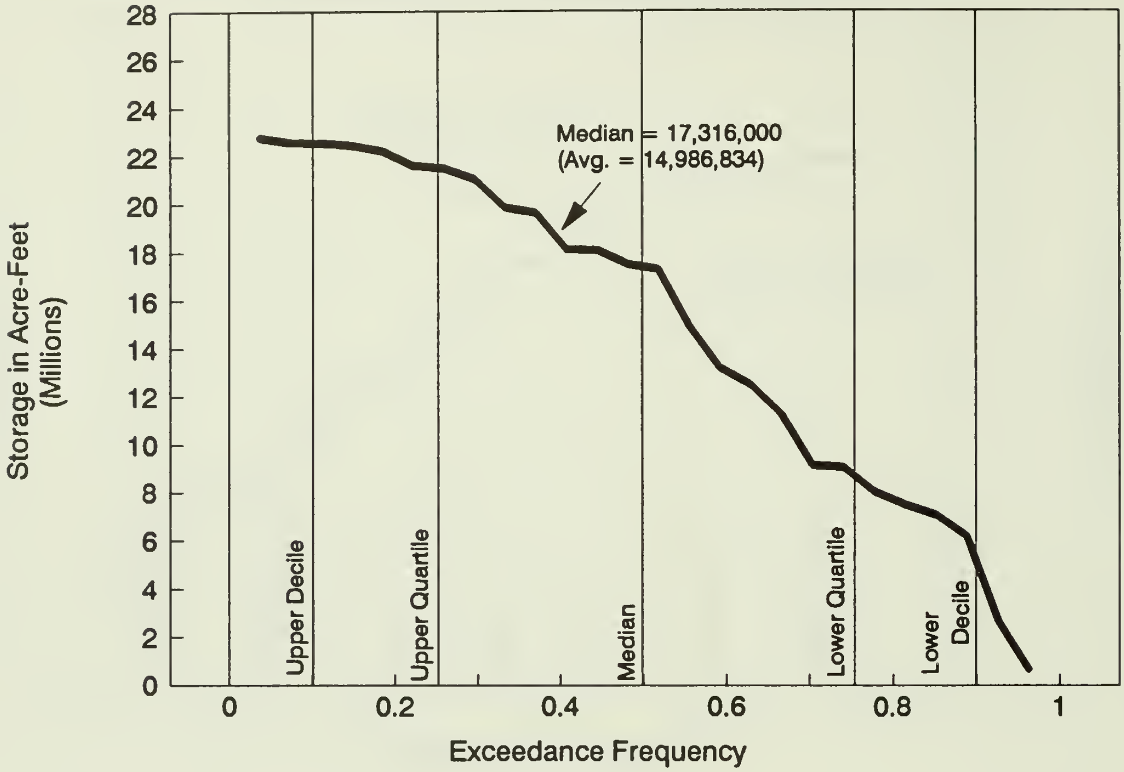



Historic February End of Month Storage in Lake Powell
Exceedance Levels for Water Years 1963-1988
Median = 17,199,000
(Avg. = 15,361,440)
Storage in Acre-Feet (Millions)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
0
0.2
0.4
0.6
0.8
1


Historic March End of Month Storage in Lake Powell
Exceedance Levels for Water Years 1963-1988
Median = 15,945,000
(Avg. = 14,820,336)
Storage in Acre-Feet (Millions)
Exceedance Frequency
Upper Decile
Upper Quartile
Median
Lower Quartile
Lower Decile
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
0
0.2
0.4
0.6
0.8
1

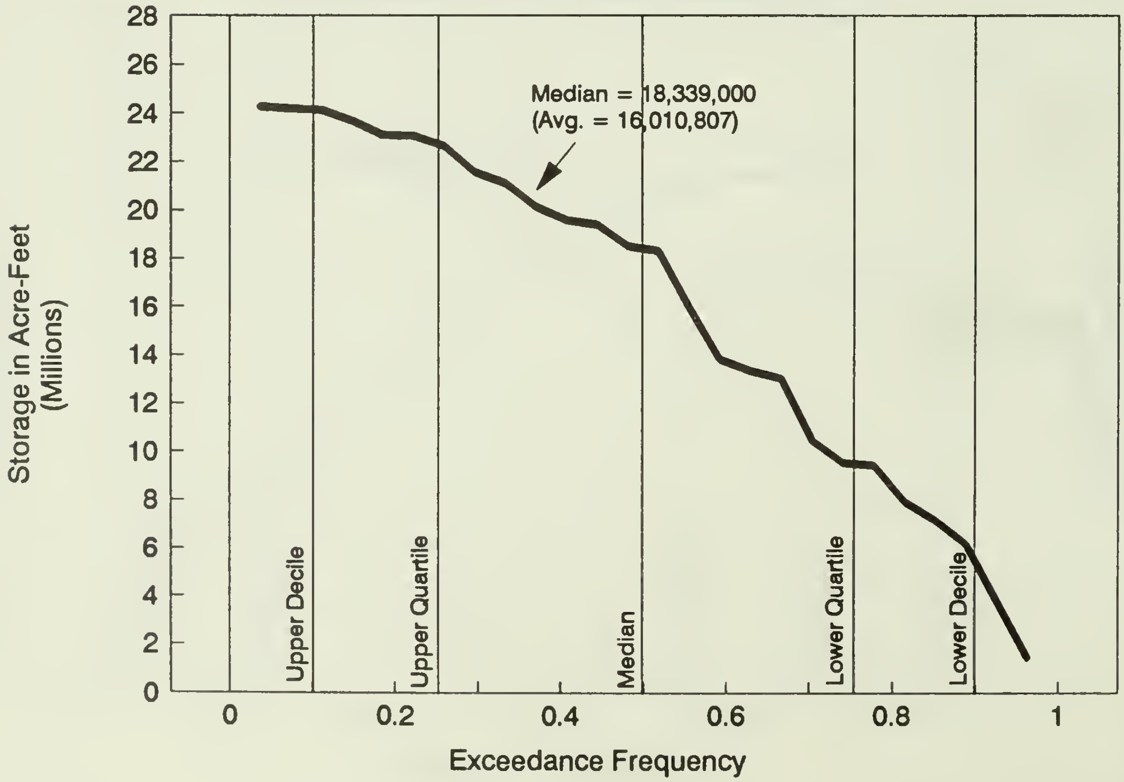
## Historic April End of Month Storage in Lake Powell

Exceedance Levels for Water Years 1963-1988



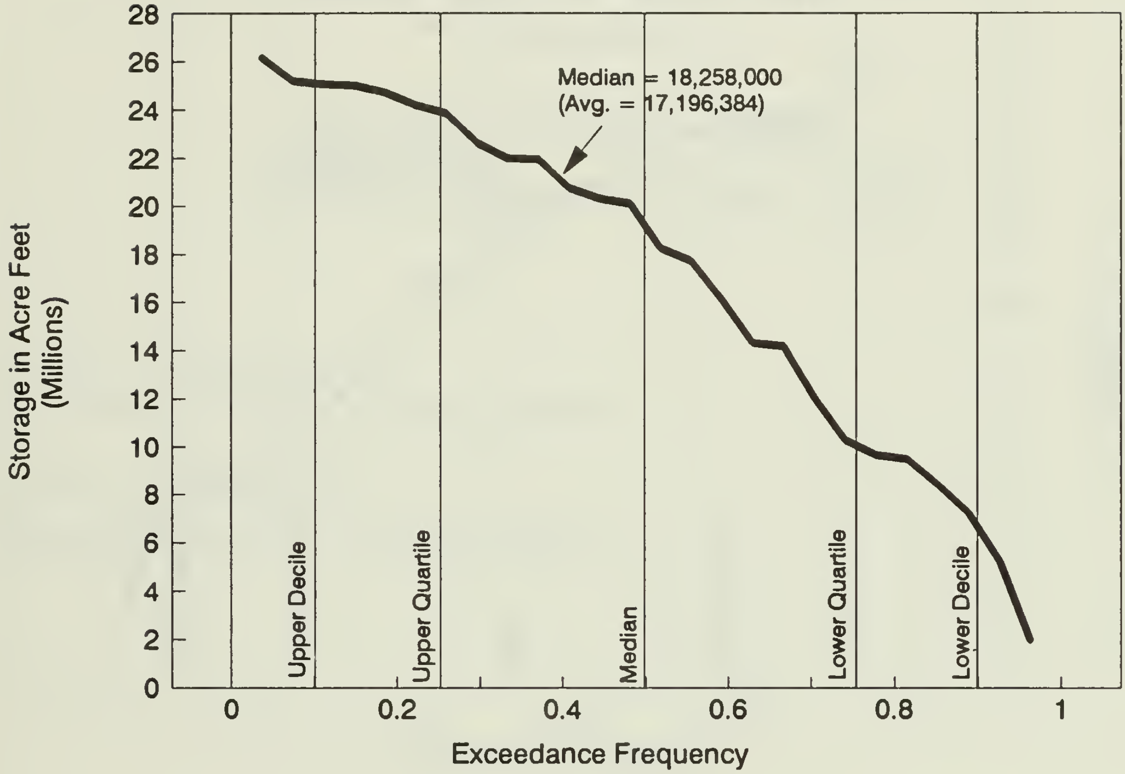

## Historic May End of Month Storage in Lake Powell

Exceedance Levels for Water Years 1963-1988



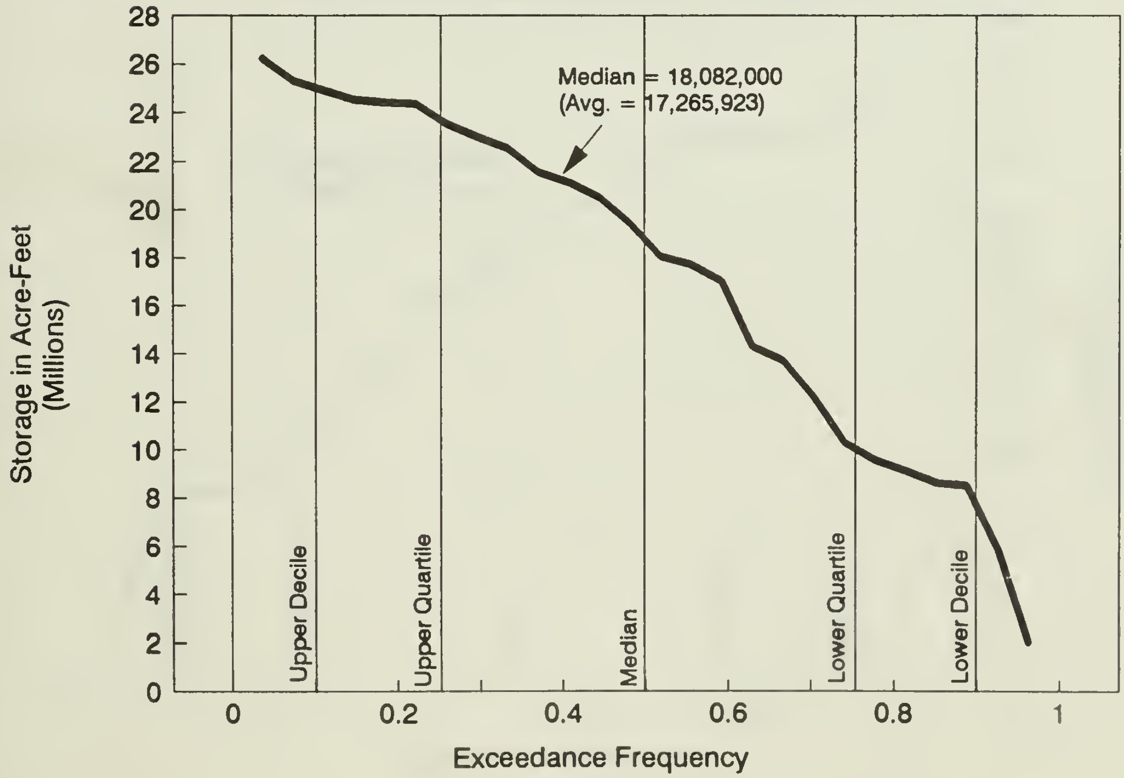
## Historic June End of Month Storage in Lake Powell

Exceedance Levels for Water Years 1963-1988



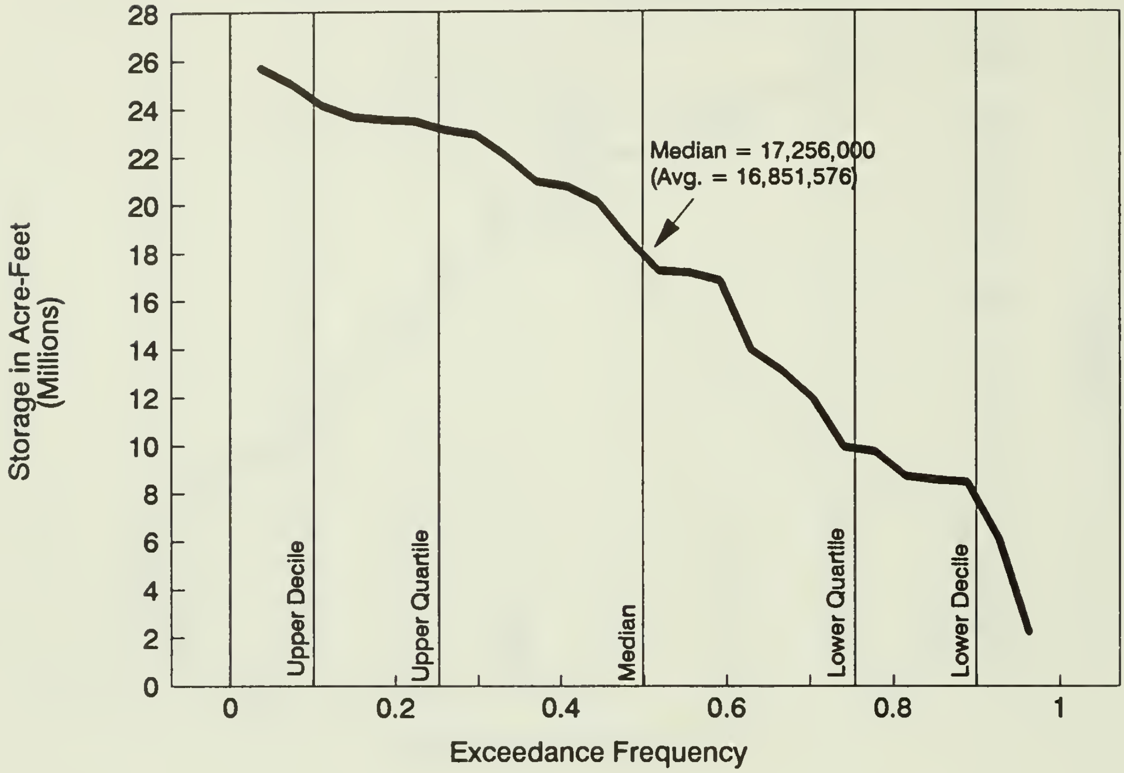

## Historic July End of Month Storage in Lake Powell

Exceedance Levels for Water Years 1963-1988



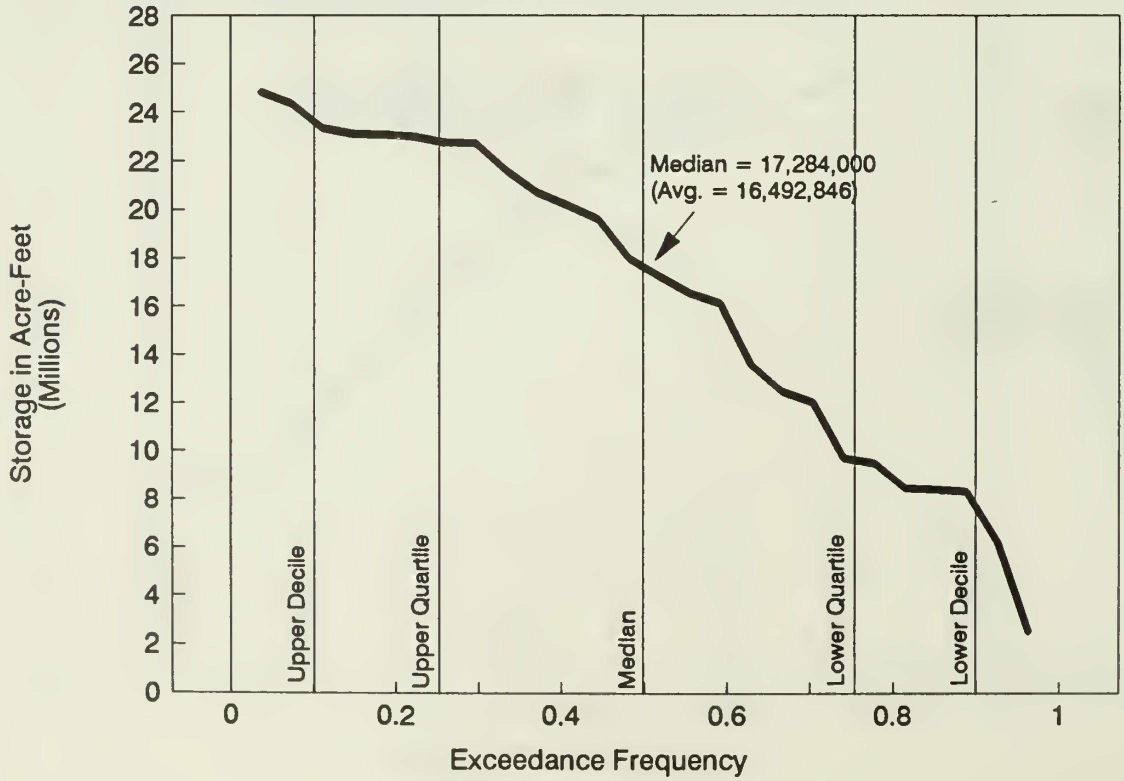
## Historic August End of Month Storage in Lake Powell

Exceedance Levels for Water Years 1963-1988




## Historic September End of Month Storage in Lake Powell

Exceedance Levels for Water Years 1963-1988

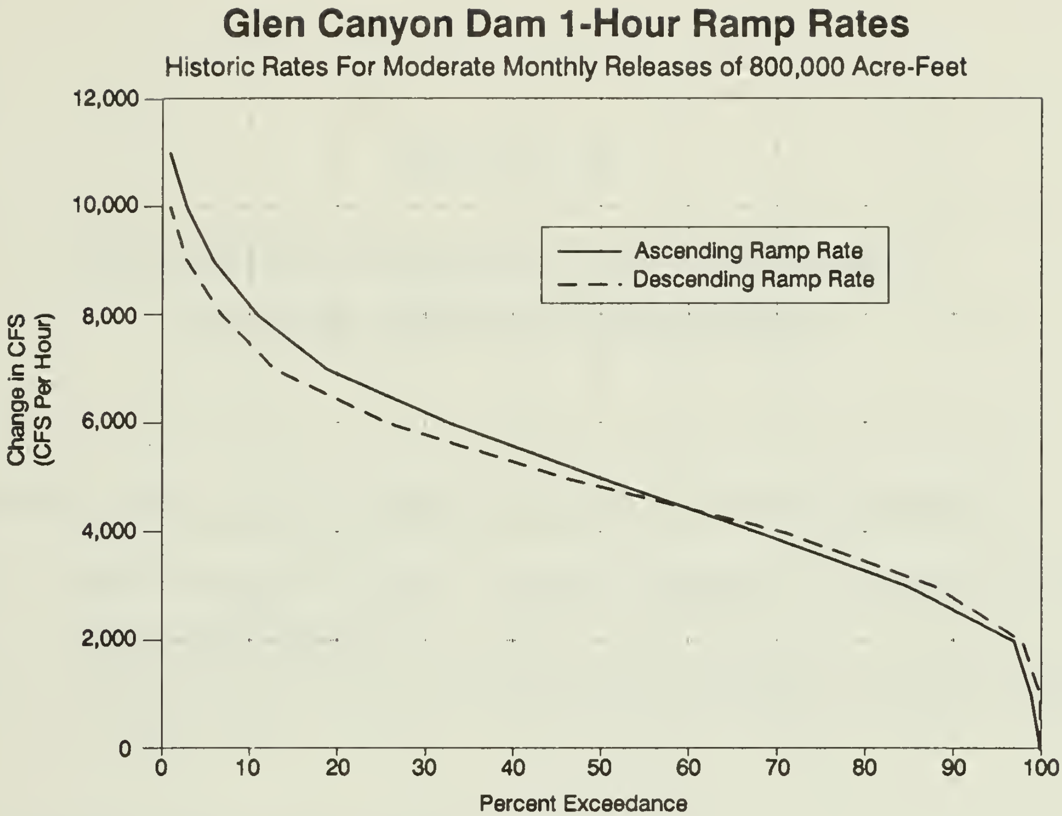


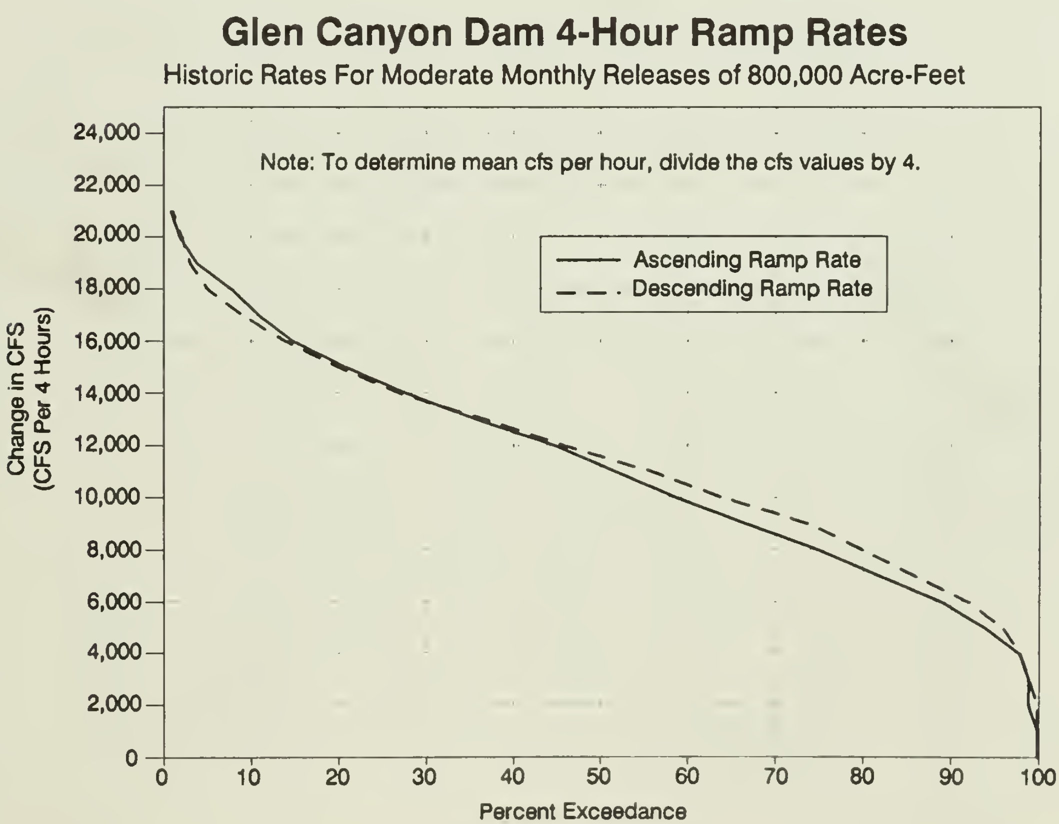
Frequencies of

# Historic Ramp Rates at Glen Canyon Dam (cfs)

A. 1-Hour Ascending and
Descending Rates (1 frequency graph)

B. 4-Hour Ascending and
Descending Rates (1 frequency graph)


Glen Canyon Dam 1-Hour Ramp Rates
Historic Rates For Moderate Monthly Releases of 800,000 Acre-Feet
Change in CFS (CFS Per Hour)
12,000
10,000
8,000
6,000
4,000
2,000
0
0
10
20
30
40
50
60
70
80
90
100
Percent Exceedance
Ascending Ramp Rate
Descending Ramp Rate


Glen Canyon Dam 4-Hour Ramp Rates
Historic Rates For Moderate Monthly Releases of 800,000 Acre-Feet
Note: To determine mean cfs per hour, divide the cfs values by 4.
Change in CFS (CFS Per 4 Hours)
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
10
20
30
40
50
60
70
80
90
100
Percent Exceedance
Ascending Ramp Rate
Descending Ramp Rate

Frequencies of

# Projected Annual Flow Volumes at Lees Ferry (acre-feet)

A. Summary Tables of CRSS Model Results with Several Alternatives

1. With Increased Storage Capacity Method of Reducing Flood Frequency (1 table)
2. With Lower Storage Level Method of Reducing Flood Frequency (1 table)

B. 1 Frequency Graph with Several Alternatives

# Annual Lake Powell Total Releases (Summary of CRSS Model Results)

With increased storage capacity to reduce frequency of flood flows

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | Average (Median) | FREQUENCY | | | Average (Median) | FREQUENCY | | |
| | | =8.23 maf | >8.23 maf <=11.0 maf | >11.0 maf | | =8.23 maf | >8.23 maf <=11.0 maf | >11.0 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 10,161,000 af (9,367,000 af) | 30.3% | 40.2% | 29.5% | 9,881,000 af (8,573,000 af) | 46.0% | 27.2% | 26.8% |
| High Fluctuating Flow | 10,148,000 af (9,329,000 af) | 30.7% | 39.9% | 29.4% | 9,875,000 af (8,559,000 af) | 46.3% | 27.3% | 26.4% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 10,142,000 af (9,361,000 af) | 30.1% | 41.6% | 28.3% | 9,871,000 af (8,554,000 af) | 45.7% | 28.8% | 25.5% |
| Year-Round Steady Flow | 10,149,000 af (9,359,000 af) | 30.1% | 41.3% | 28.6% | 9,877,000 af (8,578,000 af) | 45.8% | 28.6% | 25.6% |

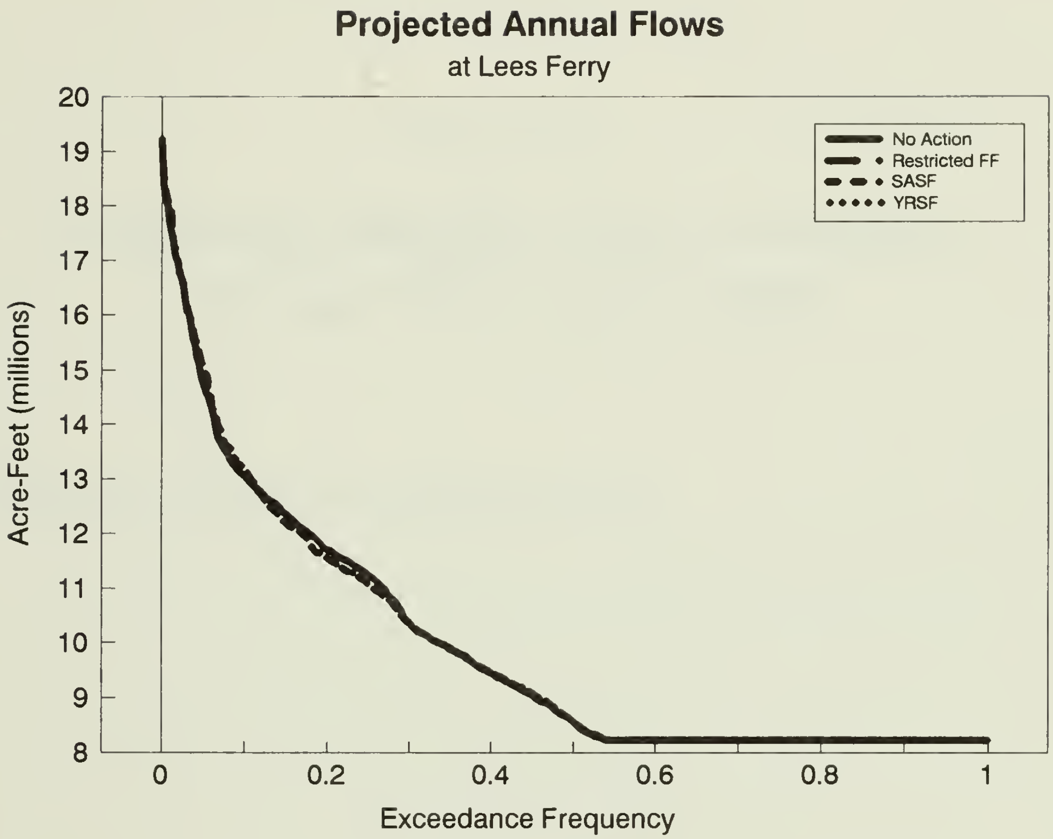
* Same as for High Fluctuating Flow Alternative

## Annual Lake Powell Total Releases
## (Summary of CRSS Model Results)

With lower reservoir storage to reduce frequency of flood flows

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | Average (Median) | FREQUENCY | | | Average (Median) | FREQUENCY | | |
| | | =8.23 maf | >8.23 maf <=11.0 maf | >11.0 maf | | =8.23 maf | >8.23 maf <=11.0 maf | >11.0 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 10,161,000 af (9,367,000 af) | 30.3% | 40.2% | 29.5% | 9,881,000 af (8,573,000 af) | 46.0% | 27.2% | 26.8% |
| High Fluctuating Flow | 10,161,000 af (9,367,000 af) | 30.3% | 40.2% | 29.5% | 9,882,000 af (8,567,000 af) | 45.9% | 27.3% | 26.8% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 10,160,000 af (9,375,000 af) | 30.2% | 40.3% | * | 9,880,000 af (8,554,000 af) | 45.8% | 27.4% | * |
| Year-Round Steady Flow | 10,167,000 af (9,378,000 af) | 30.1% | 40.3% | 29.6% | 9,885,000 af (8,575,000 af) | 45.7% | 27.4% | 26.9% |

* Same as for High Fluctuating Flow Alternative


Projected Annual Flows
at Lees Ferry
20
19
18
17
16
15
14
13
12
11
10
9
8
Acre-Feet (millions)
No Action
Restricted FF
SASF
YRSF
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

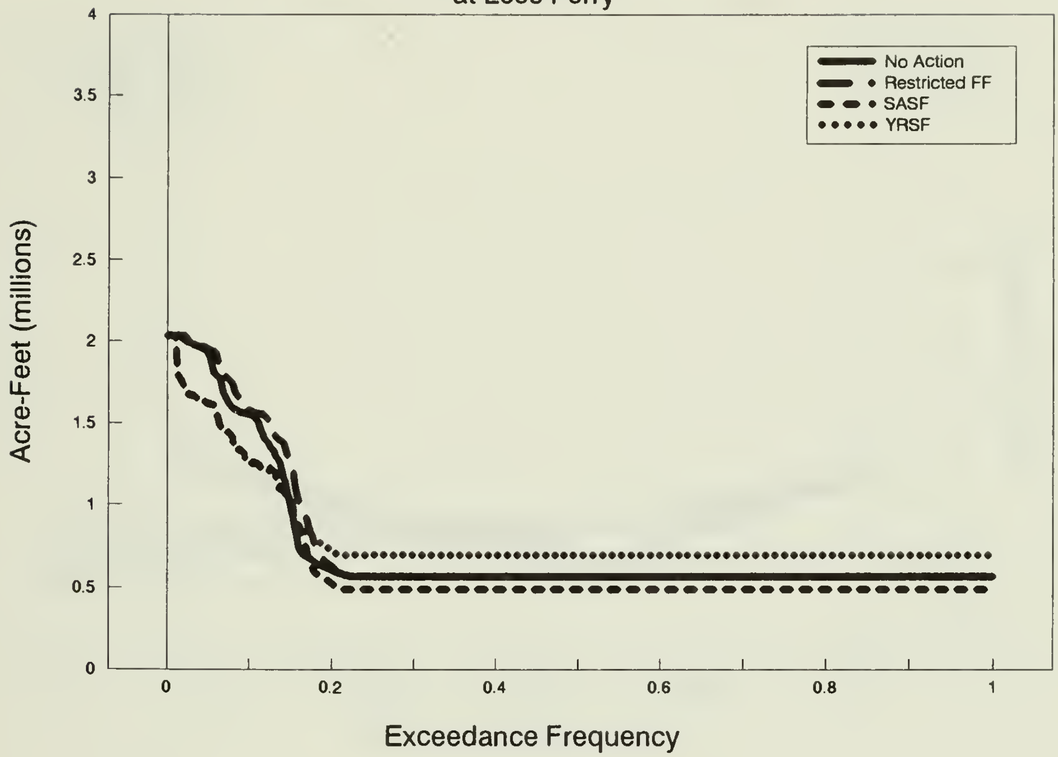
Frequencies of

# Projected Monthly Flow Volumes at Lees Ferry (acre-feet)

- 12 Graphs, Each with Several Alternatives

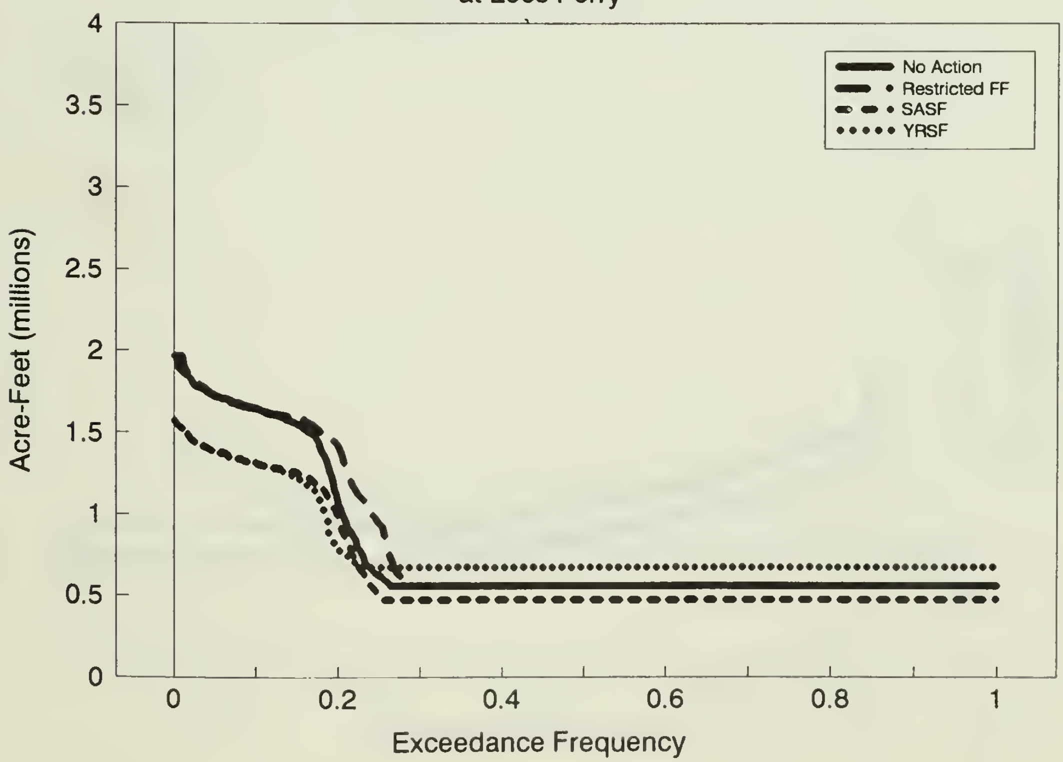
## Projected October Monthly Flows

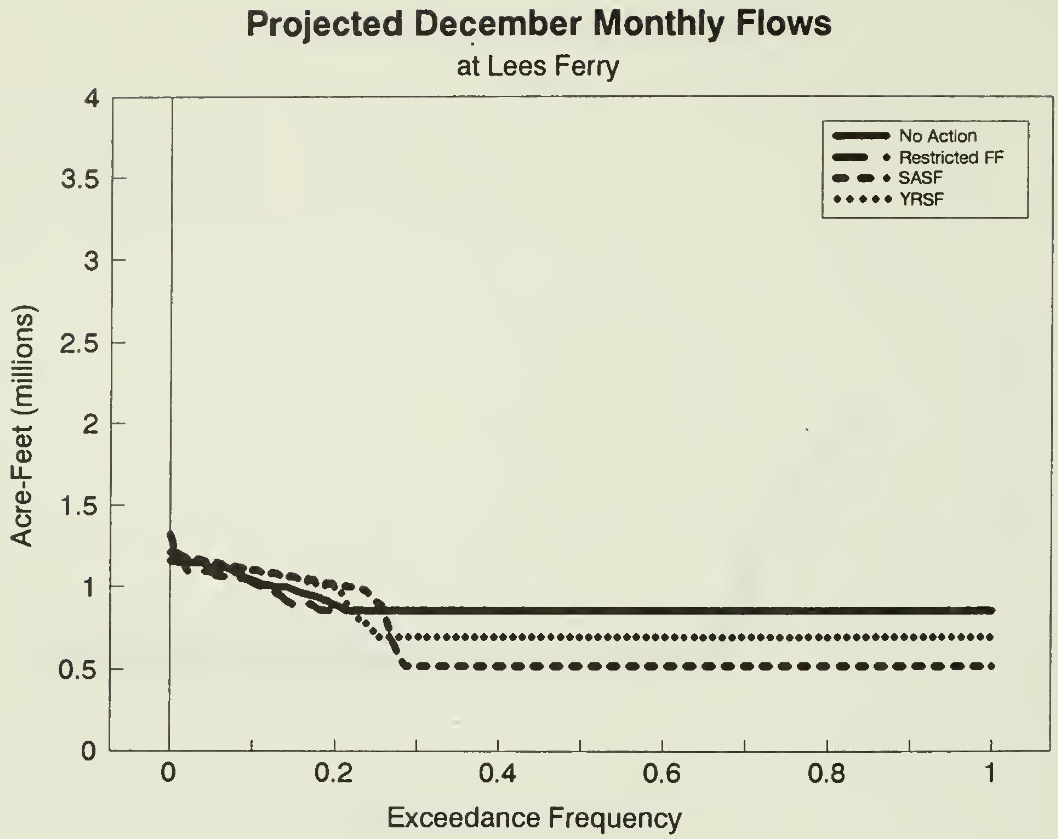
at Lees Ferry

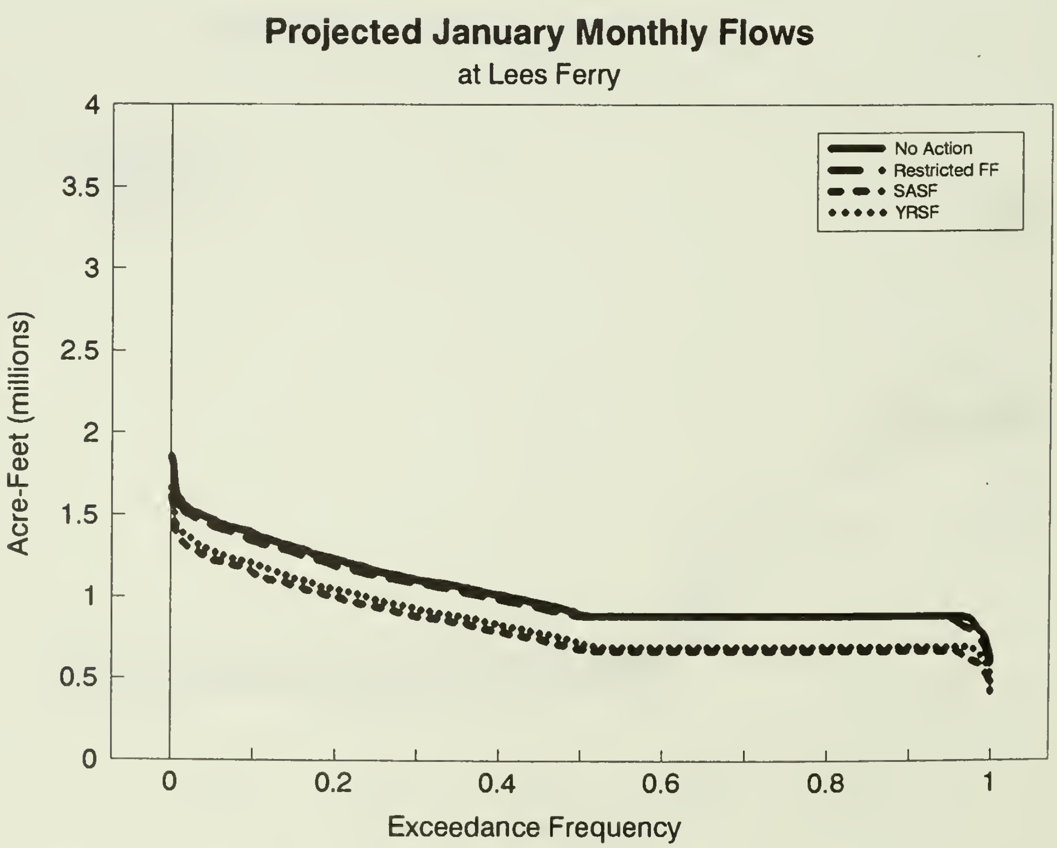



## Projected November Monthly Flows

at Lees Ferry

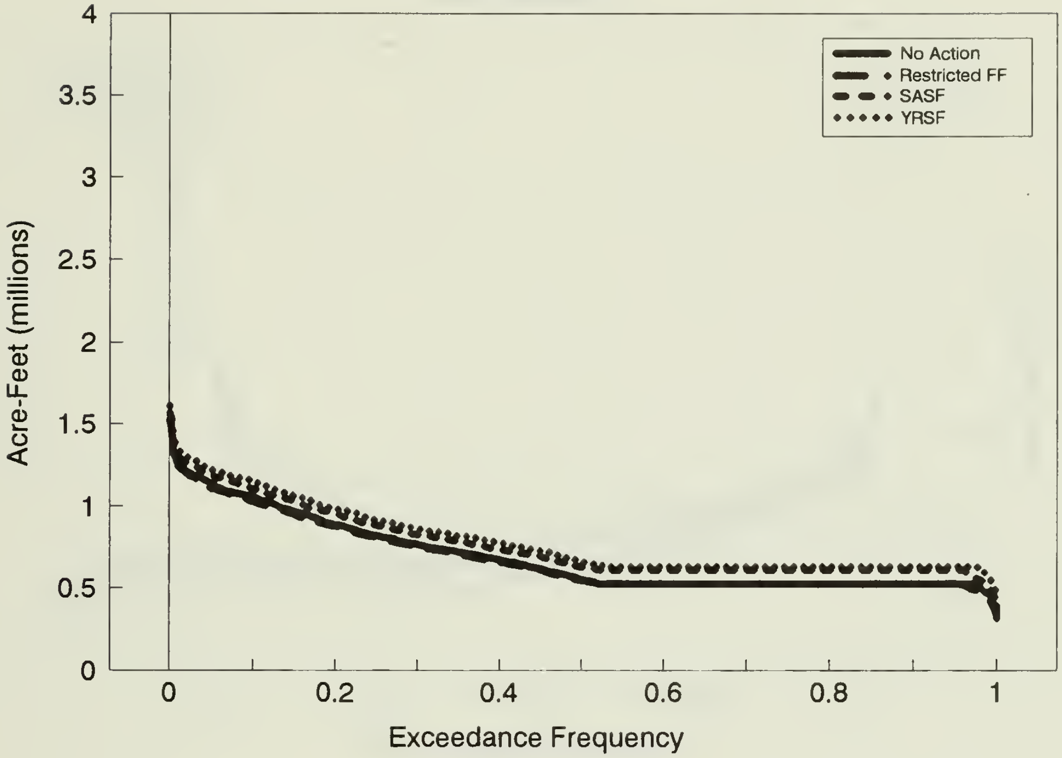



Projected December Monthly Flows
at Lees Ferry
Acre-Feet (millions)
Exceedance Frequency
No Action
Restricted FF
SASF
YRSF
0
0.5
1
1.5
2
2.5
3
3.5
4
0
0.2
0.4
0.6
0.8
1


Projected January Monthly Flows
at Lees Ferry
Acre-Feet (millions)
Exceedance Frequency
No Action
Restricted FF
SASF
YRSF
0
0.5
1
1.5
2
2.5
3
3.5
4
0
0.2
0.4
0.6
0.8
1

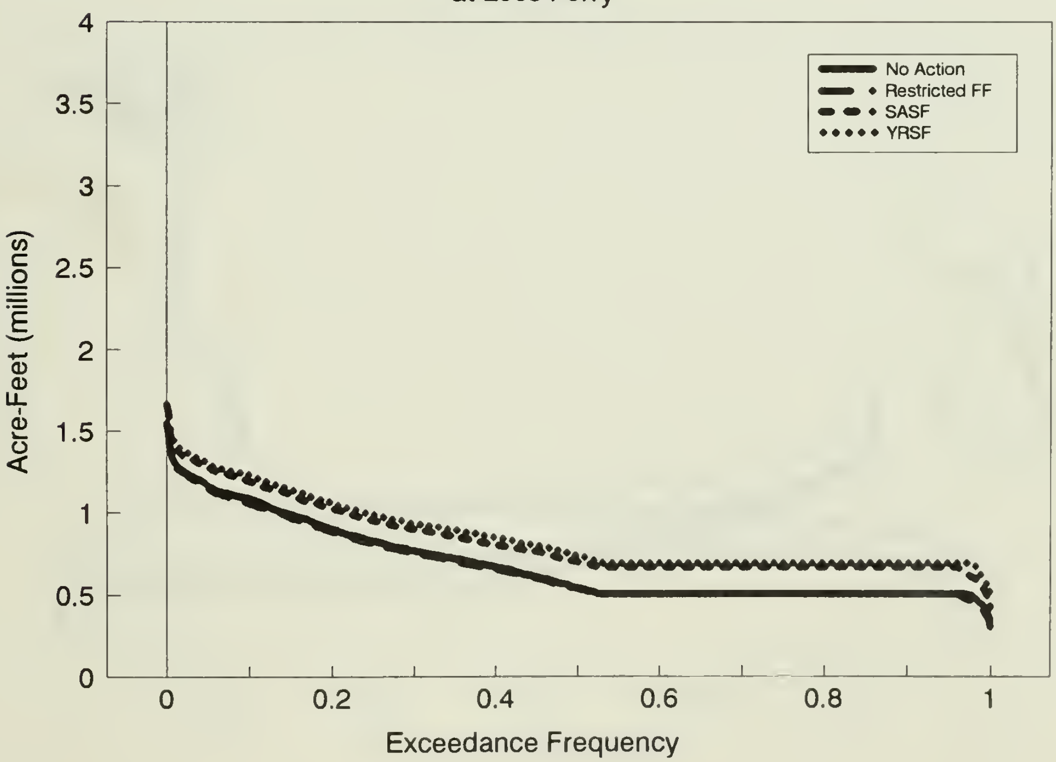
## Projected February Monthly Flows

at Lees Ferry



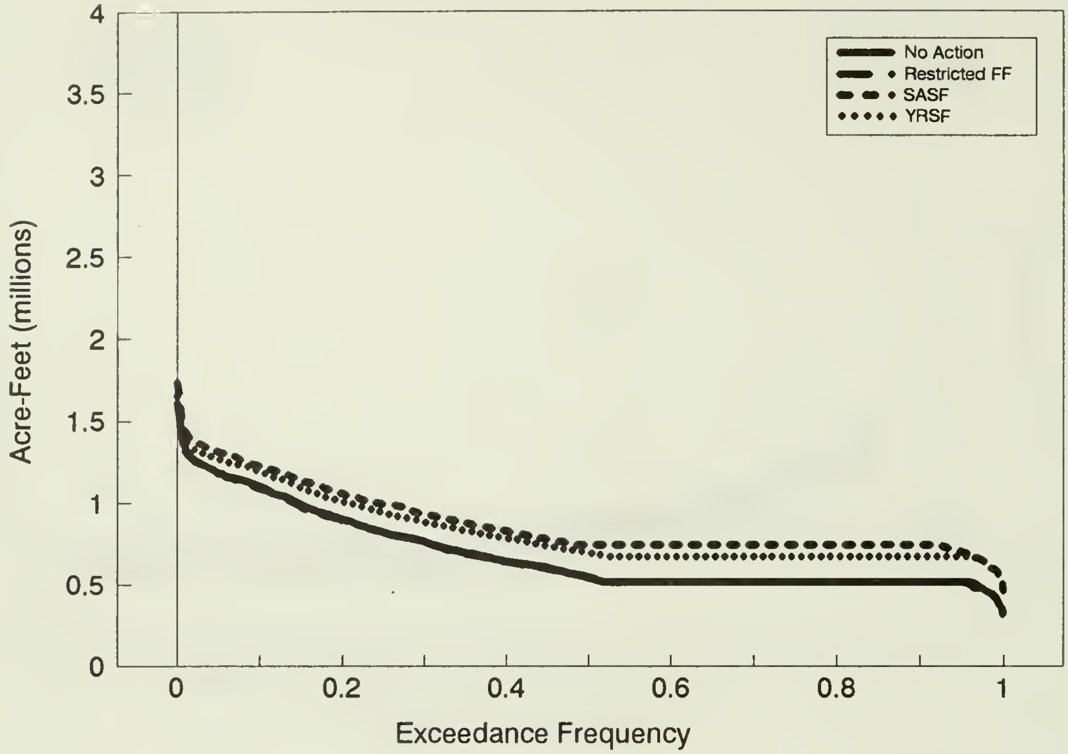

## Projected March Monthly Flows

at Lees Ferry



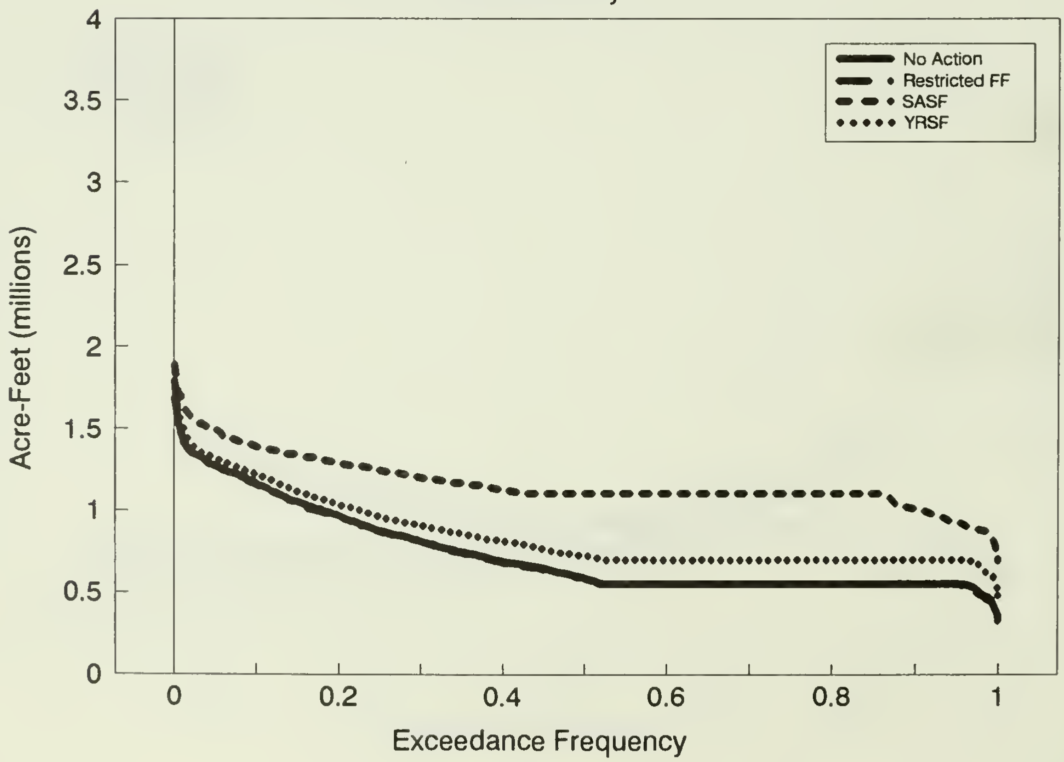
## Projected April Monthly Flows

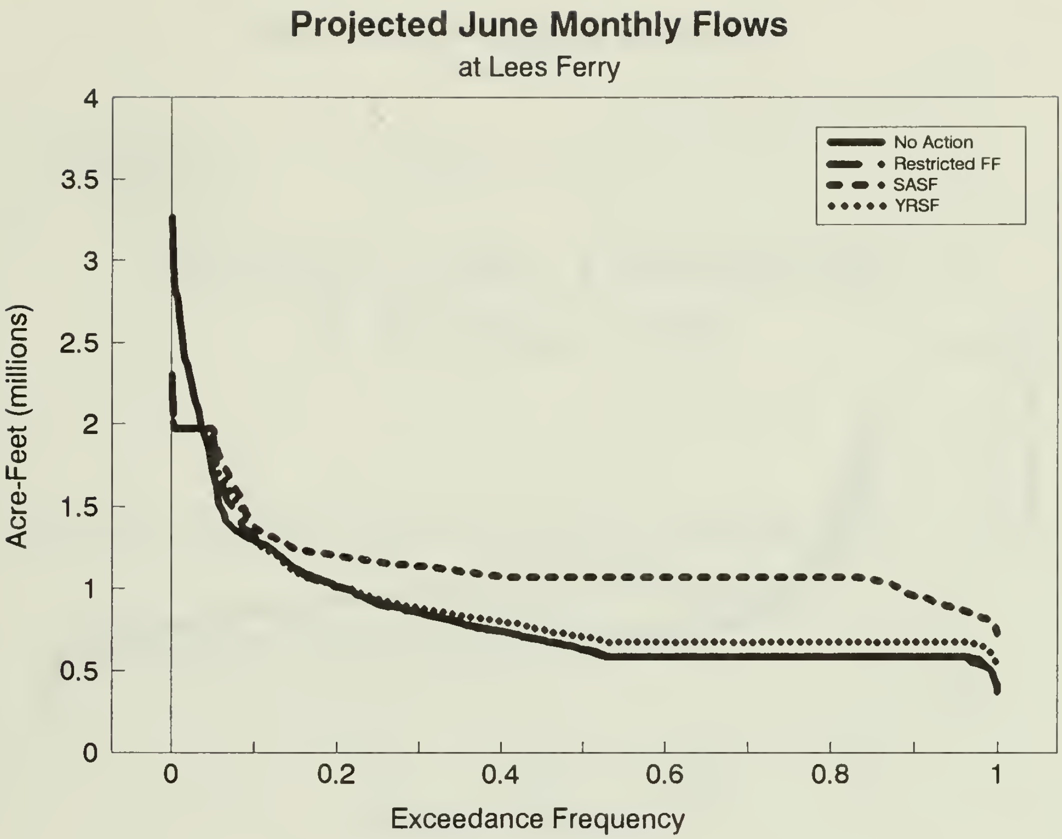
at Lees Ferry

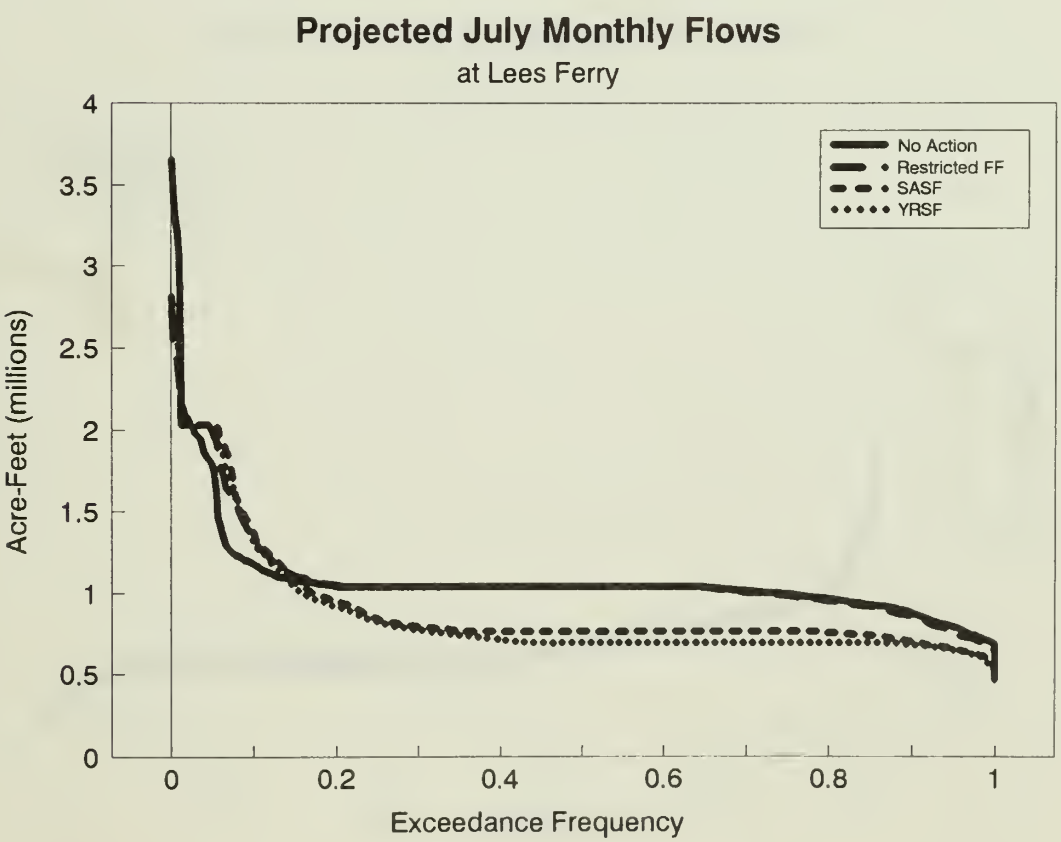



## Projected May Monthly Flows

at Lees Ferry

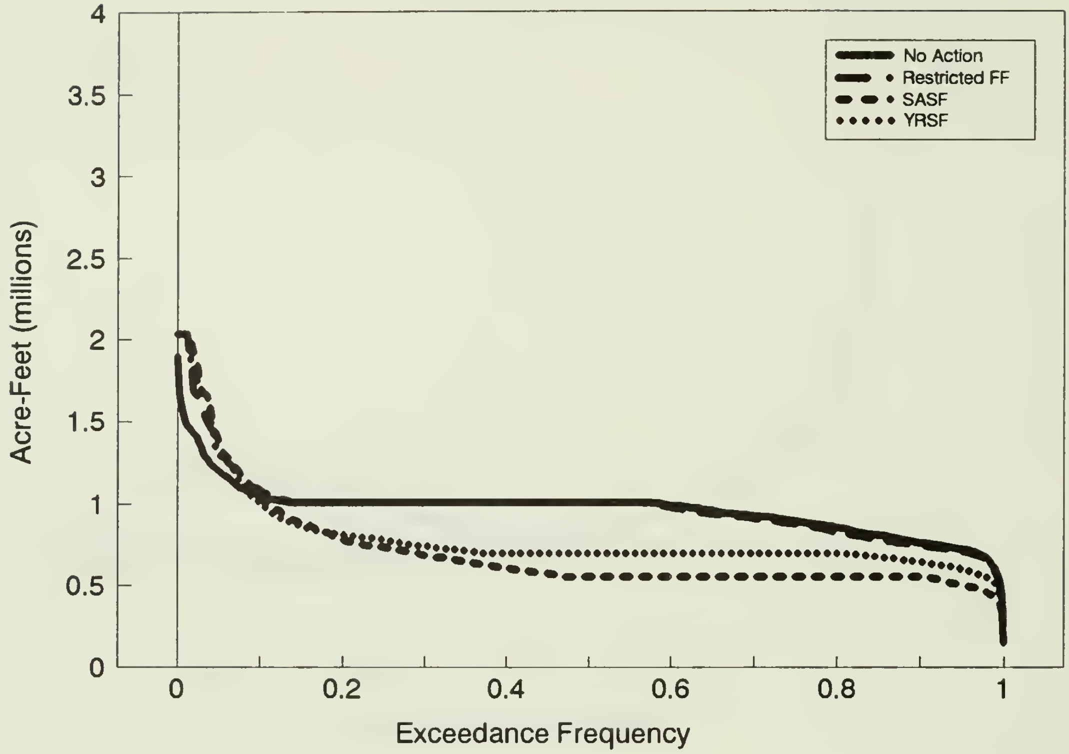



Projected June Monthly Flows
at Lees Ferry
Acre-Feet (millions)
Exceedance Frequency
No Action
Restricted FF
SASF
YRSF
0
0.5
1
1.5
2
2.5
3
3.5
4
0.2
0.4
0.6
0.8


Projected July Monthly Flows
at Lees Ferry
Acre-Feet (millions)
Exceedance Frequency
No Action
Restricted FF
SASF
YRSF
0
0.5
1
1.5
2
2.5
3
3.5
4
0.2
0.4
0.6
0.8

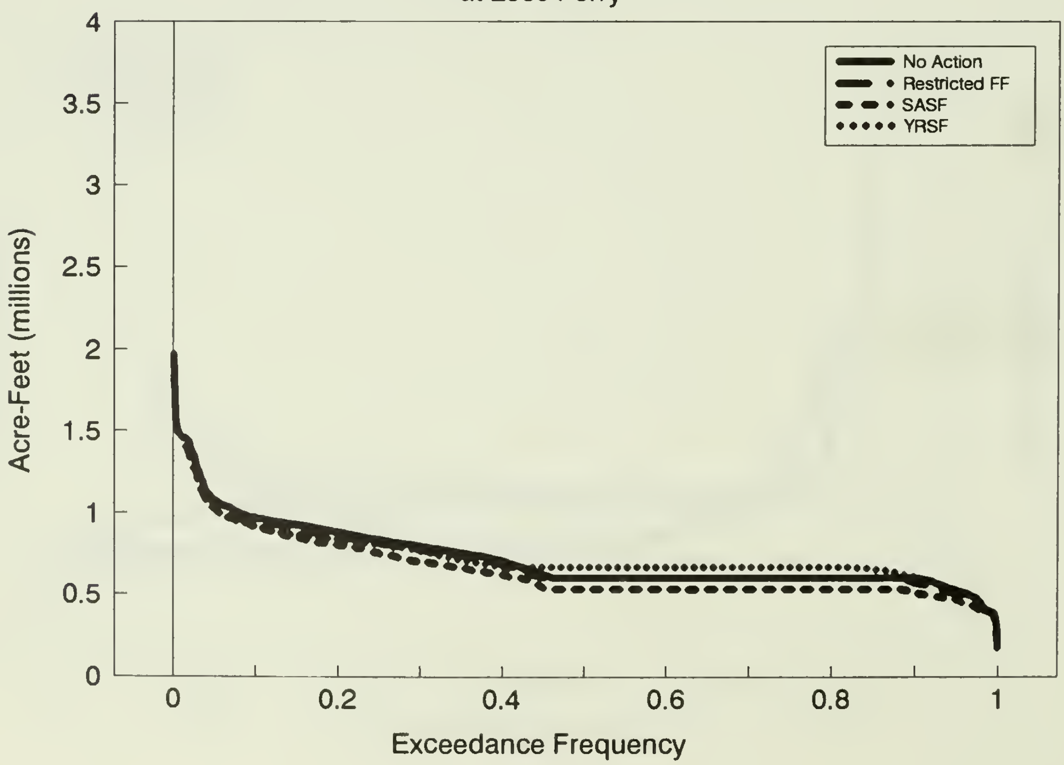
## Projected August Monthly Flows

at Lees Ferry




## Projected September Monthly Flows

at Lees Ferry

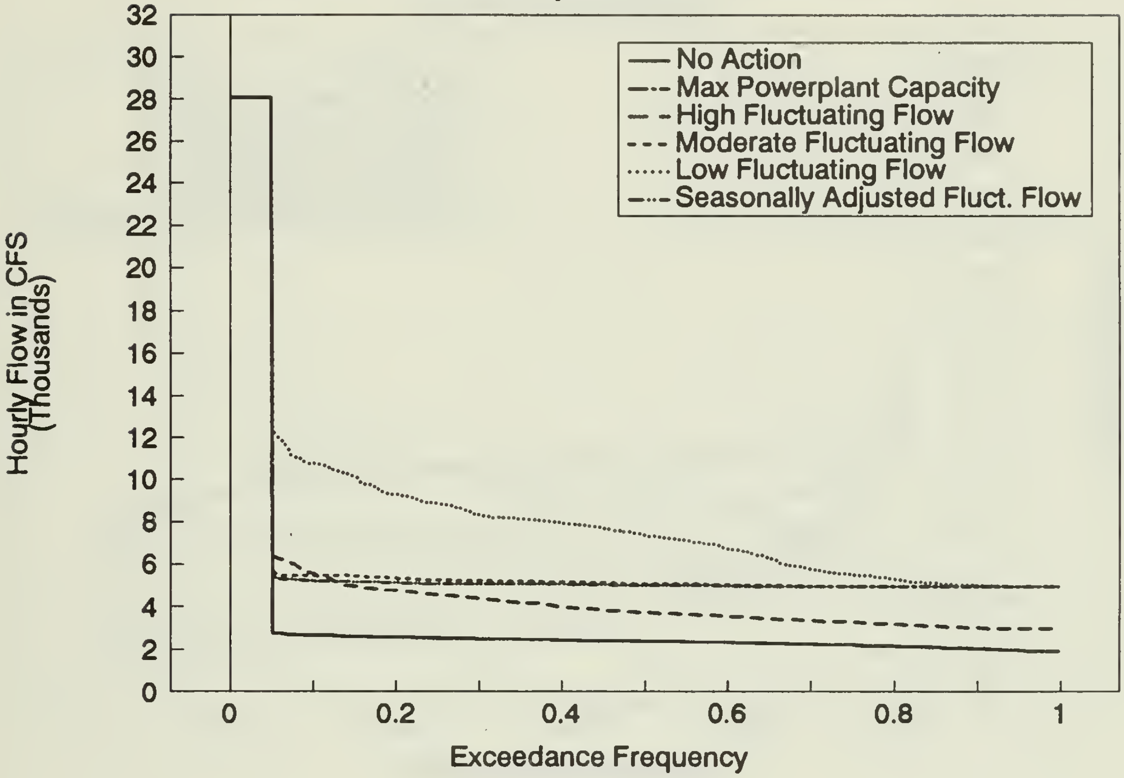


Frequencies of

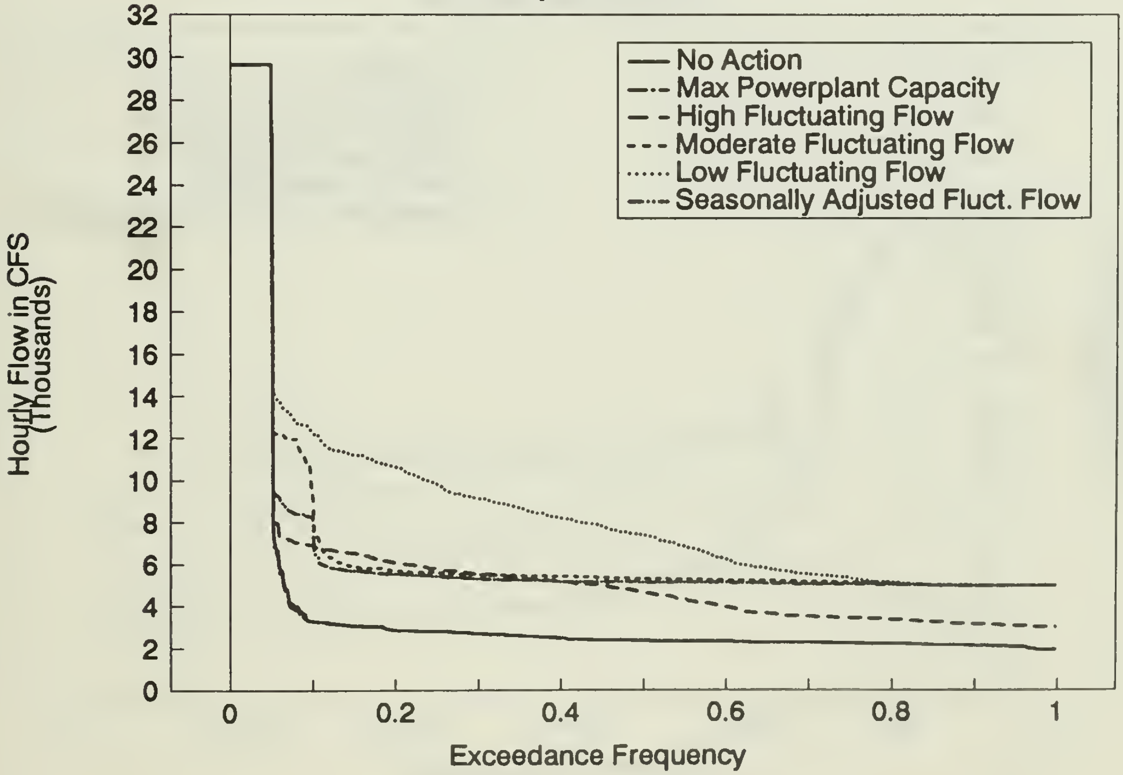
# Projected Daily Fluctuations in Releases (cfs)

- 12 Frequency Graphs, Each with Several Alternatives

## Projected Minimum Hourly Releases
for Days in October

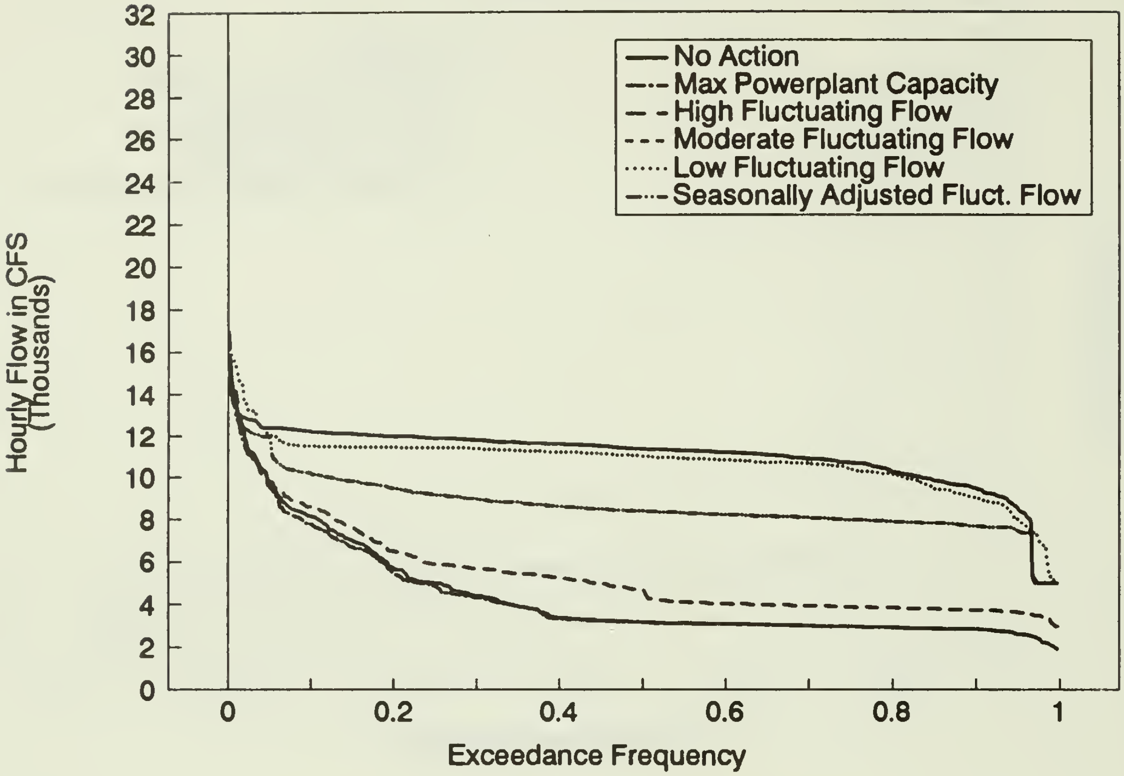



## Projected Minimum Hourly Releases
for Days in November



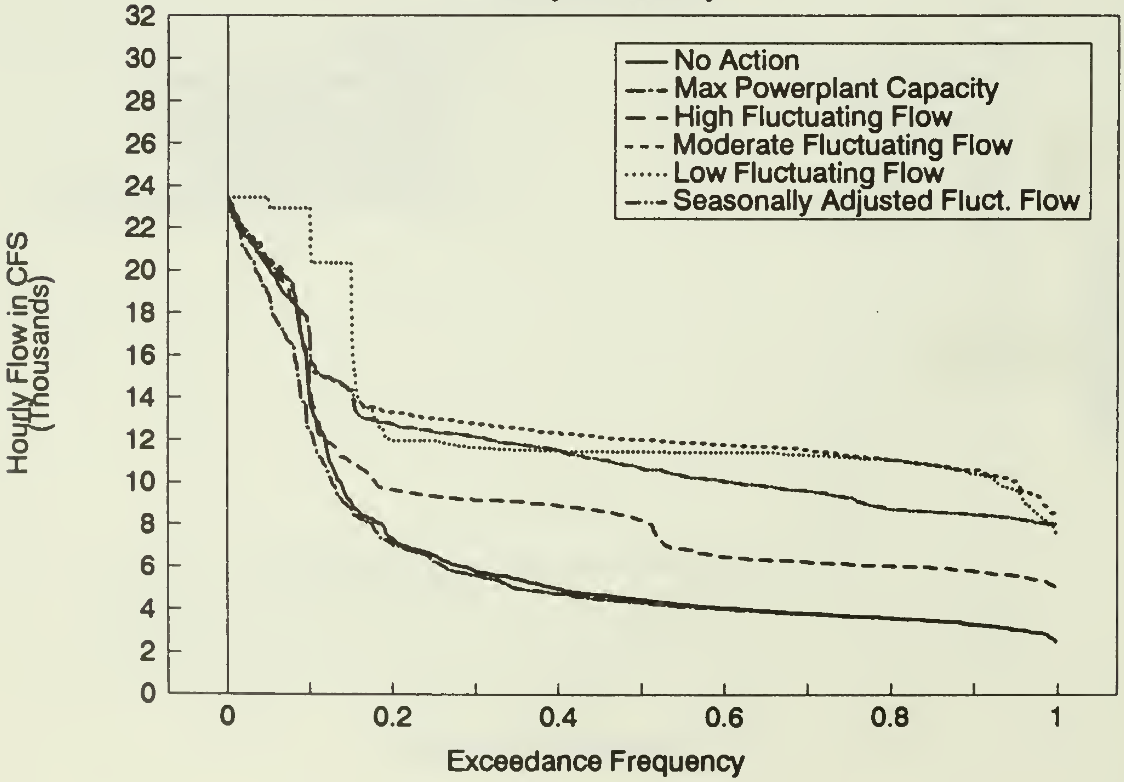
## Projected Minimum Hourly Releases

for Days in December



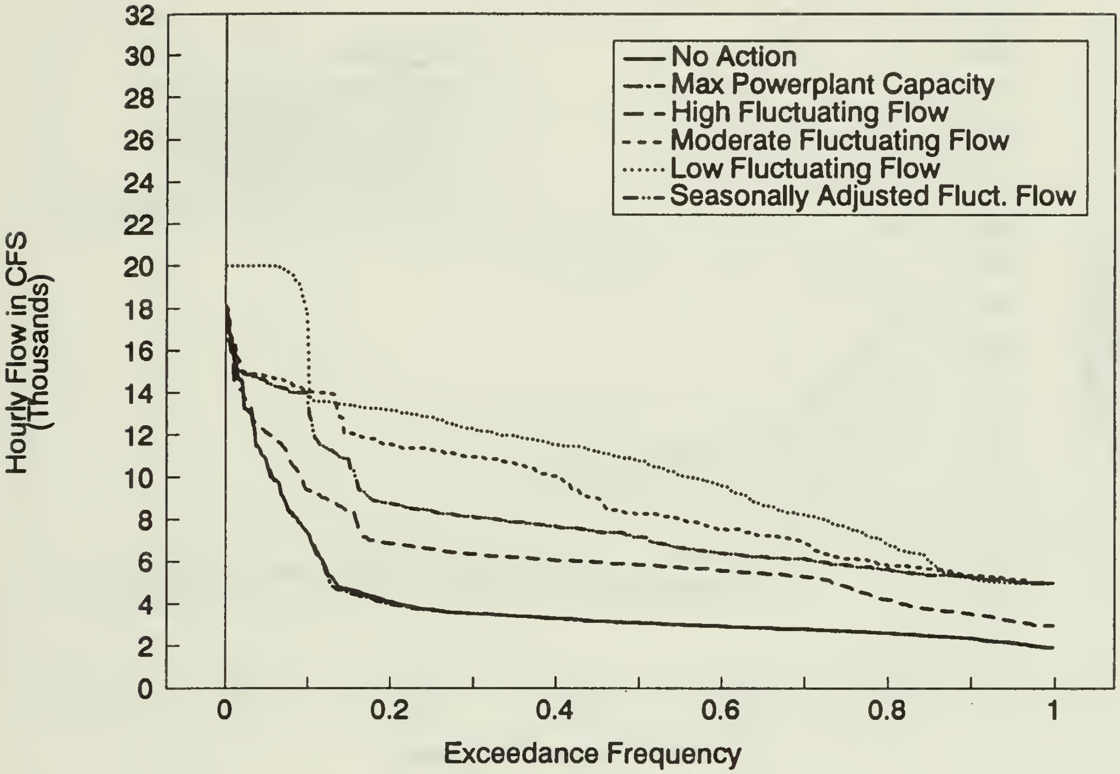

## Projected Minimum Hourly Releases

for Days in January



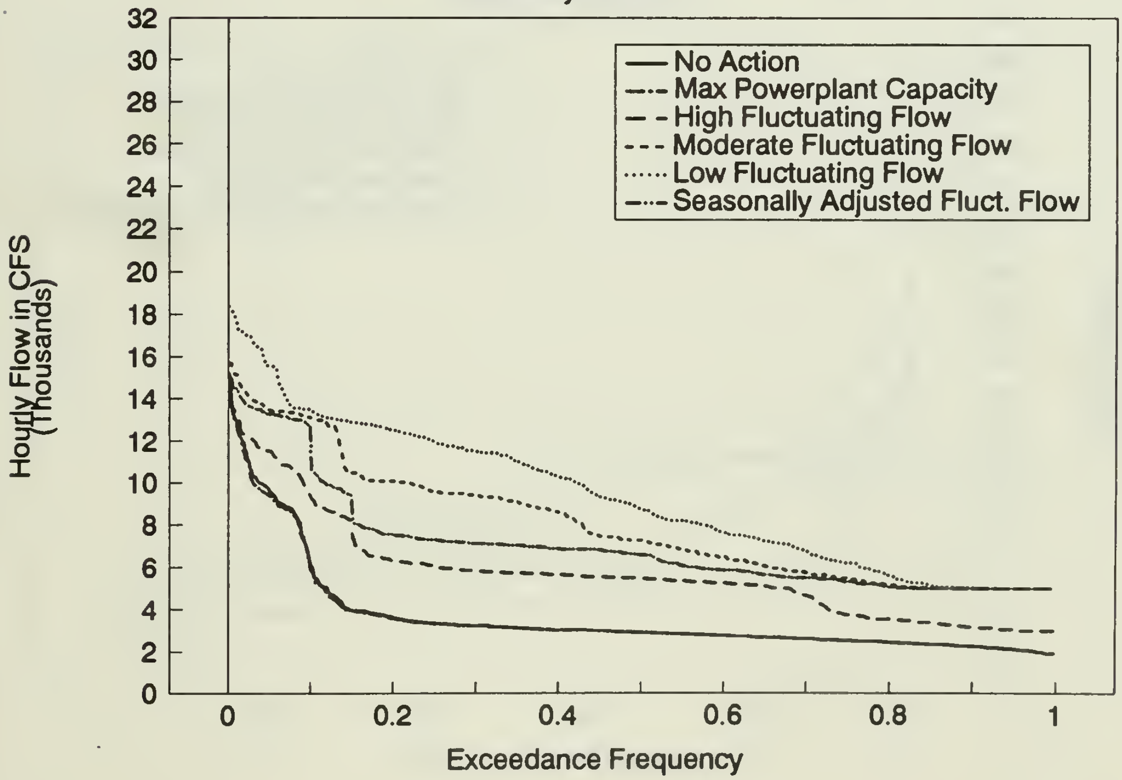
## Projected Minimum Hourly Releases

for Days in February



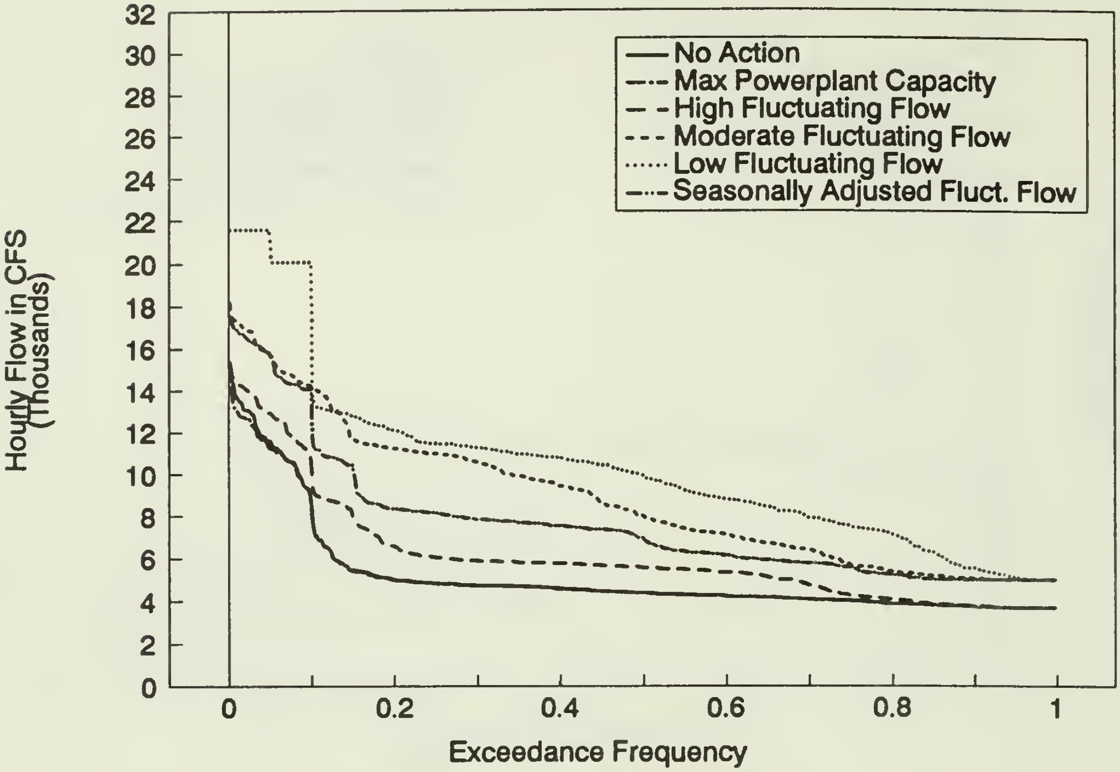

## Projected Minimum Hourly Releases

for Days in March



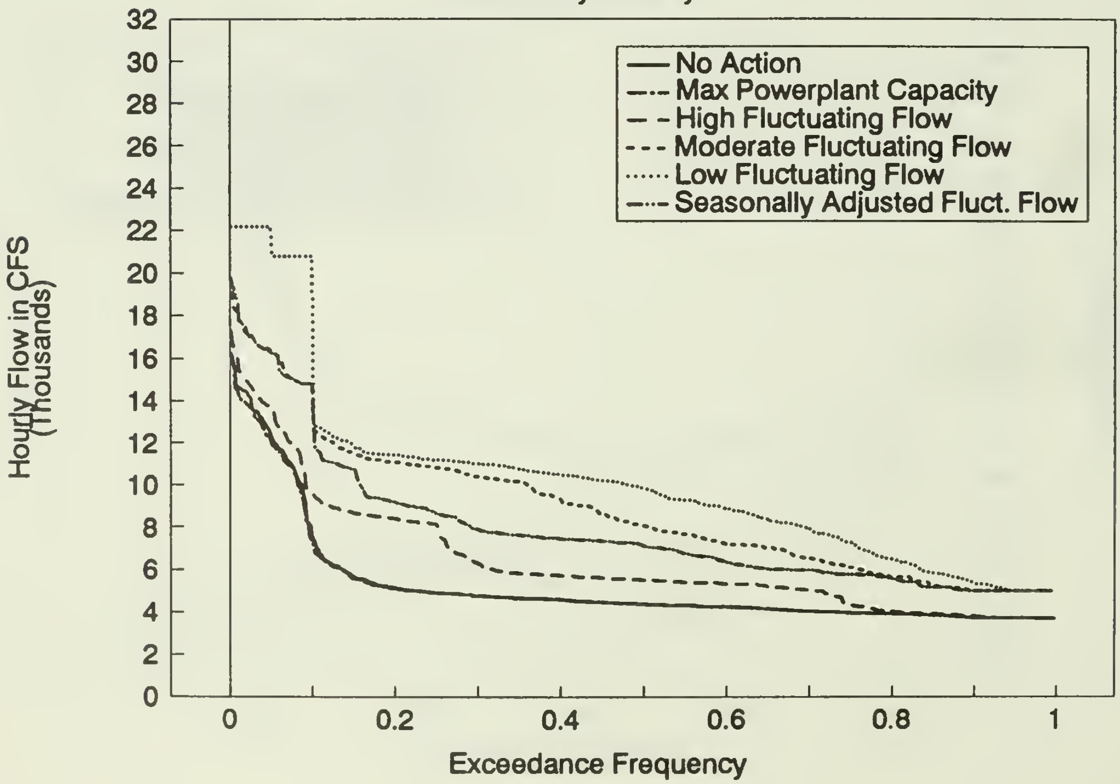
## Projected Minimum Hourly Releases

for Days in April



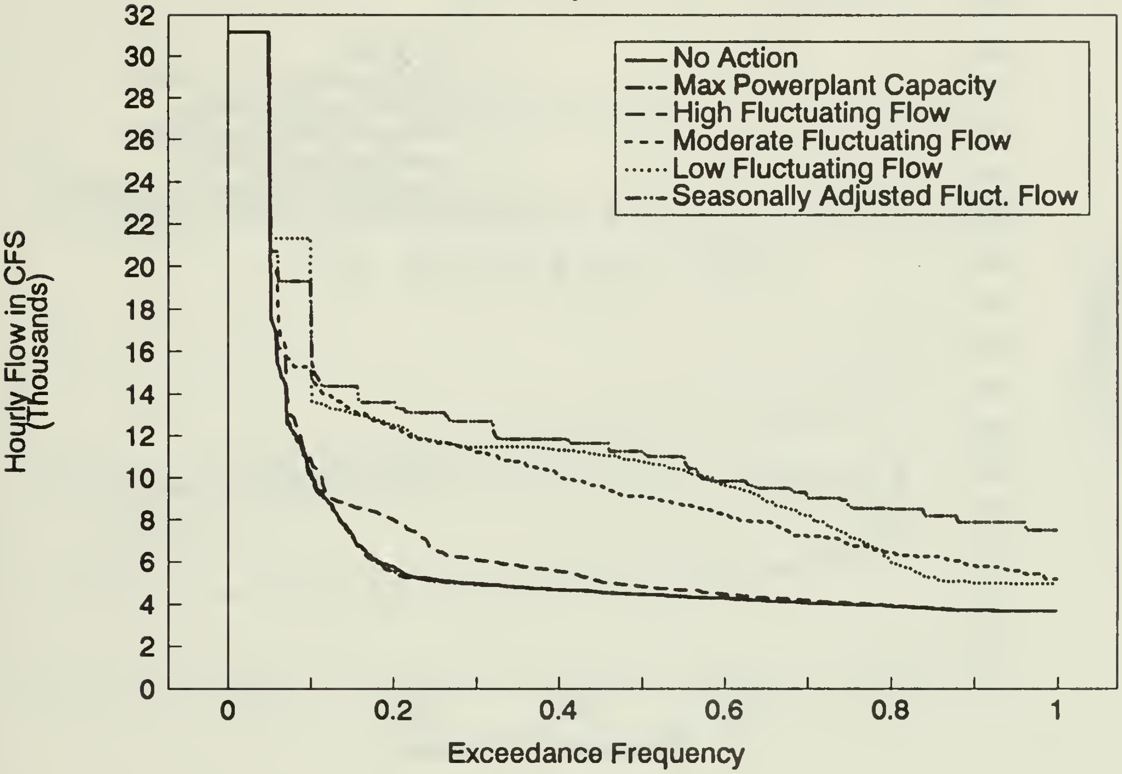

## Projected Minimum Hourly Releases

for Days in May



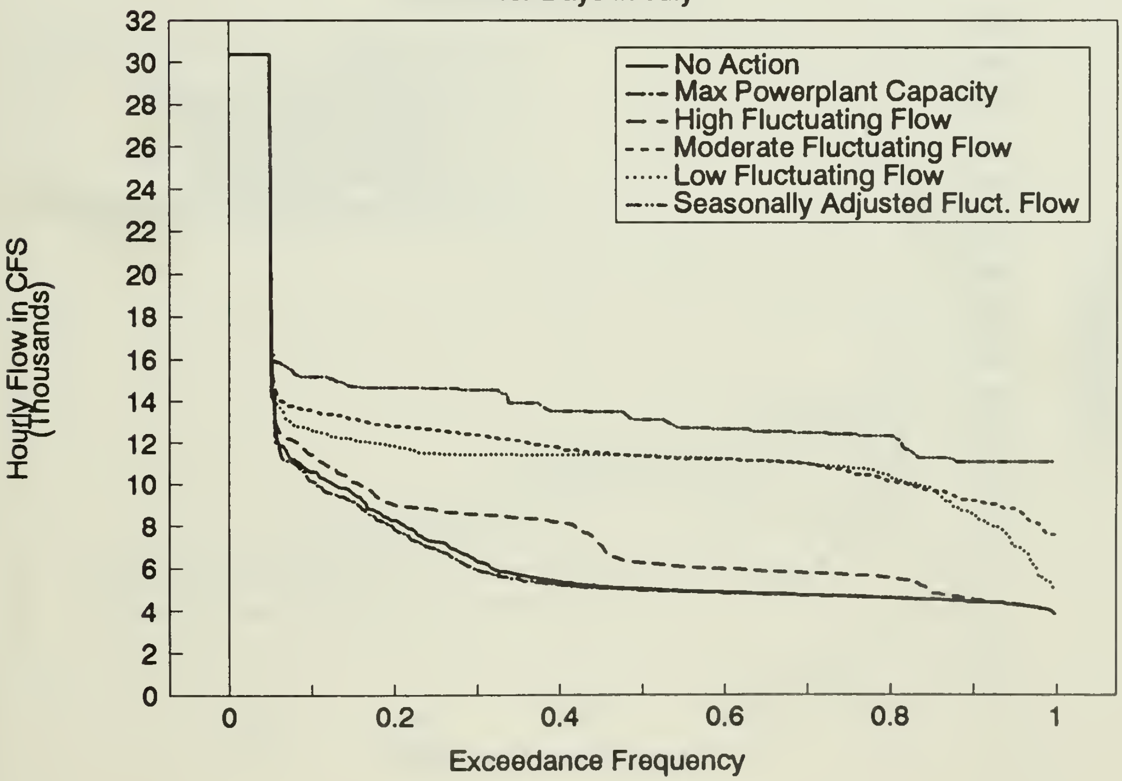
## Projected Minimum Hourly Releases

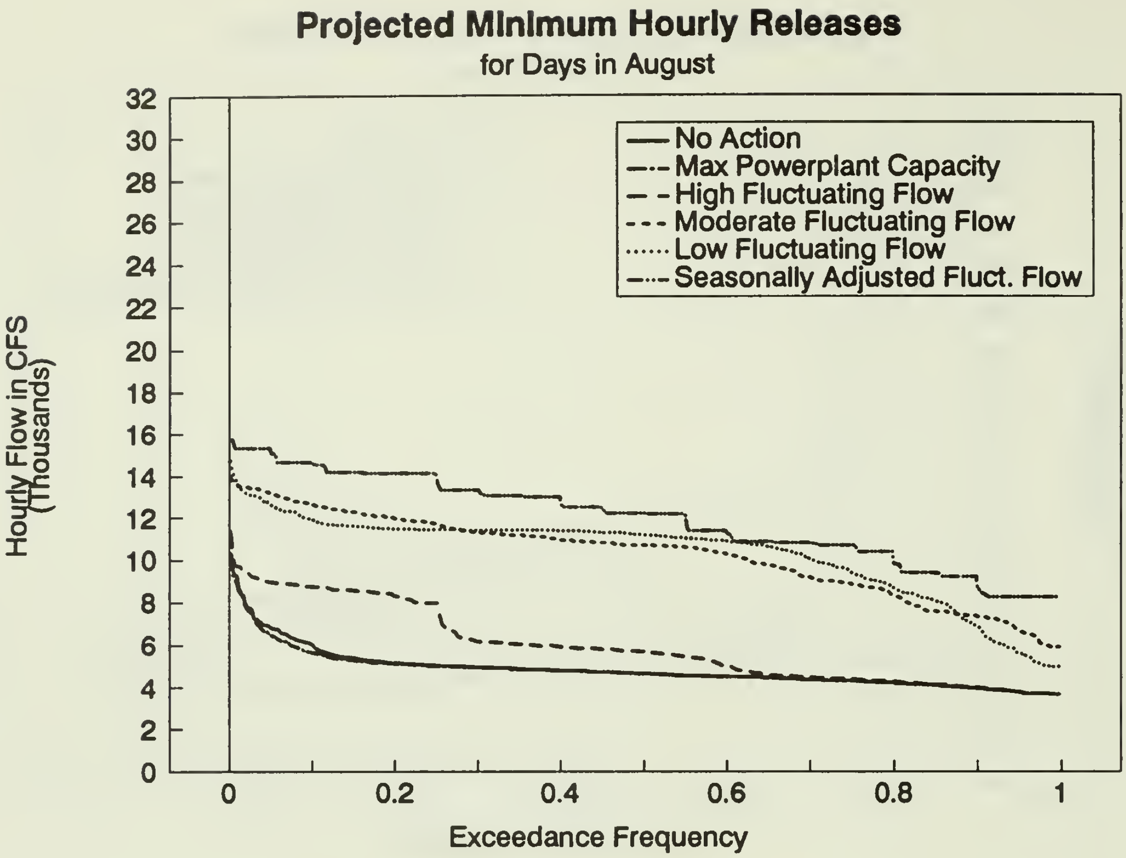
for Days in June

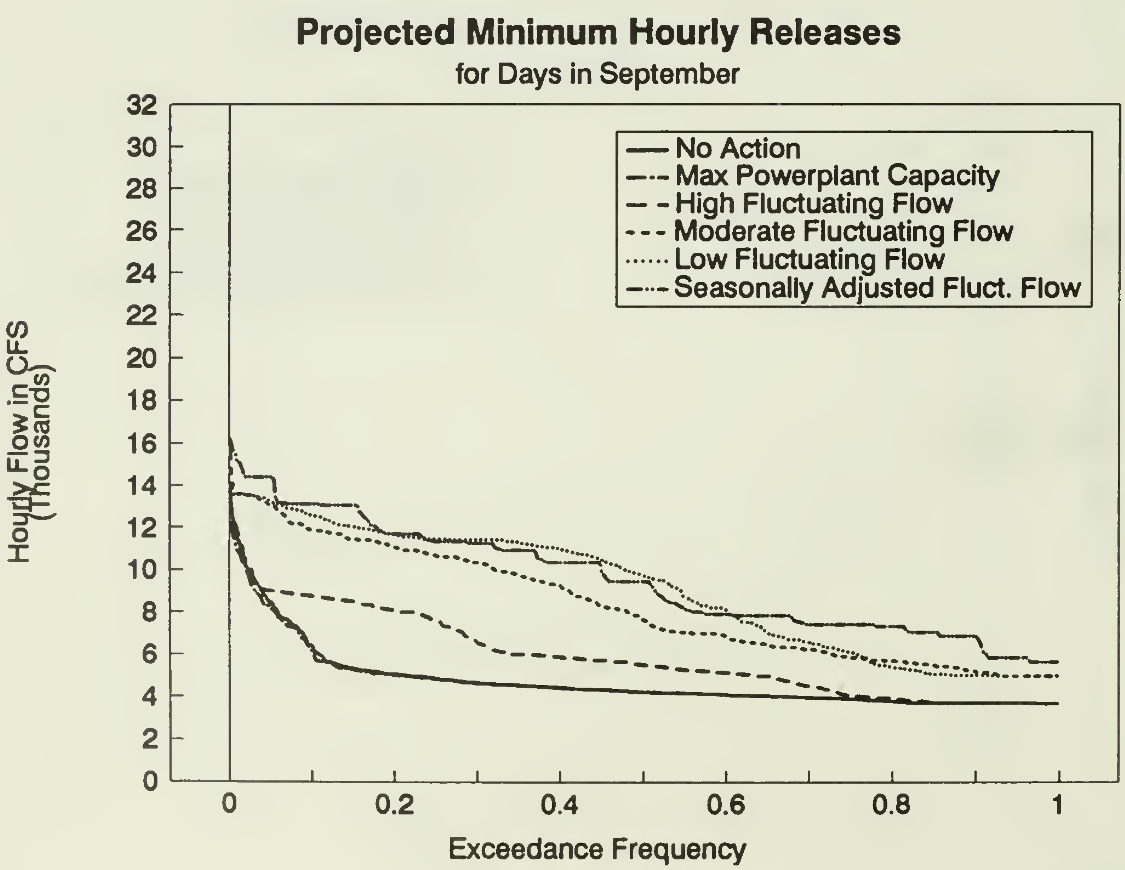



## Projected Minimum Hourly Releases

for Days in July



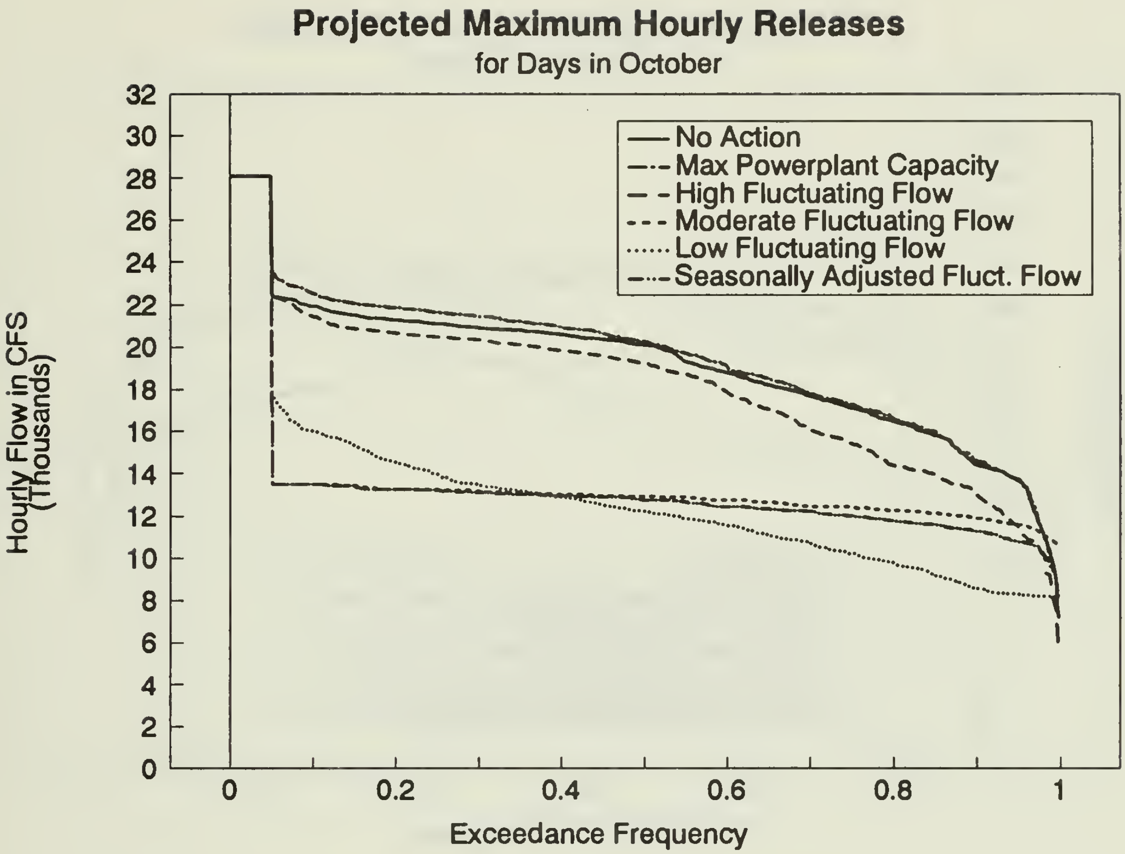

Projected Minimum Hourly Releases
for Days in August
Hourly Flow in CFS
(Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency


Projected Minimum Hourly Releases
for Days in September
Hourly Flow in CFS
(Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

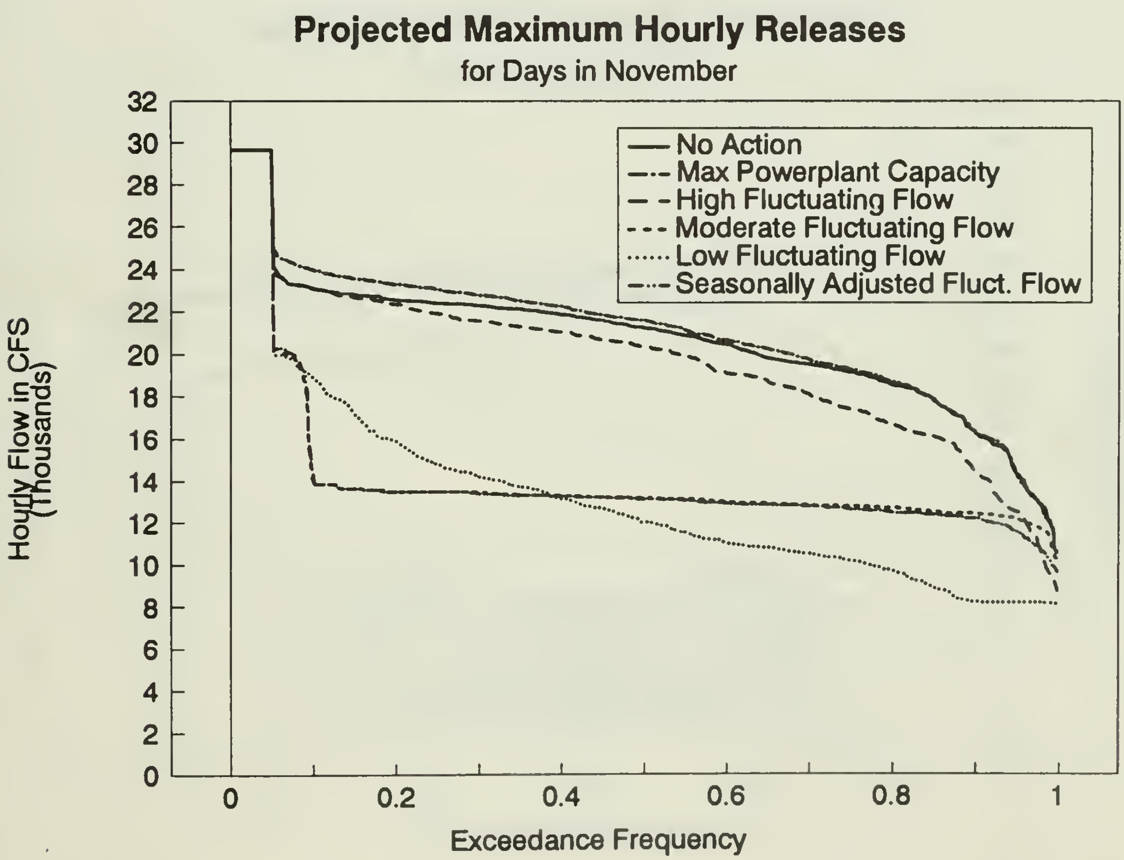
Frequencies of

# Projected Minimum Hourly Releases for Each Day (cfs)

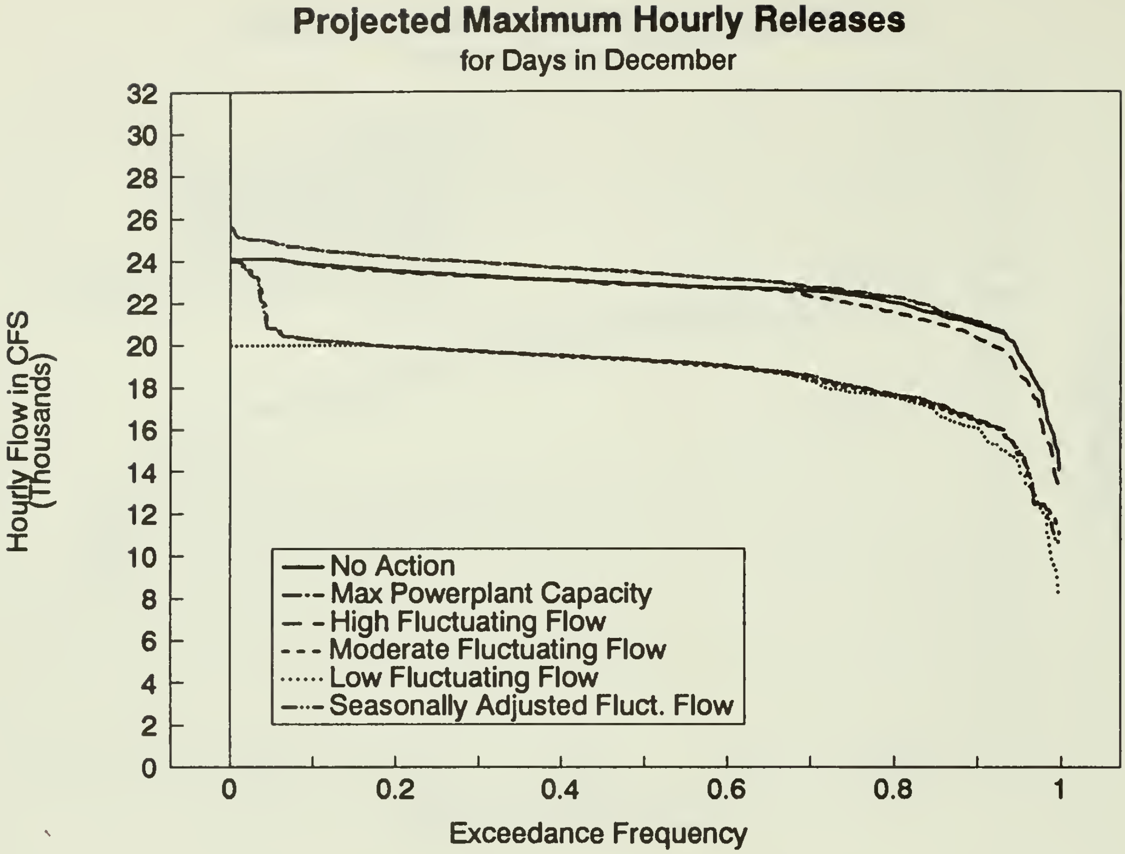
- 12 Frequency Graphs, Each with Several Alternatives

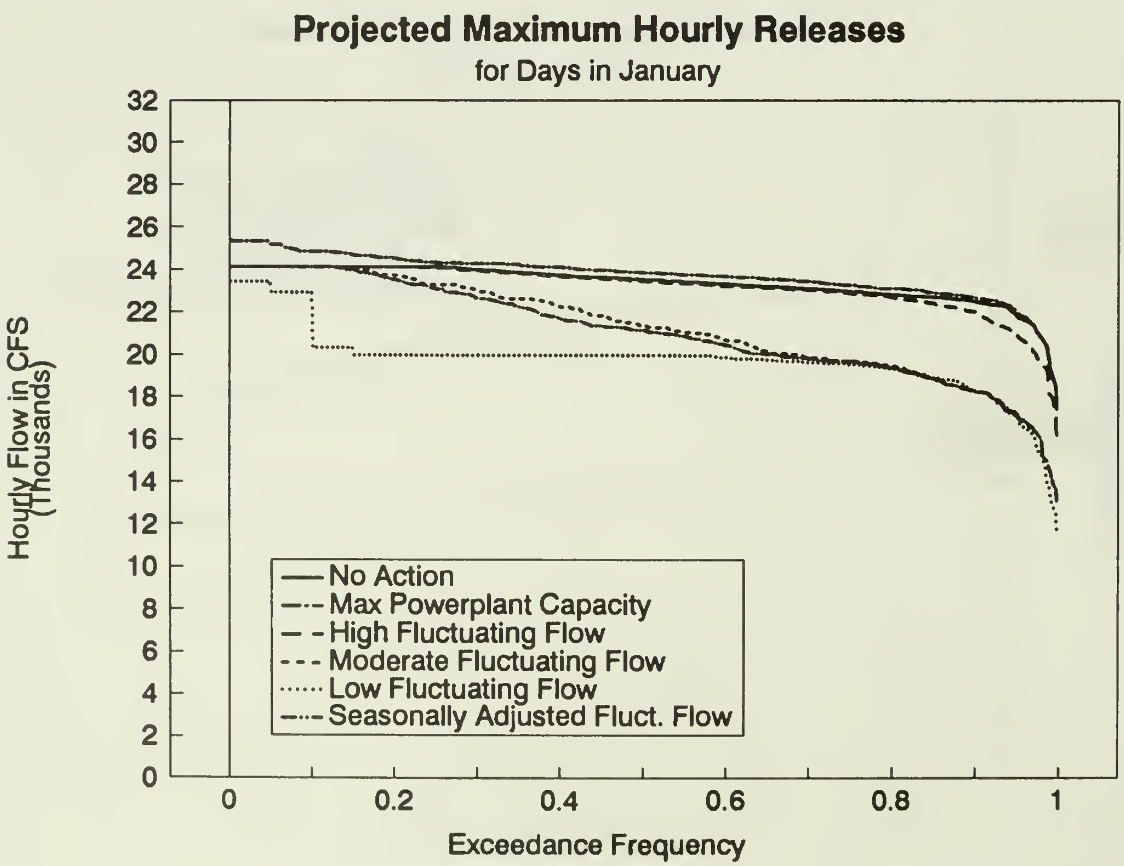


Projected Maximum Hourly Releases
for Days in October
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow

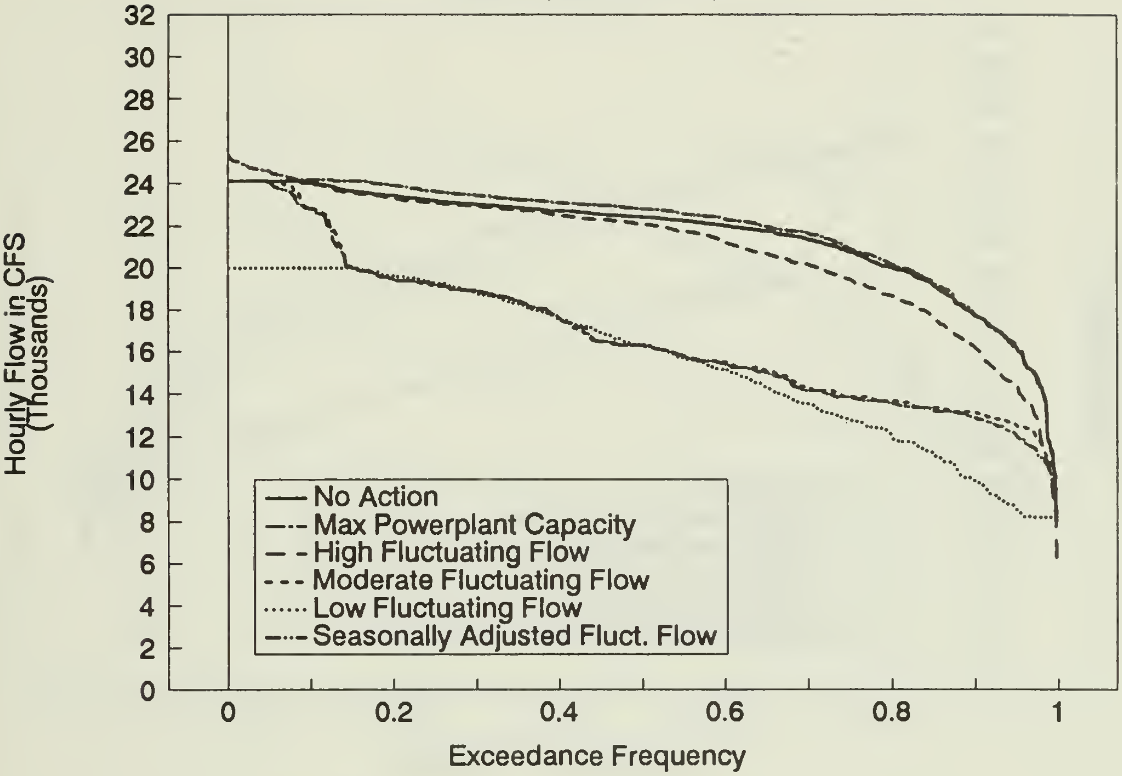



Projected Maximum Hourly Releases
for Days in November
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow

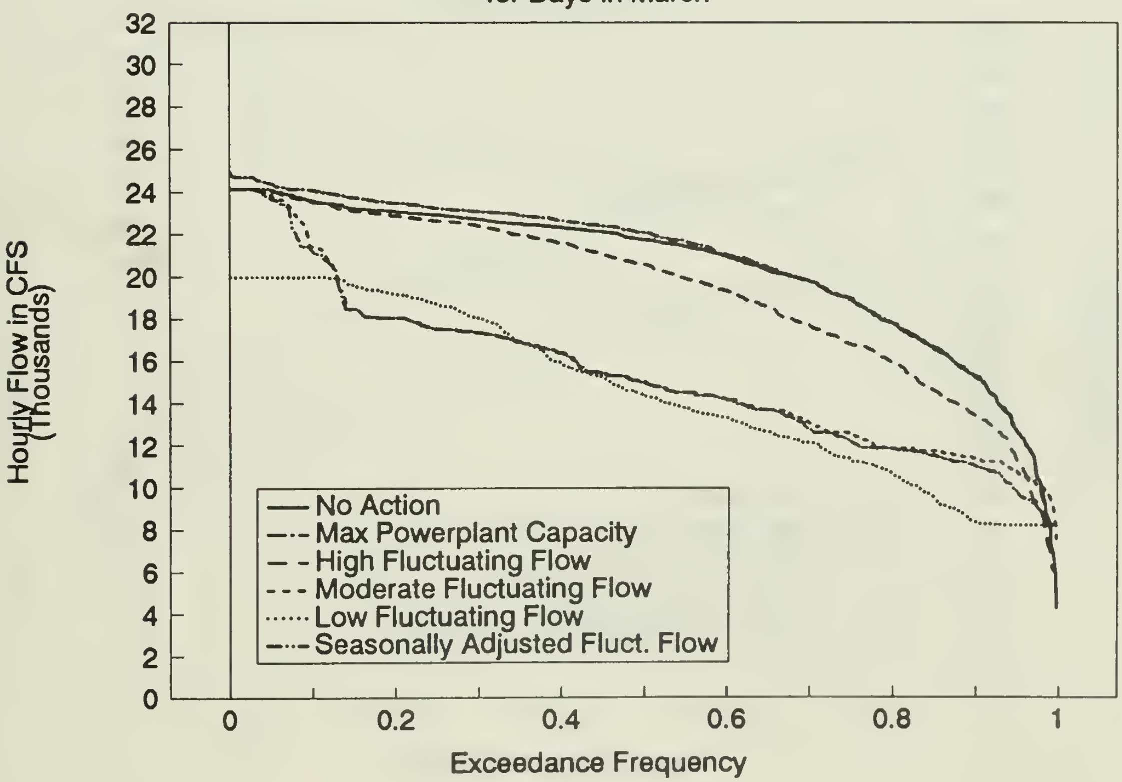

Projected Maximum Hourly Releases
for Days in December
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

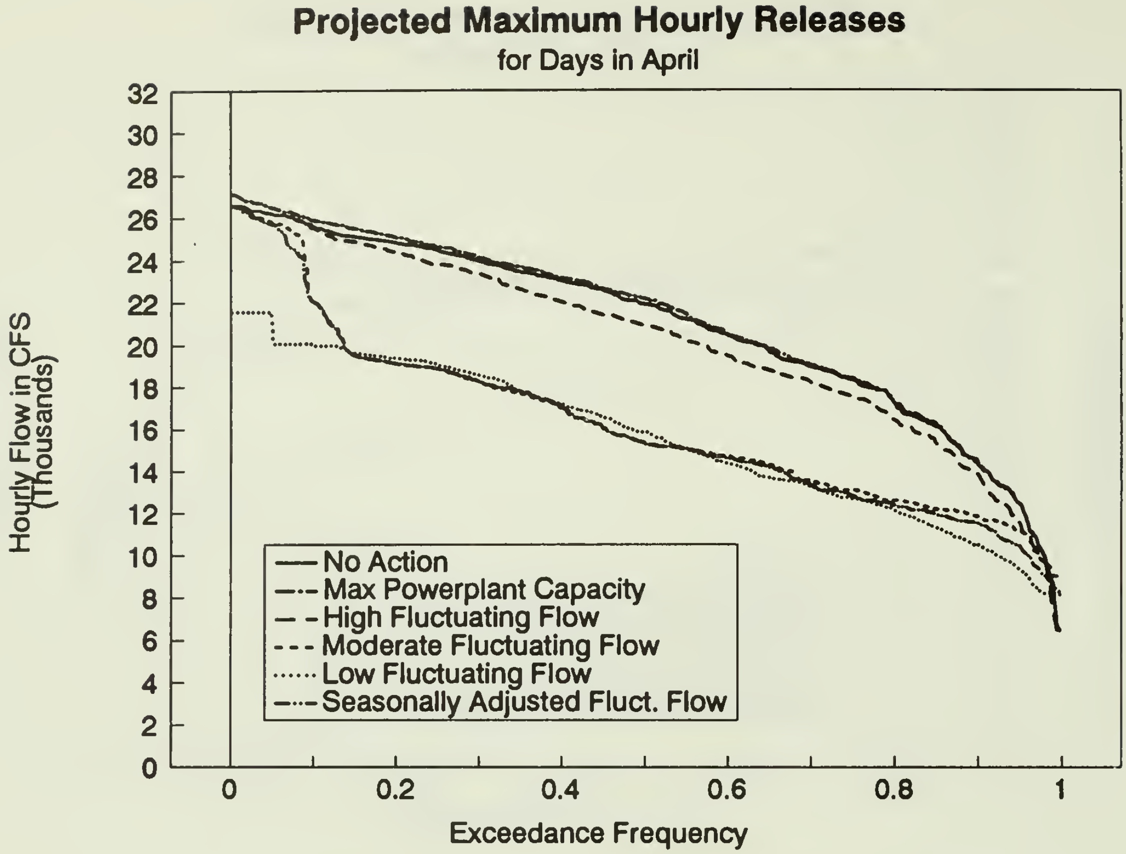

Projected Maximum Hourly Releases
for Days in January
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

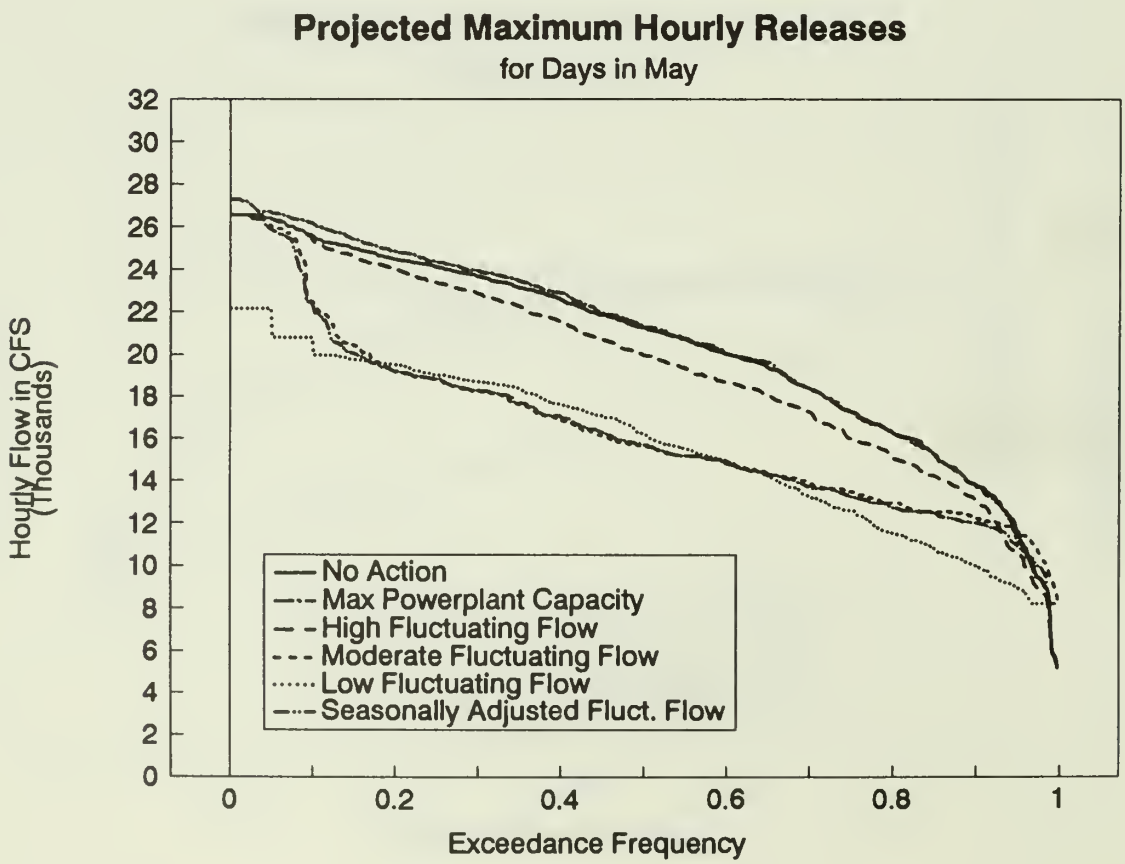
## Projected Maximum Hourly Releases
for Days in February




## Projected Maximum Hourly Releases
for Days in March

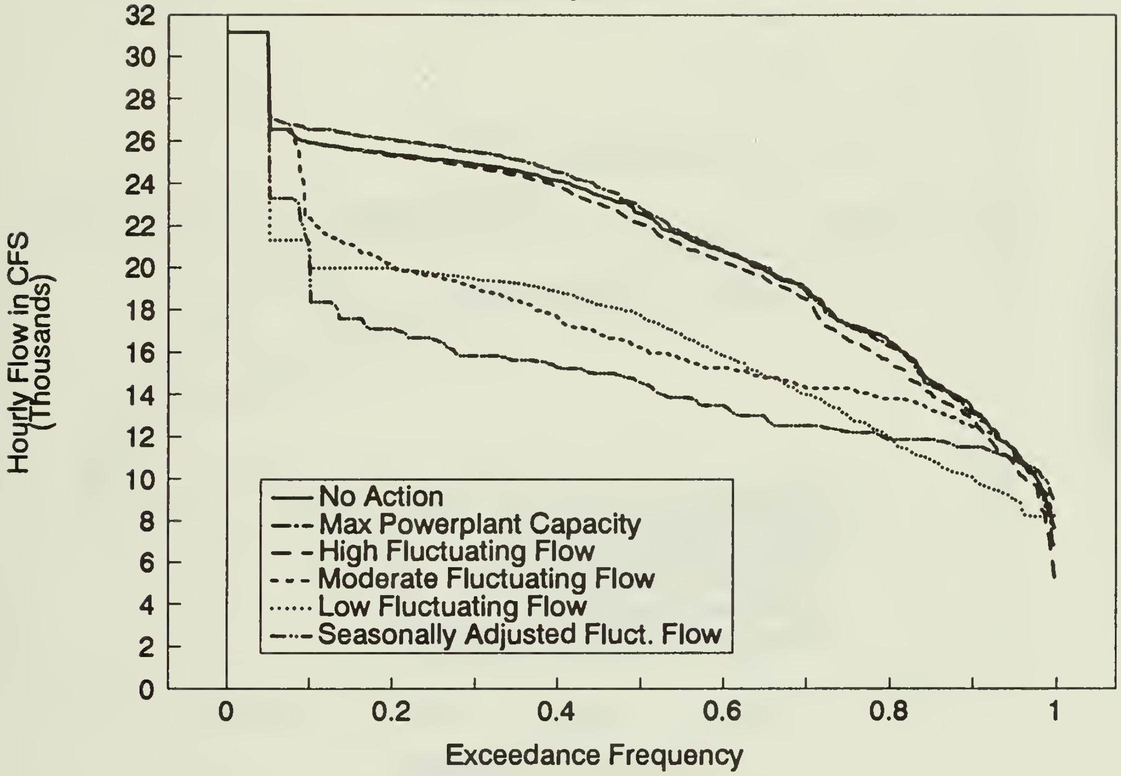



Projected Maximum Hourly Releases
for Days in April
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow


Projected Maximum Hourly Releases
for Days in May
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow

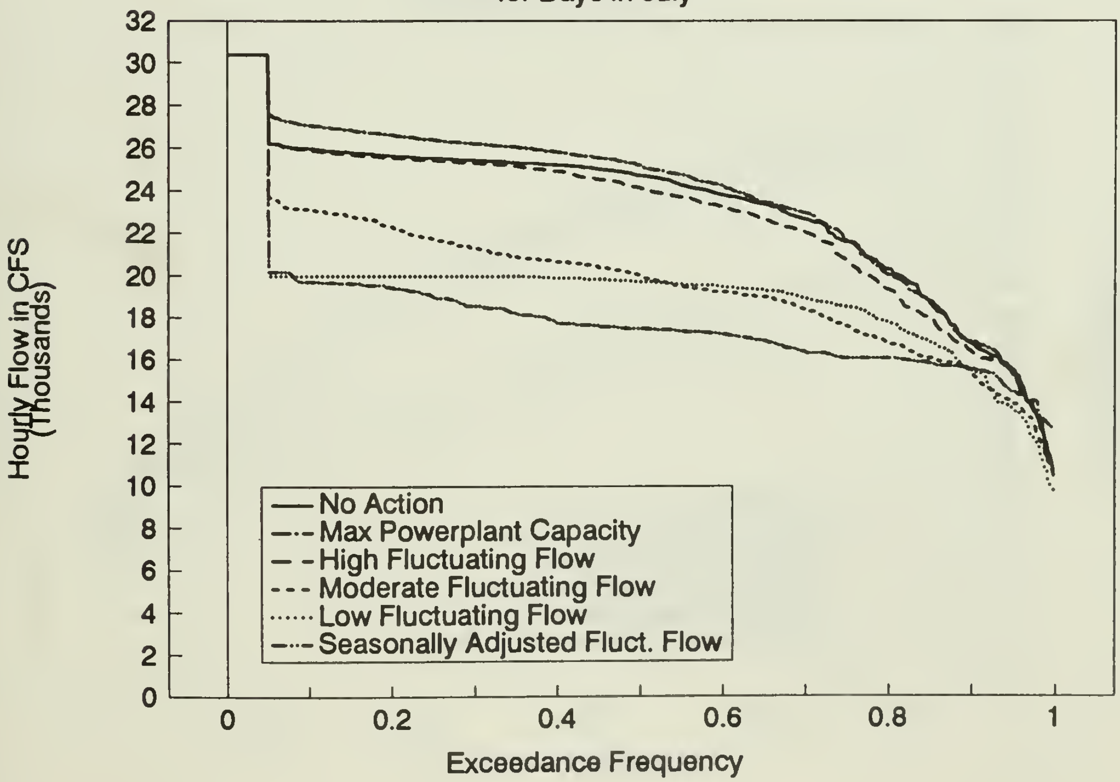
## Projected Maximum Hourly Releases

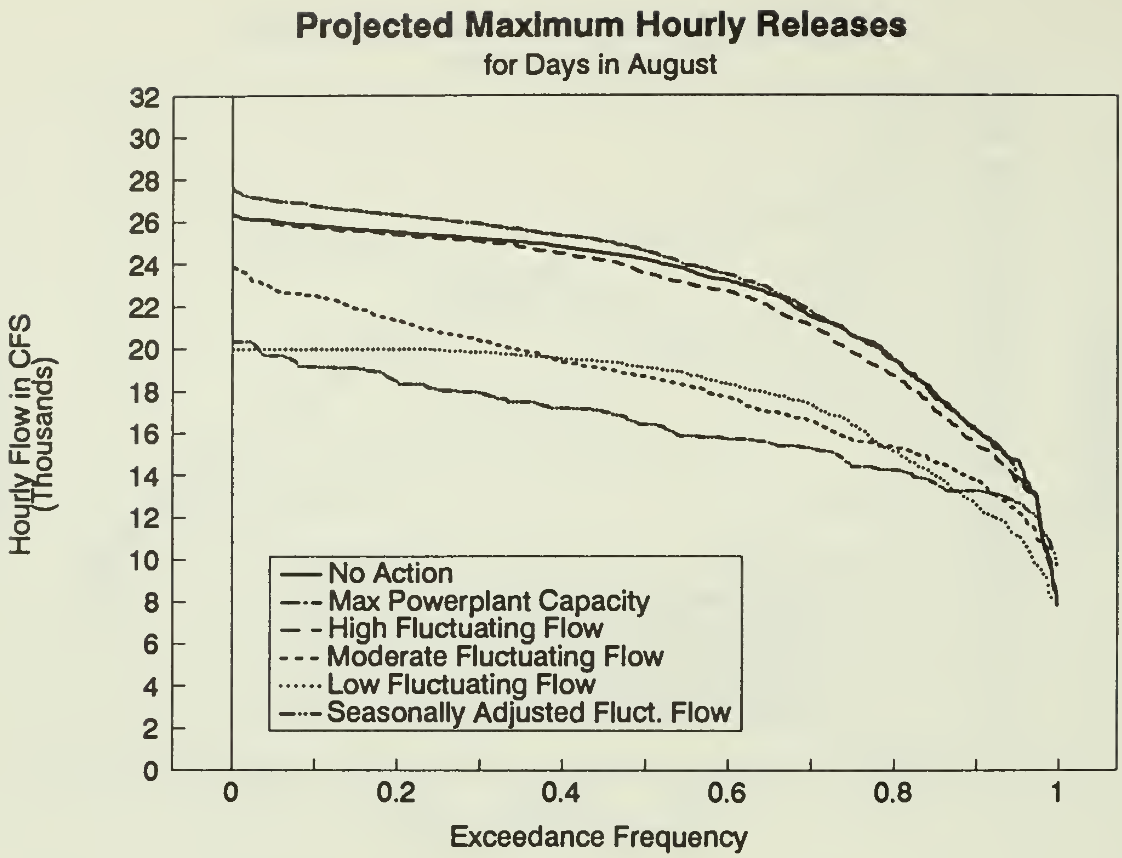
for Days in June

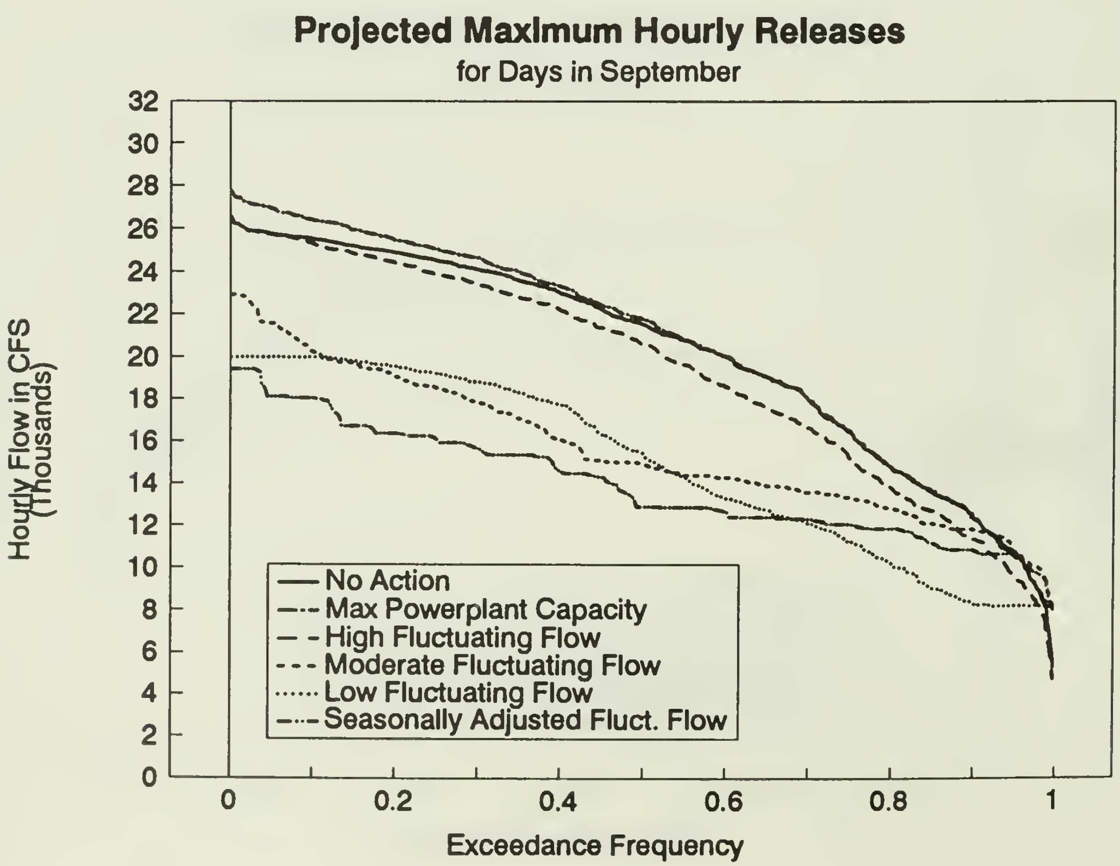



## Projected Maximum Hourly Releases

for Days in July




Projected Maximum Hourly Releases
for Days in August
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow

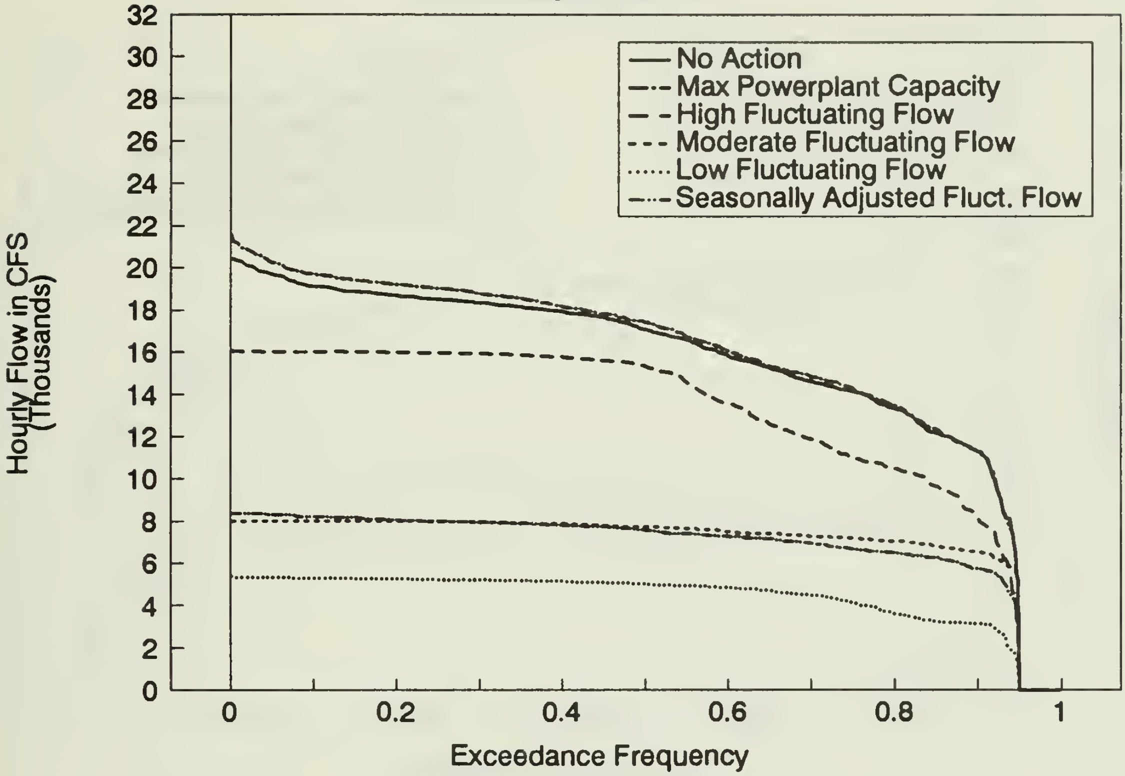

Projected Maximum Hourly Releases
for Days in September
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow

Frequencies of

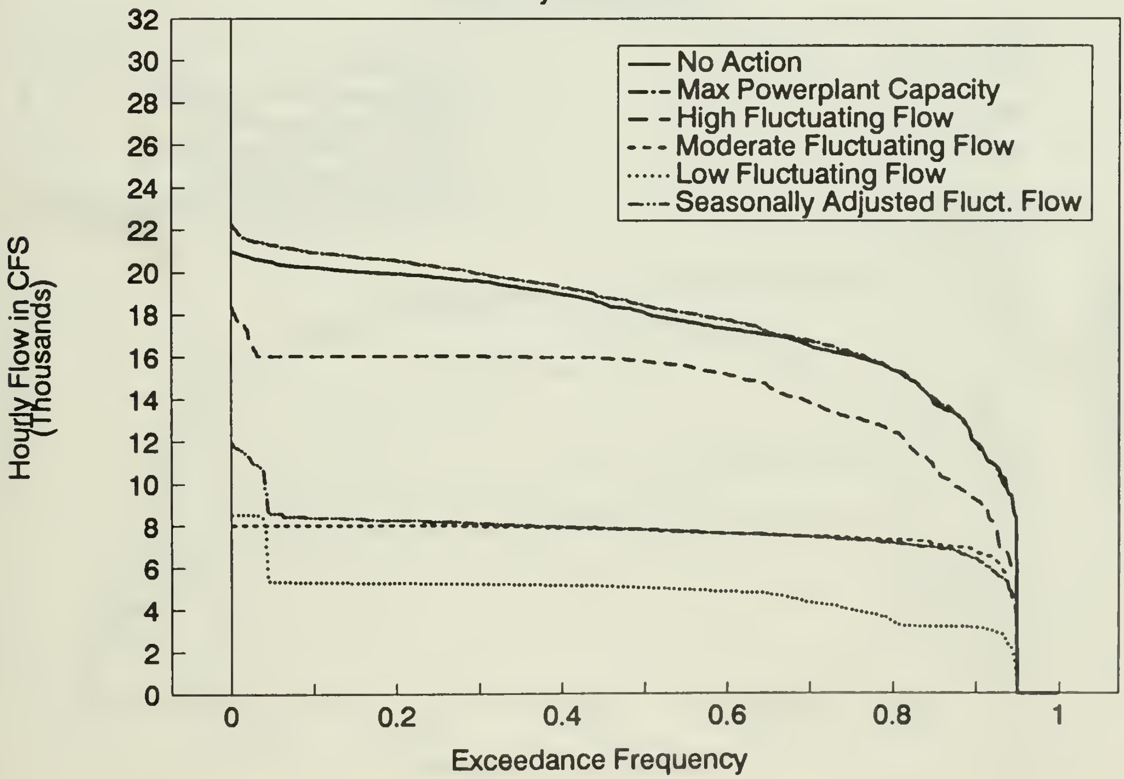
# Projected Maximum Hourly Releases for Each Day (cfs)

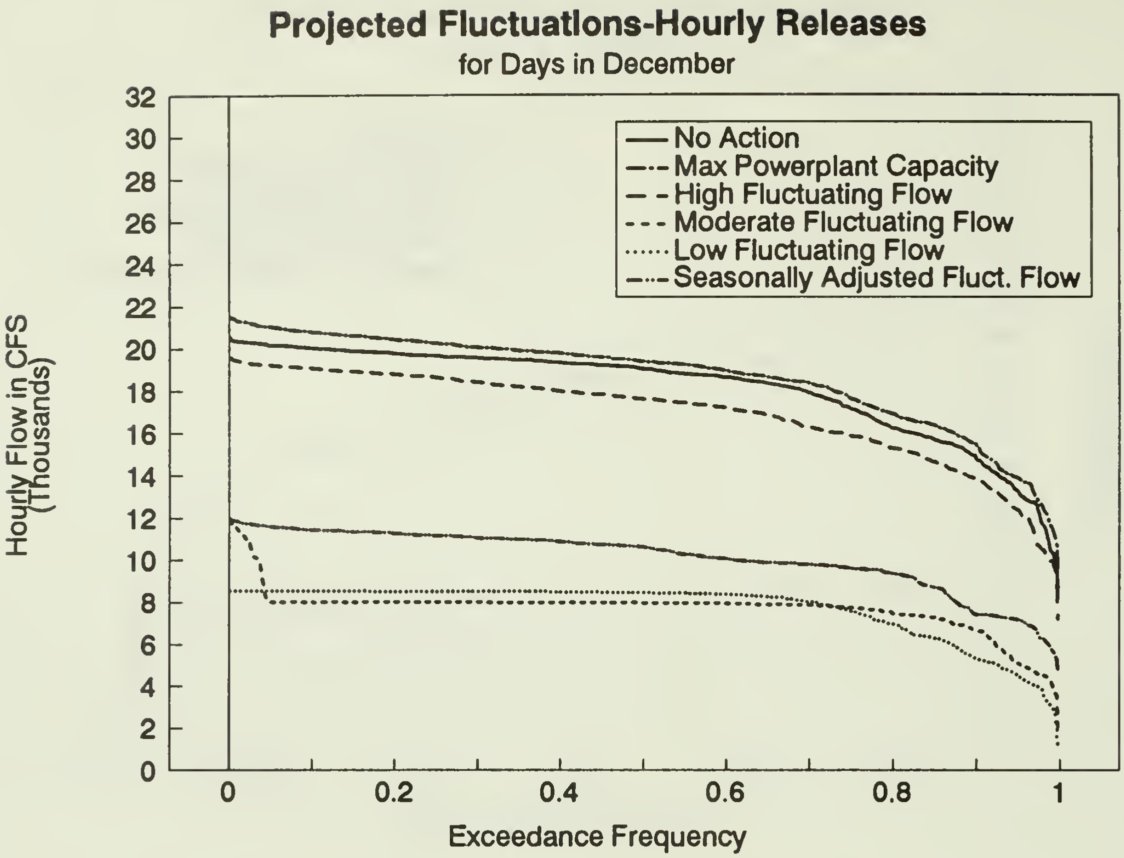
- 12 Frequency Graphs, Each with Several Alternatives

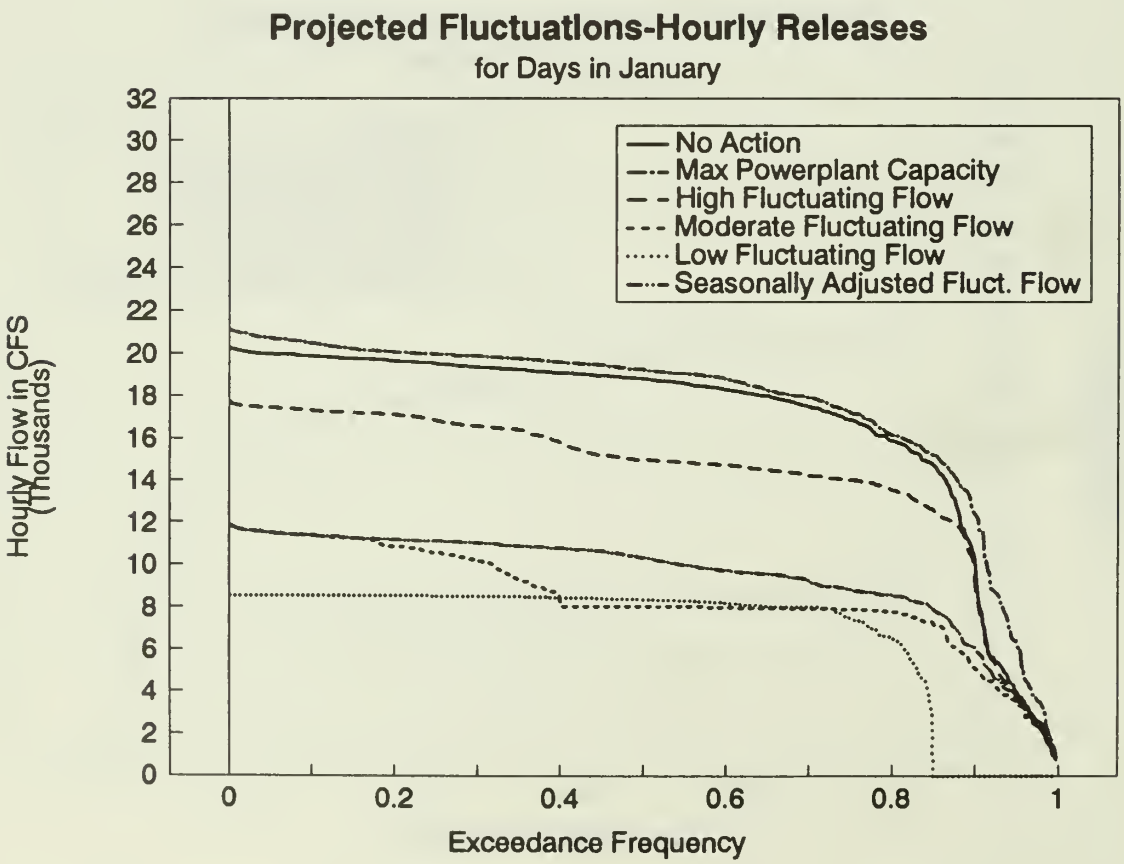
## Projected Fluctuations-Hourly Releases
for Days in October

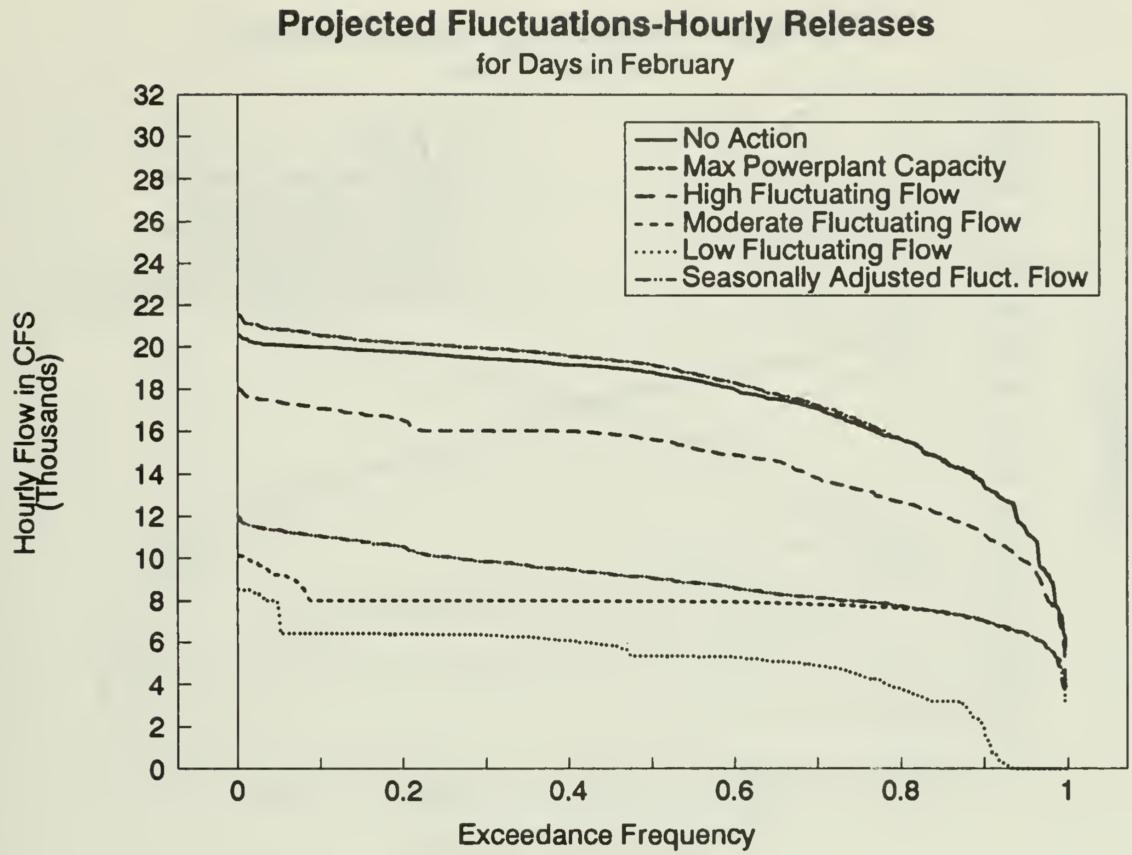



## Projected Fluctuations-Hourly Releases
for Days in November

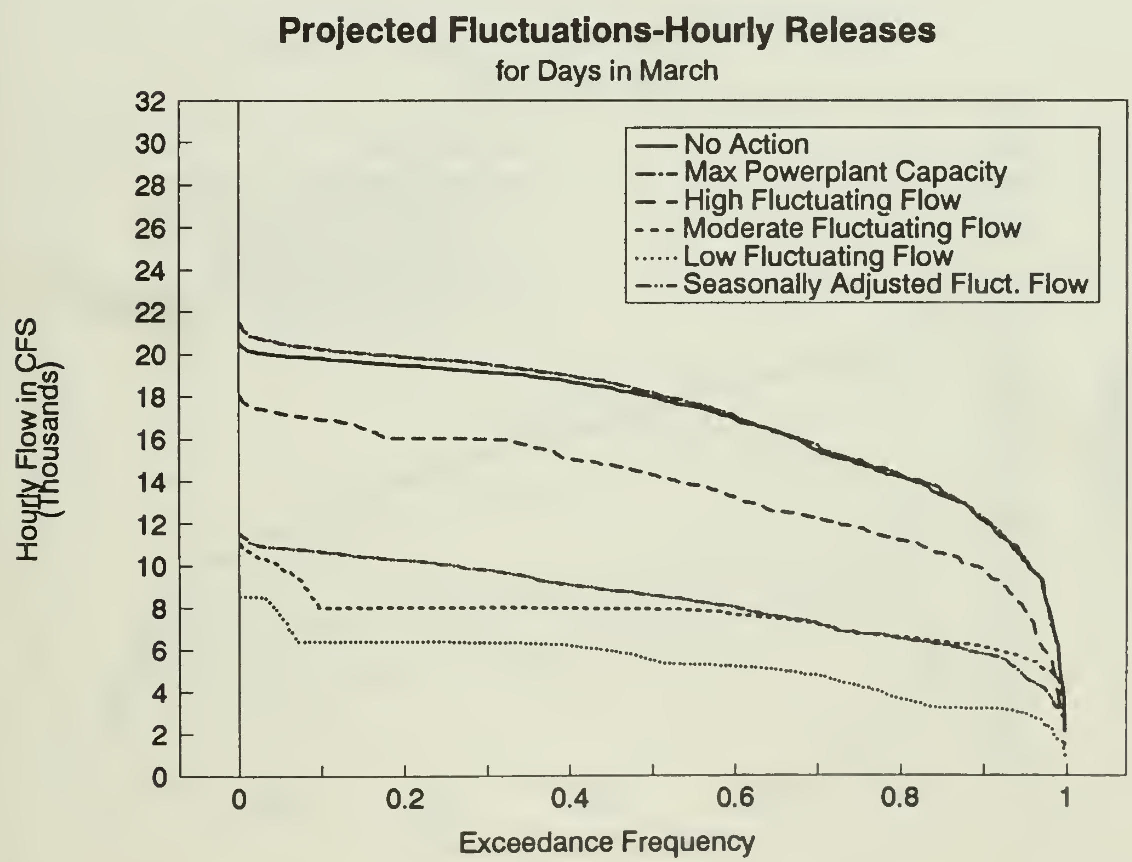



Projected Fluctuations-Hourly Releases
for Days in December
Hourly Flow in CFS (Thousands)
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
0.2
0.4
0.6
0.8
1

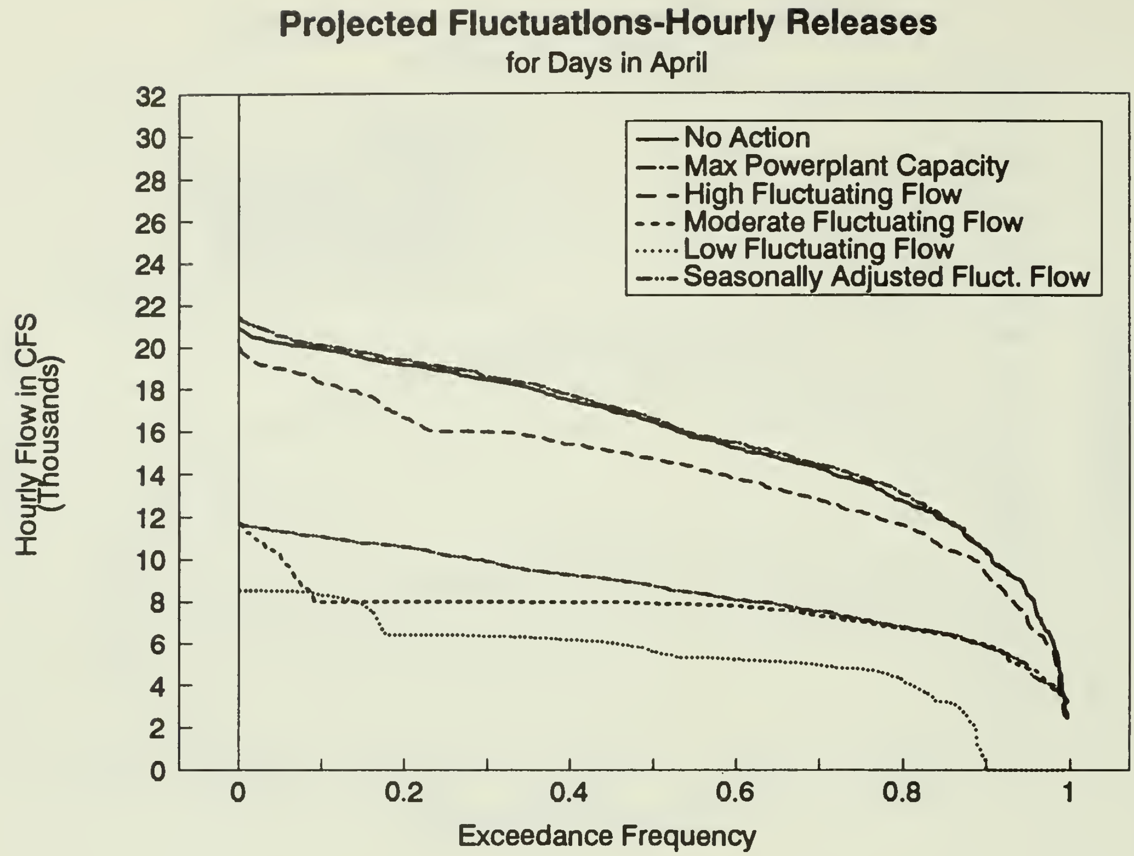

Projected Fluctuations-Hourly Releases
for Days in January
Hourly Flow in CFS (Thousands)
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
0
0.2
0.4
0.6
0.8
1

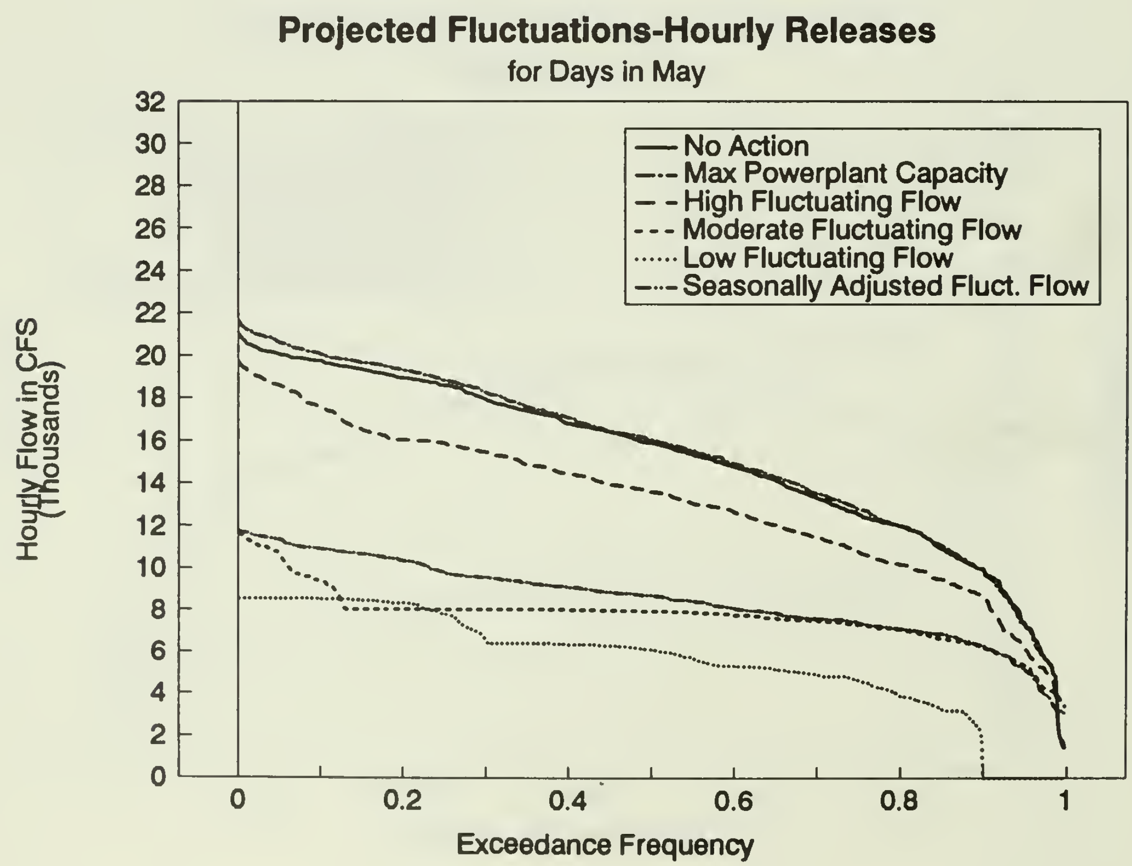


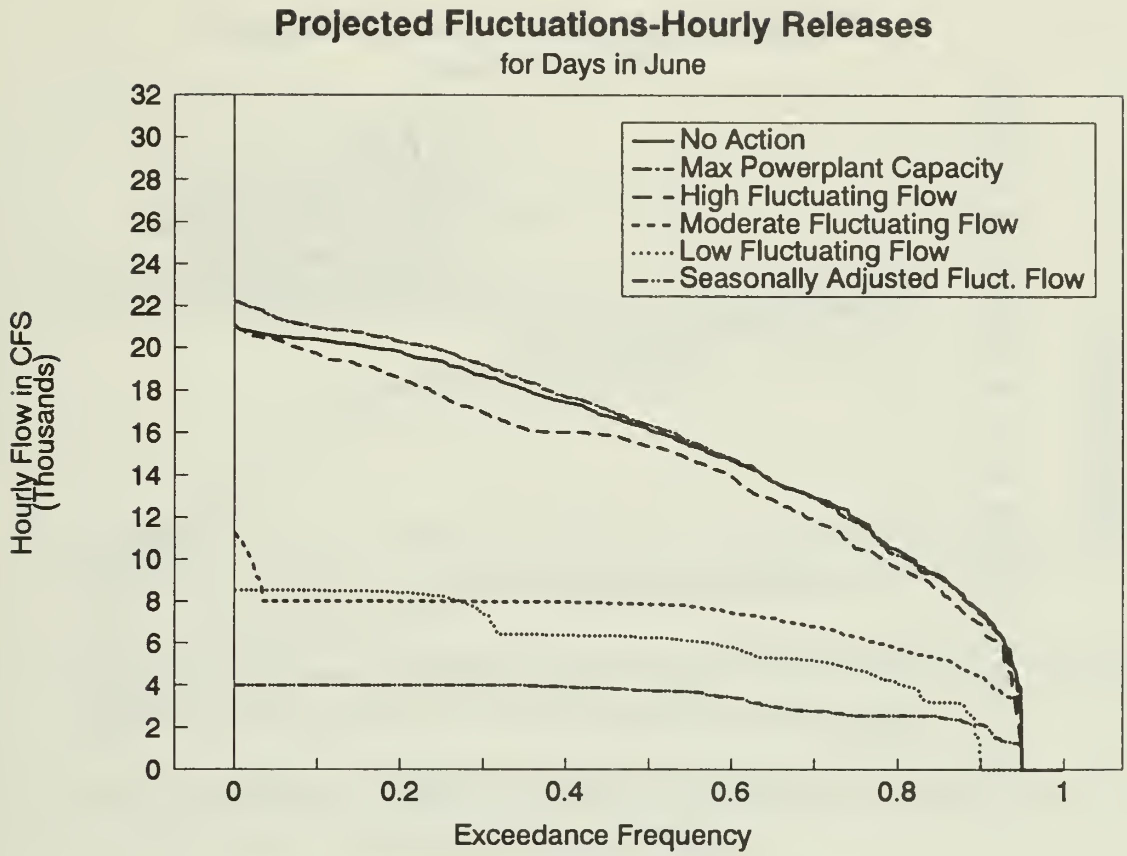
Projected Fluctuations-Hourly Releases
for Days in February
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

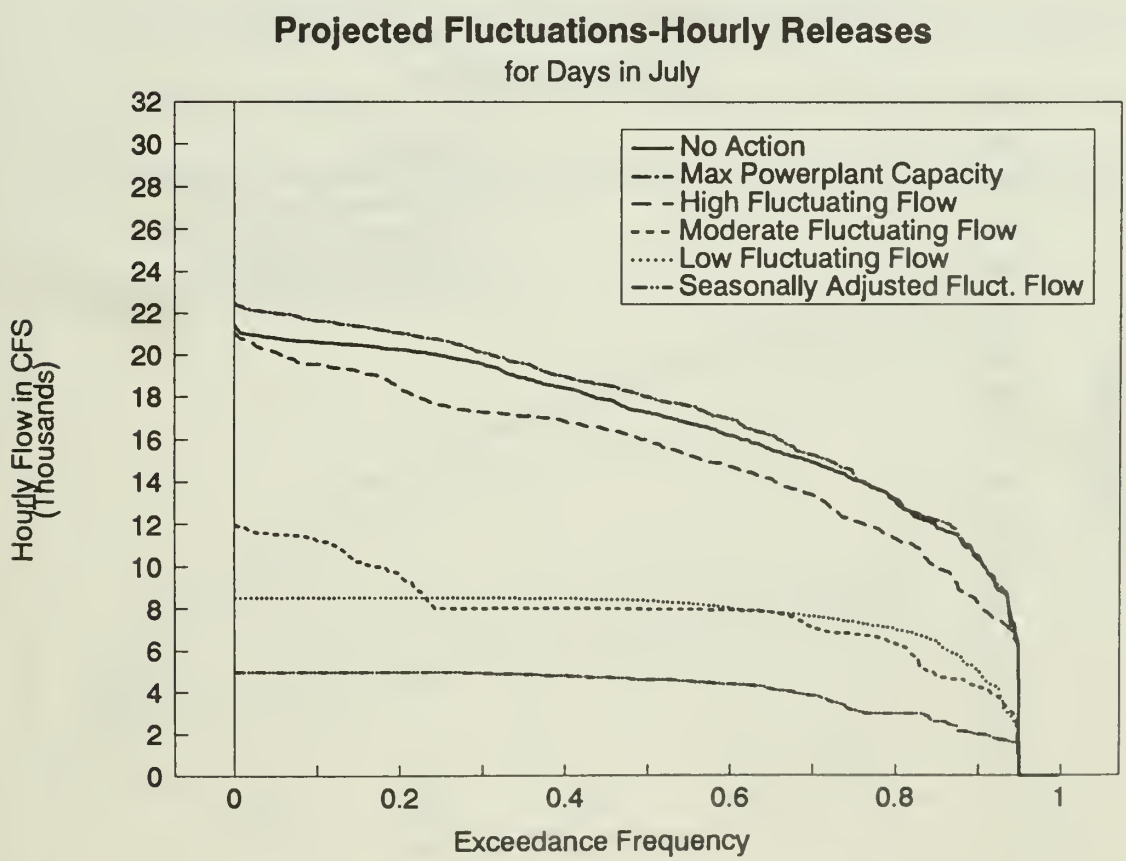



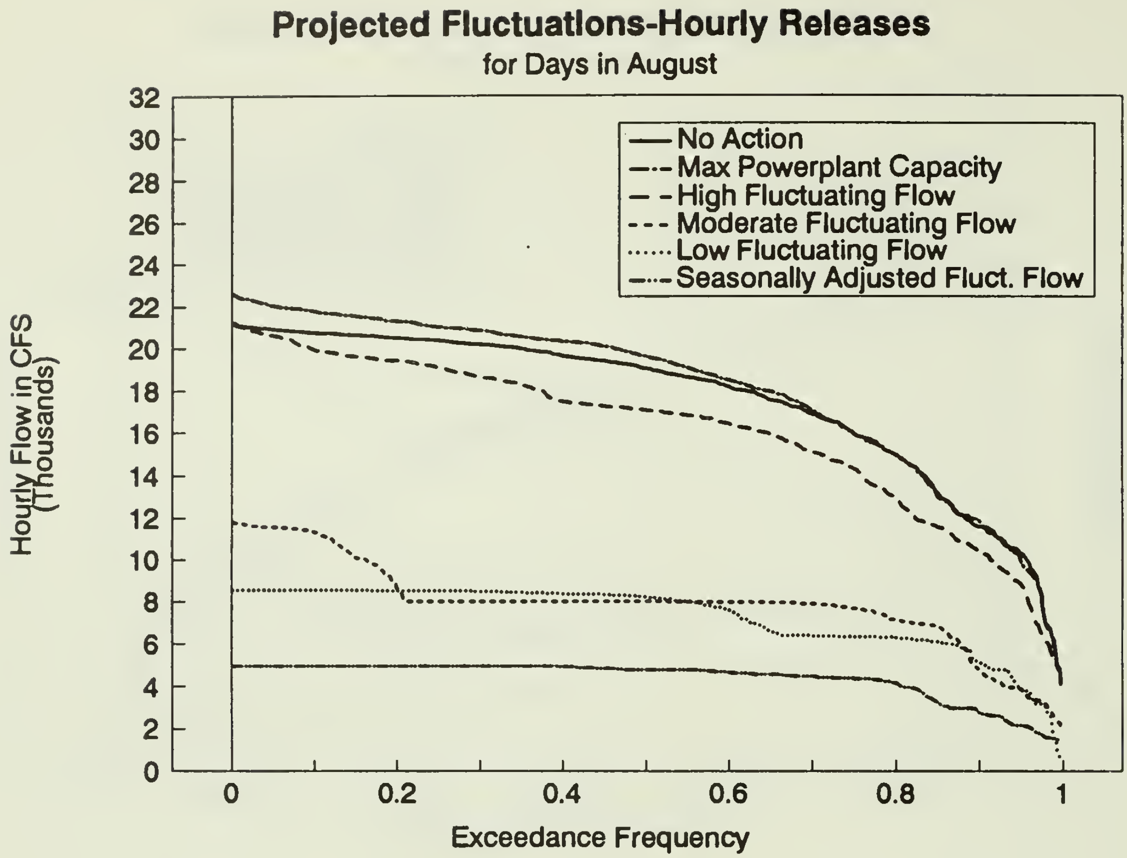
Projected Fluctuations-Hourly Releases
for Days in March
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

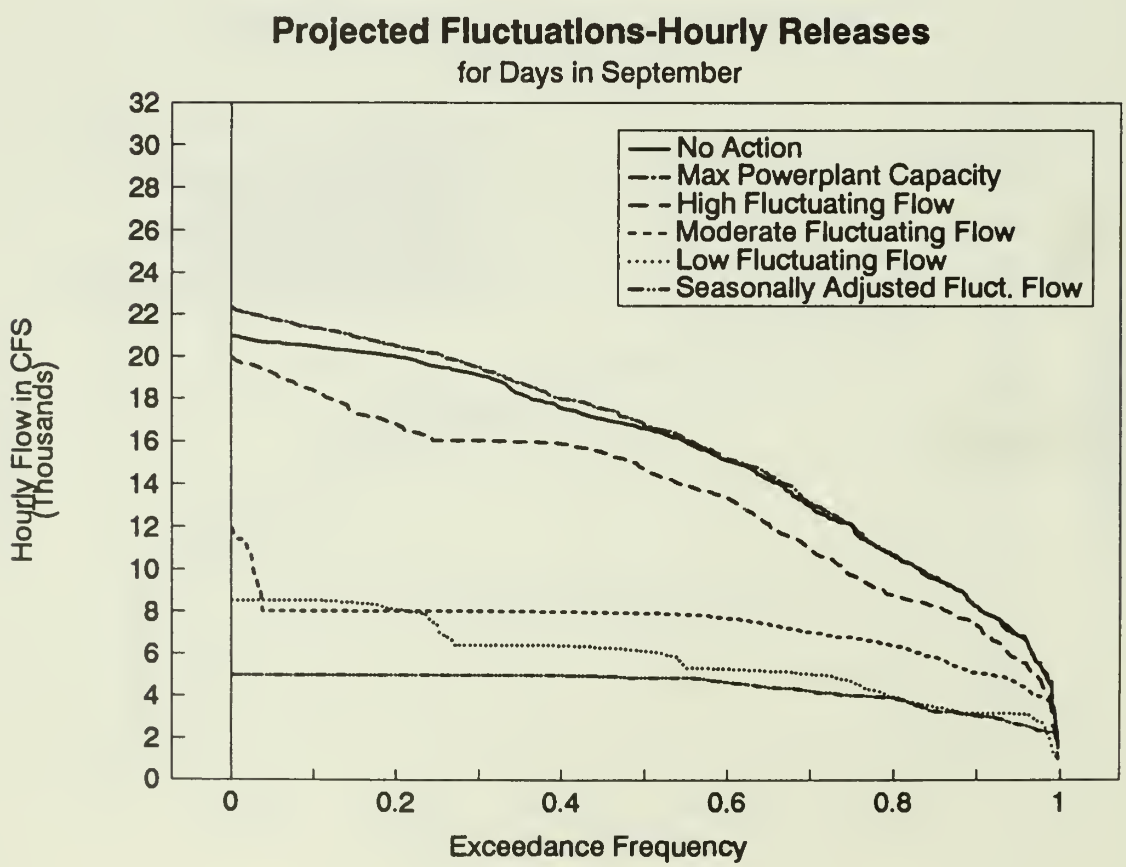

Projected Fluctuations-Hourly Releases
for Days in April
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow


Projected Fluctuations-Hourly Releases
for Days in May
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow


Projected Fluctuations-Hourly Releases
for Days in June
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
Hourly Flow in CFS (Thousands)
Exceedance Frequency


Projected Fluctuations-Hourly Releases
for Days in July
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow
Hourly Flow in CFS (Thousands)
Exceedance Frequency


Projected Fluctuations-Hourly Releases
for Days in August
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow


Projected Fluctuations-Hourly Releases
for Days in September
Hourly Flow in CFS (Thousands)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Max Powerplant Capacity
High Fluctuating Flow
Moderate Fluctuating Flow
Low Fluctuating Flow
Seasonally Adjusted Fluct. Flow

Frequencies of

# Projected Annual Depletions (acre-feet)

A. 2 Summary Tables of CRSS Model Results for Upper Basin Depletions (1 table for each method of flood frequency reduction)

B. 2 Summary Tables of CRSS Model Results for Lower Basin Depletions (1 table for each method of flood frequency reduction)

C. 2 Summary Tables of CRSS Model Results for Mexico Depletions (1 table for each method of flood frequency reduction)

D. 1 Frequency Graph for Upper Basin Depletions with Several Alternatives

E. 1 Frequency Graph for Lower Basin Depletions with Several Alternatives

F. 1 Frequency Graph for Mexico Depletions with Several Alternatives

# Annual Upper Basin Depletions
# (Summary of CRSS Model Results)

With increased storage capacity to reduce frequency of flood flows

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | AVERAGE | FREQUENCY | | | AVERAGE | FREQUENCY | | |
| | | <=4 maf | >4 maf <=5 maf | >5 maf | | <=4 maf | >4 maf <=5 maf | >5 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 4,154,000 af | 42.6% | 57.4% | 0.0% | 4,562,000 af | 17.6% | 69.2% | 13.2% |
| High Fluctuating Flow | 4,154,000 af | 42.6% | 57.4% | 0.0% | 4,562,000 af | 17.6% | 69.2% | 13.2% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | * | * | * | * | * | * | 69.4% | 13.0% |
| Year-Round Steady Flow | * | * | * | * | * | * | * | * |

* Same as for High Fluctuating Flow Alternative

With lower reservoir storage to reduce frequency of flood flows

## Annual Upper Basin Depletions (Summary of CRSS Model Results)

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | AVERAGE | FREQUENCY | | | AVERAGE | FREQUENCY | | |
| | | <=4 maf | >4 maf <=5 maf | >5 maf | | <=4 maf | >4 maf <=5 maf | >5 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 4,154,000 af | 42.6% | 57.4% | 0.0% | 4,562,000 af | 17.6% | 69.2% | 13.2% |
| High Fluctuating Flow | 4,154,000 af | 42.6% | 57.4% | 0.0% | 4,562,000 af | 17.6% | 69.2% | 13.2% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | * | * | * | * | * | * | 69.3% | 13.1% |
| Year-Round Steady Flow | * | * | * | * | * | * | * | * |

* Same as for High Fluctuating Flow Alternative

# Annual Lower Basin Depletions
# (Summary of CRSS Model Results)

With increased storage capacity to reduce frequency of flood flows

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | AVERAGE | FREQUENCY | | | AVERAGE | FREQUENCY | | |
| | | <7.5 maf | >=7.5 maf <=8.0 maf | >8.0 maf | | <7.5 maf | >=7.5 maf <=8.0 maf | >8.0 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 8,143,000 af | 0.5% | 70.5% | 29.0% | 8,090,000 af | 9.5% | 63.5% | 27.0% |
| High Fluctuating Flow | 8,120,000 af | 0.5% | 72.2% | 27.3% | 8,075,000 af | 8.8% | 65.7% | 25.5% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 8,130,000 af | 0.9% | 71.6% | 27.5% | 8,078,000 af | 10.1% | 63.6% | 26.3% |
| Year-Round Steady Flow | 8,131,000 af | * | 71.9% | 27.6% | 8,087,000 af | 8.7% | 65.0% | 26.3% |

* Same as for High Fluctuating Flow Alternative

## Annual Lower Basin Depletions
## (Summary of CRSS Model Results)

With lower reservoir storage to reduce frequency of flood flows

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | AVERAGE | FREQUENCY | | | AVERAGE | FREQUENCY | | |
| | | <7.5 maf | >=7.5 maf <=8.0 maf | >8.0 maf | | <7.5 maf | >=7.5 maf <=8.0 maf | >8.0 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 8,143,000 af | 0.5% | 70.5% | 29.0% | 8,090,000 af | 9.5% | 63.5% | 27.0% |
| High Fluctuating Flow | 8,144,000 af | 0.5% | 70.5% | 29.0% | 8,090,000 af | 9.5% | 63.5% | 27.0% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 8,141,000 af | 0.9% | 70.1% | * | 8,080,000 af | 10.5% | 62.6% | 26.9% |
| Year-Round Steady Flow | * | * | * | * | 8,091,000 af | 9.4% | 63.6% | 27.0% |

* Same as for High Fluctuating Flow Alternative

With increased storage capacity to reduce frequency of flood flows

# Annual Deliveries to Mexico
# (Summary of CRSS Model Results)

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | AVERAGE | FREQUENCY | | | AVERAGE | FREQUENCY | | |
| | | >=1.5 maf <=1.6 maf | >1.6 maf <=4.0 maf | >4.0 maf | | >=1.5 maf <=1.6 maf | >1.6 maf <=4.0 maf | >4.0 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 2,225,000 af | 73.6% | 13.8% | 12.6% | 2,133,000 af | 76.1% | 12.5% | 11.4% |
| High Fluctuating Flow | 2,211,000 af | 76.0% | 10.3% | 13.7% | 2,126,000 af | 77.8% | 9.7% | 12.5% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 2,192,000 af | 74.9% | 12.8% | 12.3% | 2,111,000 af | 76.8% | 12.0% | 11.2% |
| Year-Round Steady Flow | 2,193,000 af | 74.9% | 12.8% | 12.3% | 2,109,000 af | 77.0% | 12.0% | 11.0% |

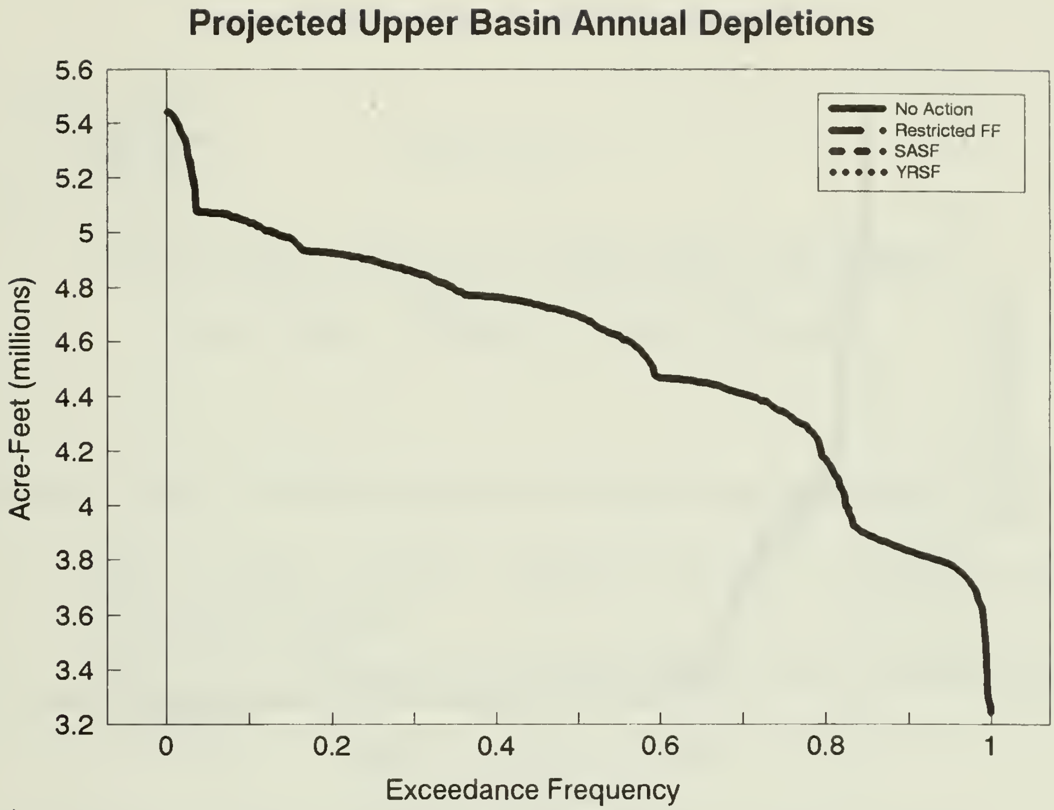
* Same as for High Fluctuating Flow Alternative

## Annual Deliveries to Mexico
## (Summary of CRSS Model Results)

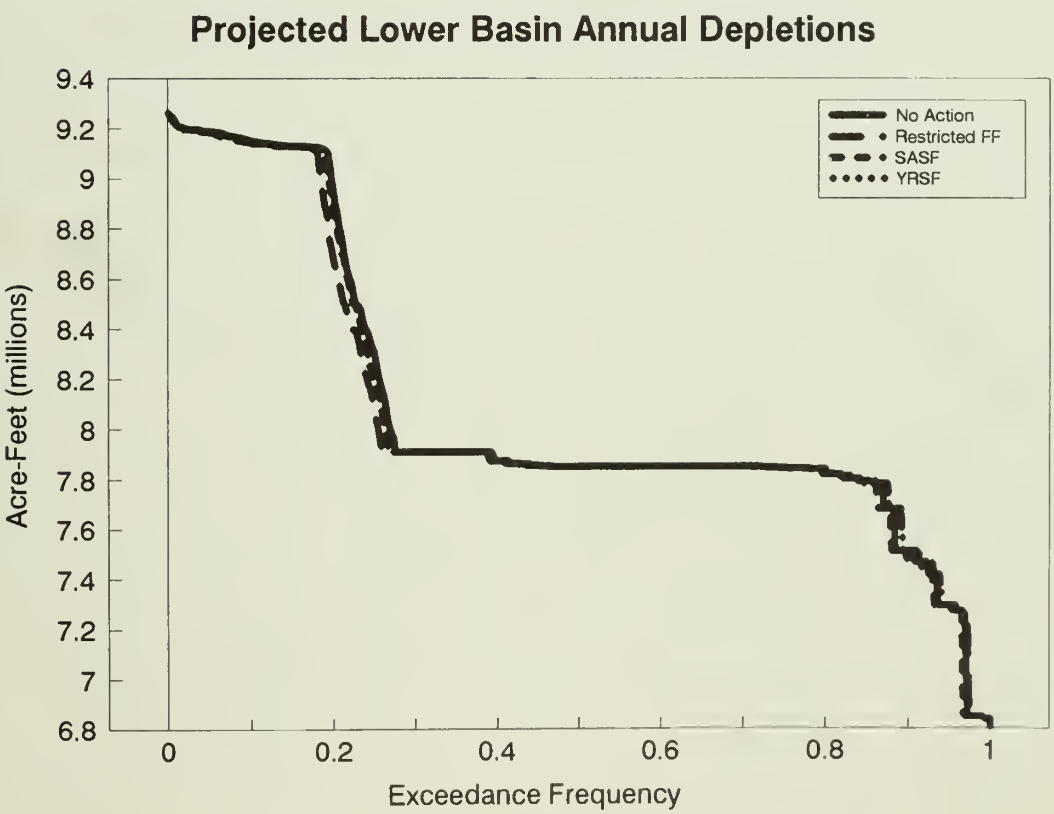
With lower reservoir storage to reduce frequency of flood flows

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | AVERAGE | FREQUENCY | | | AVERAGE | FREQUENCY | | |
| | | >=1.5 maf <=1.6 maf | >1.6 maf <=4.0 maf | >4.0 maf | | >=1.5 maf <=1.6 maf | >1.6 maf <=4.0 maf | >4.0 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 2,225,000 af | 73.6% | 13.8% | 12.6% | 2,133,000 af | 76.1% | 12.5% | 11.4% |
| High Fluctuating Flow | 2,225,000 af | 73.7% | 13.8% | 12.5% | 2,133,000 af | 76.2% | 12.5% | 11.3% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 2,224,000 af | * | * | * | * | * | * | * |
| Year-Round Steady Flow | 2,224,000 af | * | 13.7% | 12.6% | 2,132,000 af | * | * | * |

* Same as for High Fluctuating Flow Alternative

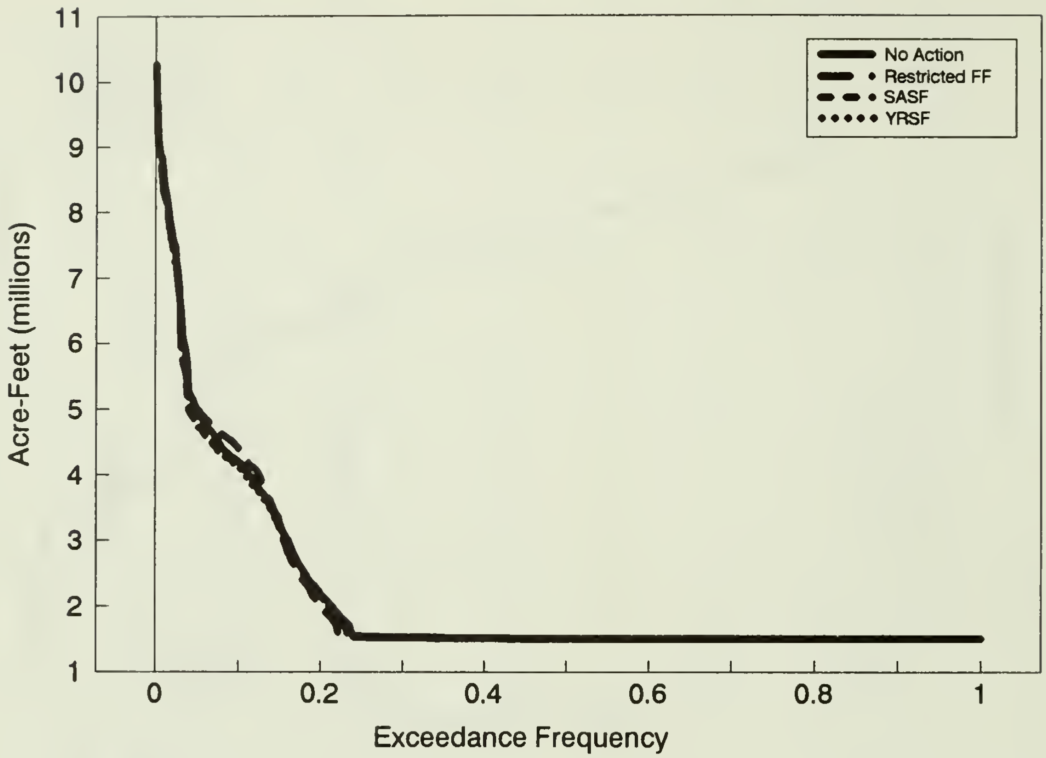


Projected Upper Basin Annual Depletions
Acre-Feet (millions)
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Restricted FF
SASF
YRSF

Projected Lower Basin Annual Depletions
Acre-Feet (millions)
9.4
9.2
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7
6.8
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
No Action
Restricted FF
SASF
YRSF

## Projected Mexico Annual Deliveries



Frequencies of

# Projected End-of-Month Storage in Lake Mead (acre-feet)

A. Summary Tables of CRSS Model Results with Several Alternatives

1. With Increased Storage Capacity Method of Reducing Flood Frequency (1 table)
2. With Lower Storage Level Method of Reducing Flood Frequency (1 table)

B. 12 Monthly Frequency Graphs, Each with Several Alternatives

# Lake Powell September 30 Storage
# (Summary of CRSS Model Results)

With increased storage capacity to reduce frequency of flood flows

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | 20th Year Average & (Median) | FREQUENCY | | | 50th Year Average & (Median) | FREQUENCY | | |
| | | <=10 maf & (Lowest) | >10 maf <=20 maf | >20 maf | | <=10 maf & (Lowest) | >10 maf <=20 maf | >20 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 18,554,000 af (18,904,000 af) | 0.4% (9.5 maf) | 54.4% | 45.2% | 17,463,000 af (19,302,000 af) | 2.6% (6.7 maf) | 56.1% | 41.3% |
| High Fluctuating Flow | 18,787,000 af (19,033,000 af) | 0.3% (9.5 maf) | 53.6% | 46.1% | 17,605,000 af (19,400,000 af) | 2.4% (6.8 maf) | 55.1% | 42.5% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 18,816,000 af (19,022,000 af) | 0.2% ( * ) | 53.7% | * | * (19,406,000 af) | * (6.7 maf) | * | * |
| Year-Round Steady Flow | 18,821,000 af (19,007,000 af) | 0.2% ( * ) | 53.7% | * | 17,646,000 af (19,384,000 af) | 2.3% ( * ) | * | 42.6% |

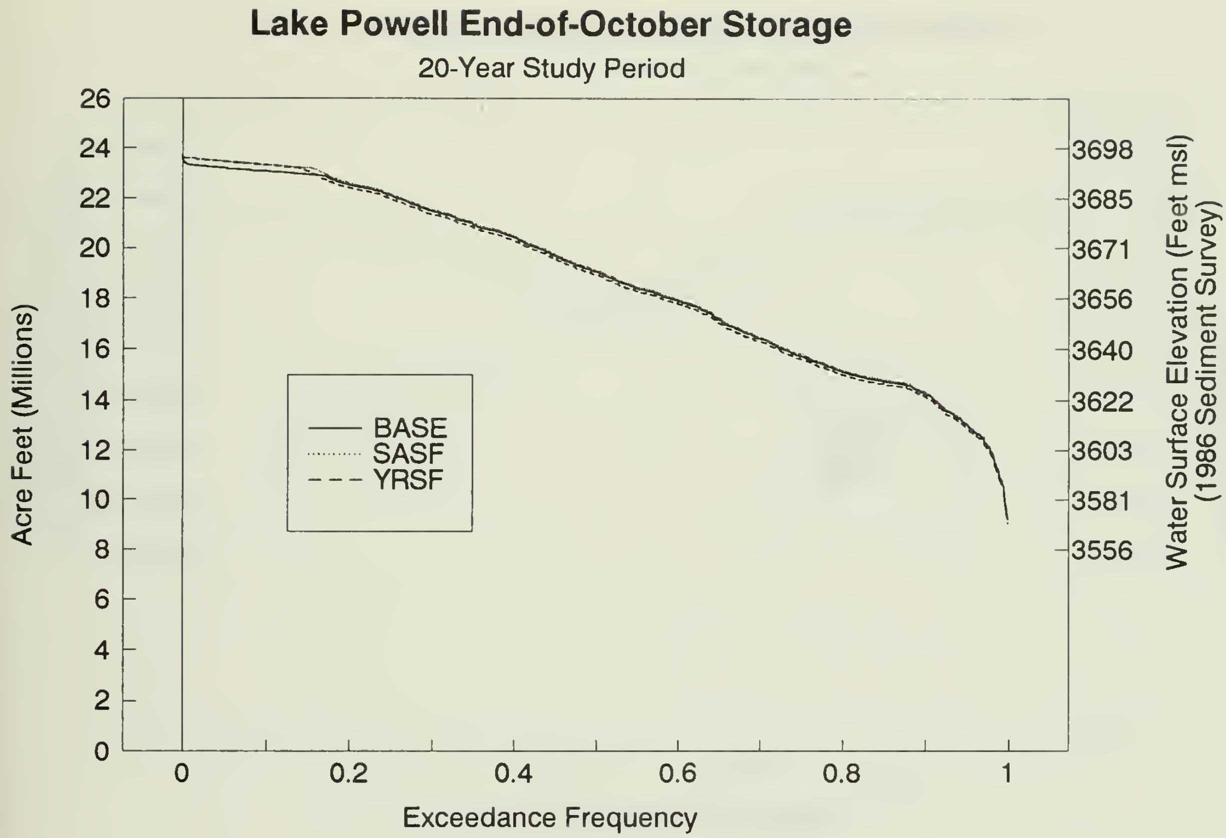
* Same as for High Fluctuating Flow Alternative

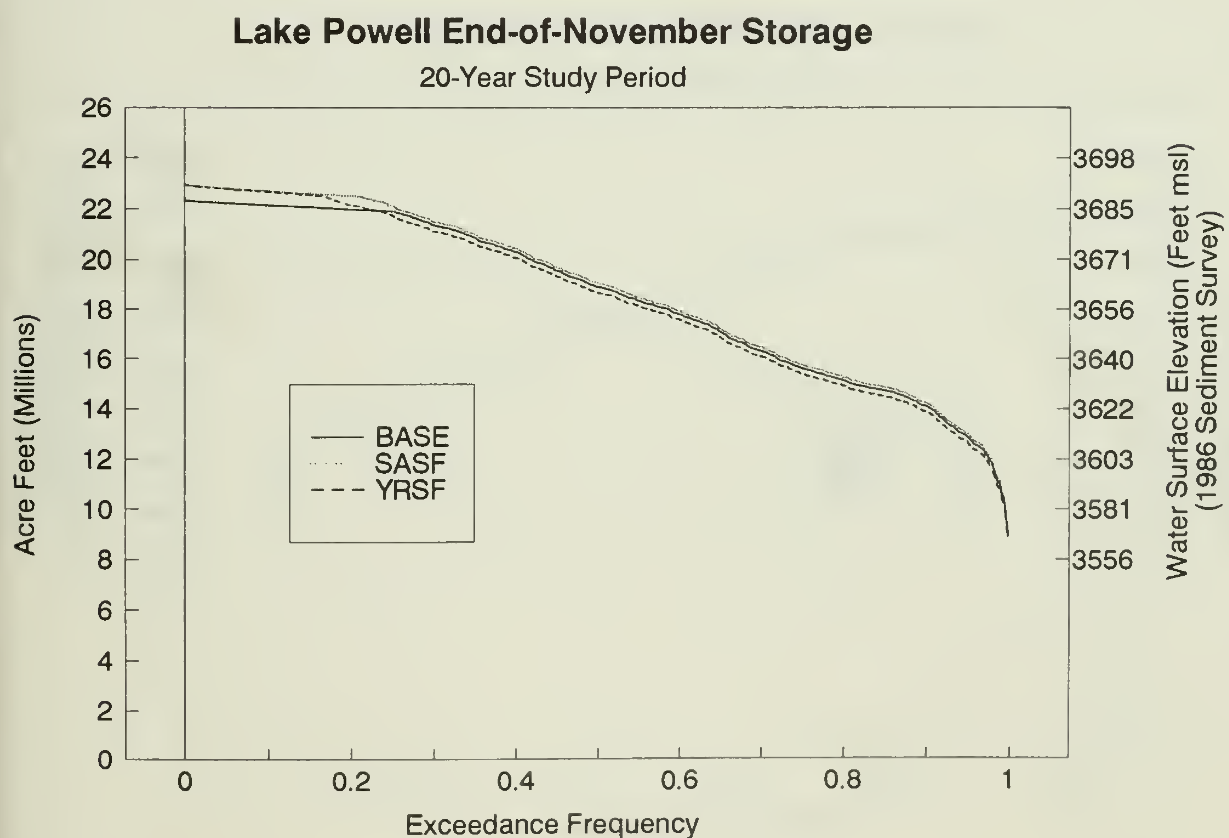
# Lake Powell September 30 Storage
# (Summary of CRSS Model Results)

With lower reservoir storage to reduce frequency of flood flows

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | 20th Year Average & (Median) | FREQUENCY | | | 50th Year Average & (Median) | FREQUENCY | | |
| | | <=10 maf & (Lowest) | >10 maf <=20 maf | >20 maf | | <=10 maf & (Lowest) | >10 maf <=20 maf | >20 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 18,554,000 af (18,904,000 af) | 0.4% (9.5 maf) | 54.4% | 45.2% | 17,463,000 af (19,302,000 af) | 2.6% (6.7 maf) | 56.1% | 41.3% |
| High Fluctuating Flow | 18,552,000 af (18,903,000 af) | 0.3% (9.5 maf) | 54.6% | 45.1% | 17,459,000 af (19,343,000 af) | 2.6% (6.7 maf) | 56.1% | 41.3% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 18,548,000 af (18,897,000 af) | 0.2% (9.4 maf) | 54.7% | * | 17,451,000 af (19,349,000 af) | * ( * ) | * | * |
| Year-Round Steady Flow | 18,552,000 af (18,894,000 af) | 0.2% ( * ) | 54.7% | * | 17,487,000 af (19,359,000 af) | 2.5% (6.8 maf) | * | 41.4% |

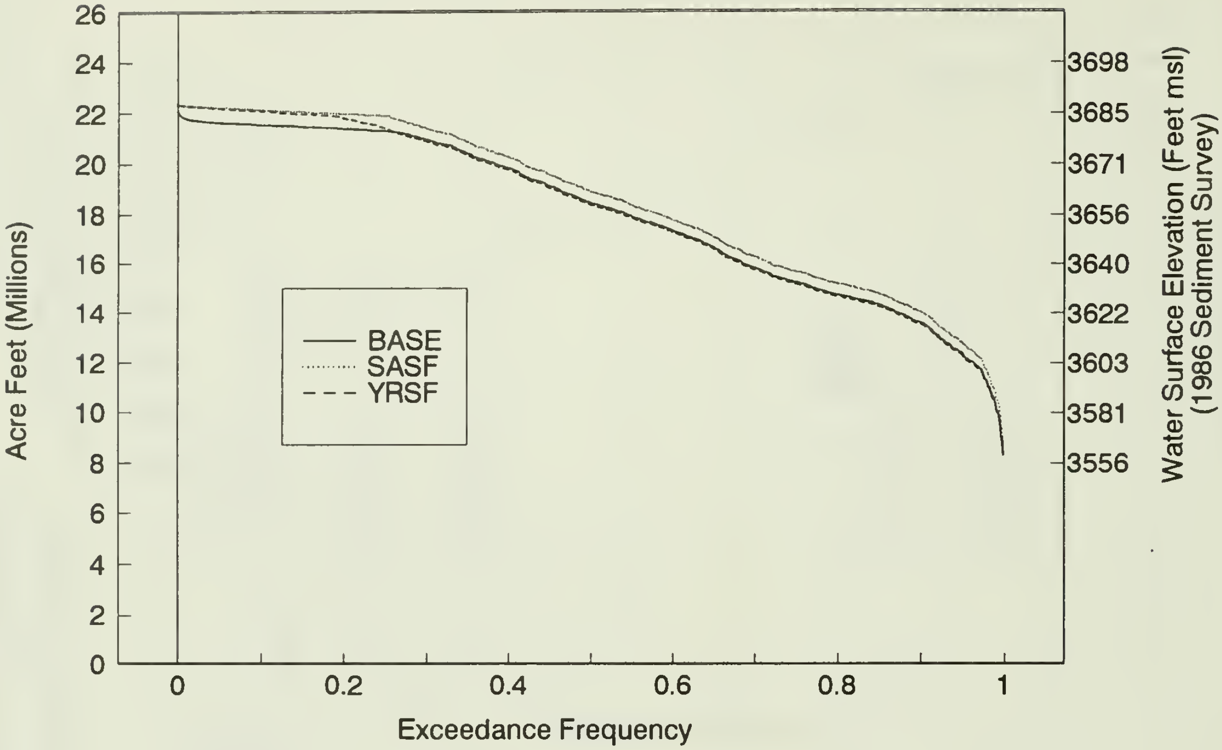
* Same as for High Fluctuating Flow Alternative


Lake Powell End-of-October Storage
20-Year Study Period
Acre Feet (Millions)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
BASE
SASF
YRSF
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
3698
3685
3671
3656
3640
3622
3603
3581
3556
Water Surface Elevation (Feet msl)
(1986 Sediment Survey)


Lake Powell End-of-November Storage
20-Year Study Period
Acre Feet (Millions)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
BASE
SASF
YRSF
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
3698
3685
3671
3656
3640
3622
3603
3581
3556
Water Surface Elevation (Feet msl)
(1986 Sediment Survey)

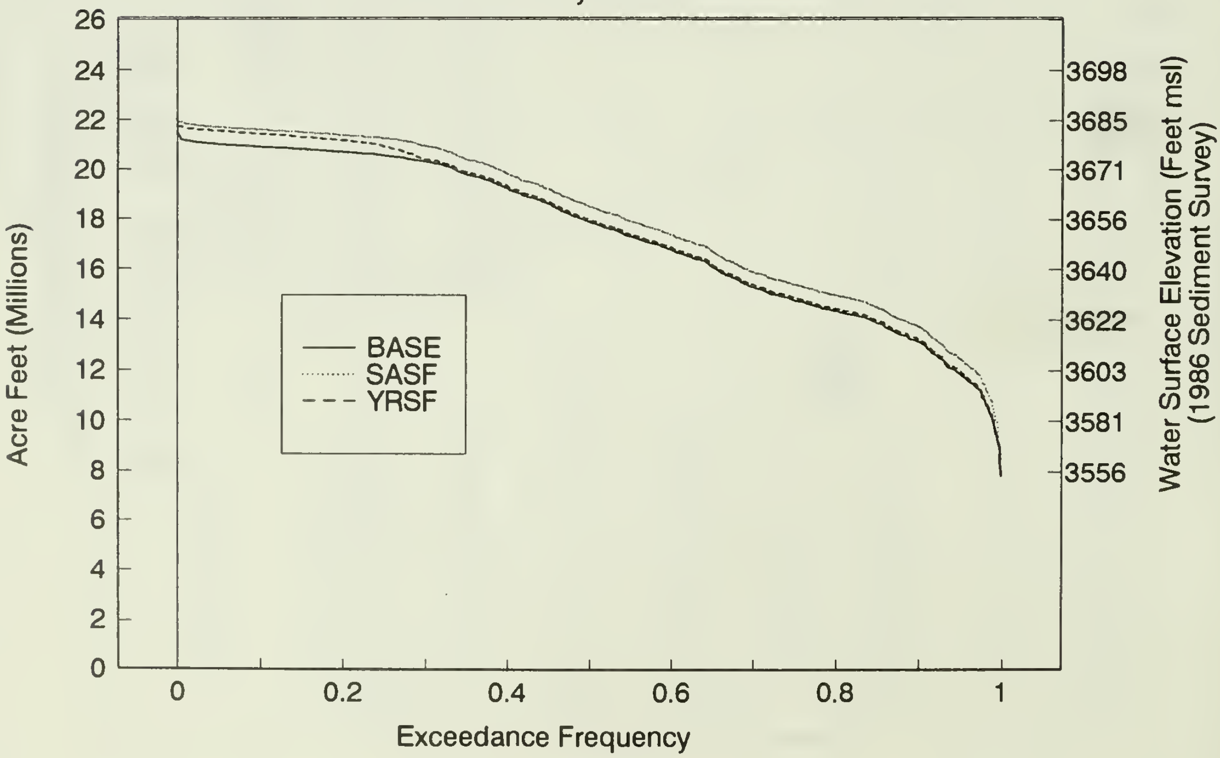
## Lake Powell End-of-December Storage

20-Year Study Period



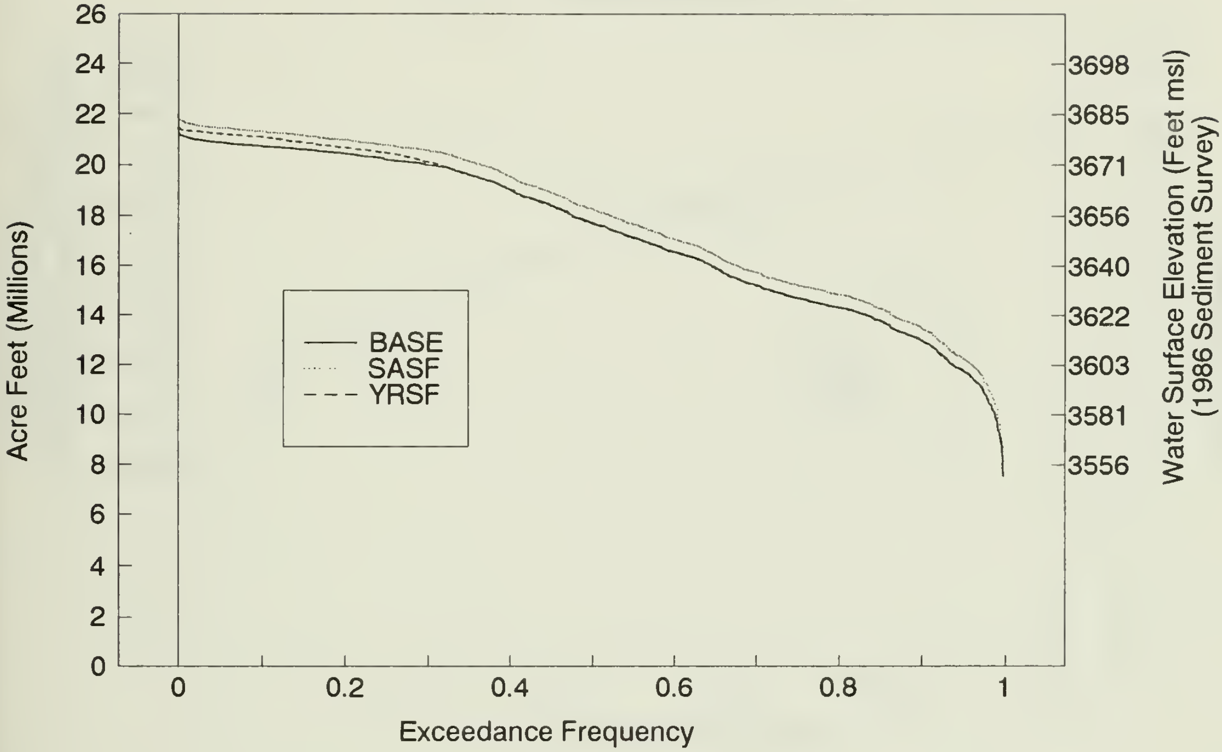

## Lake Powell End-of-January Storage

20-Year Study Period



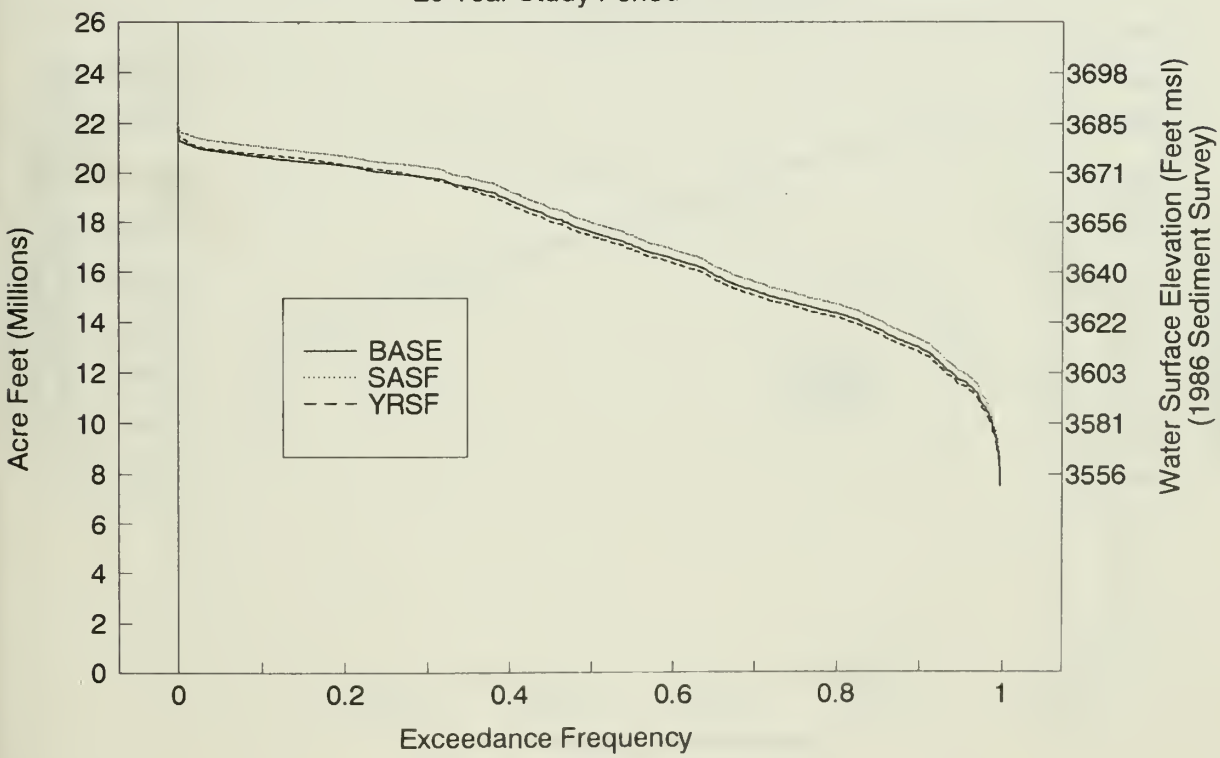
## Lake Powell End-of-February Storage

20-Year Study Period



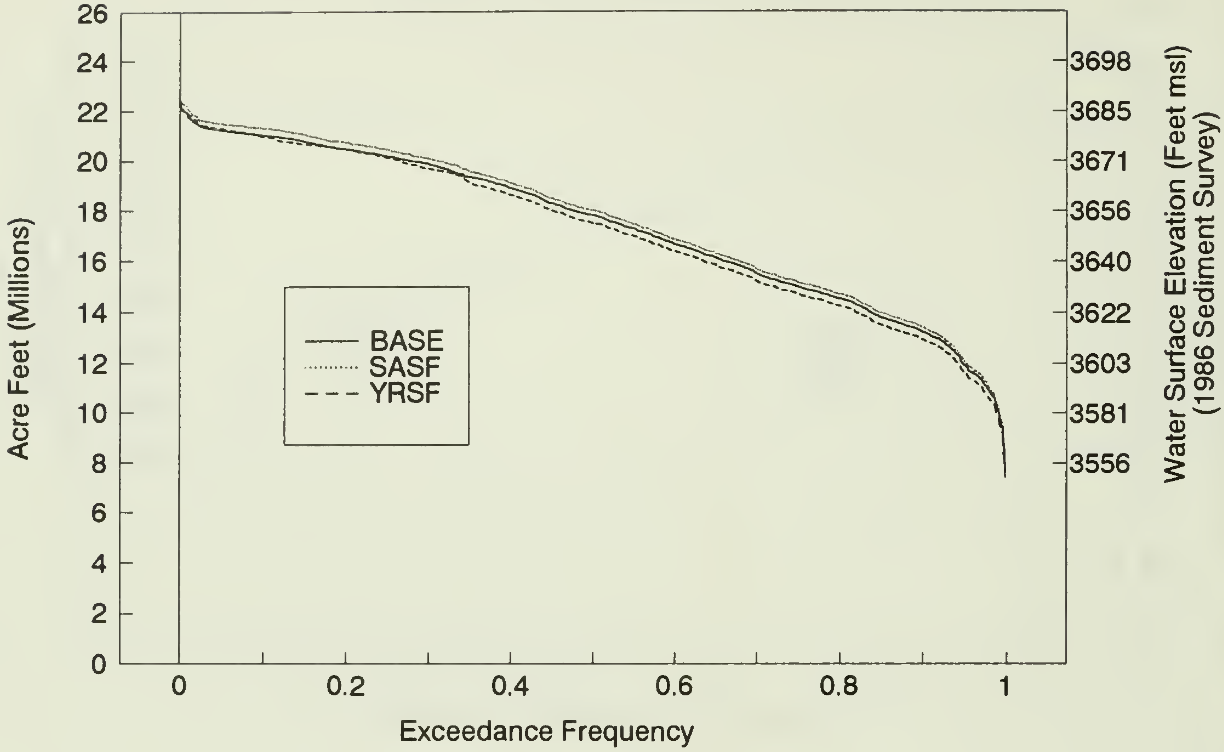

## Lake Powell End-of-March Storage

20-Year Study Period



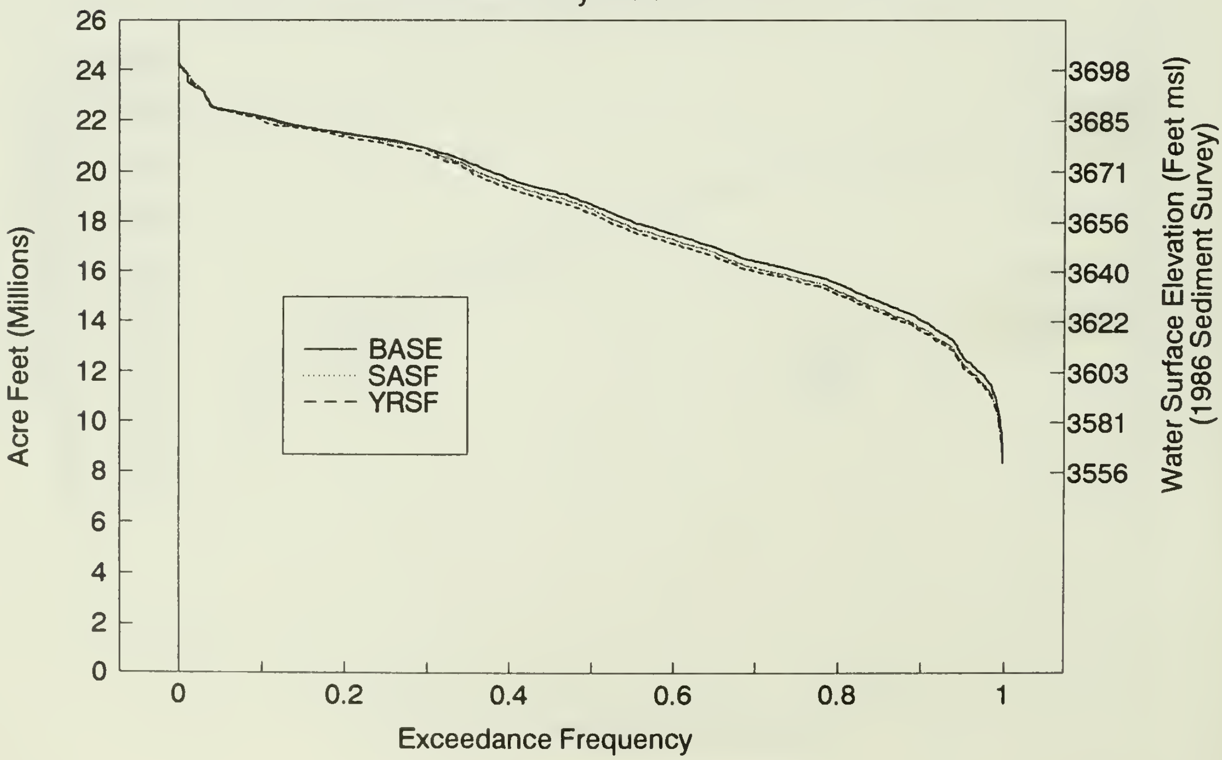
## Lake Powell End-of-April Storage

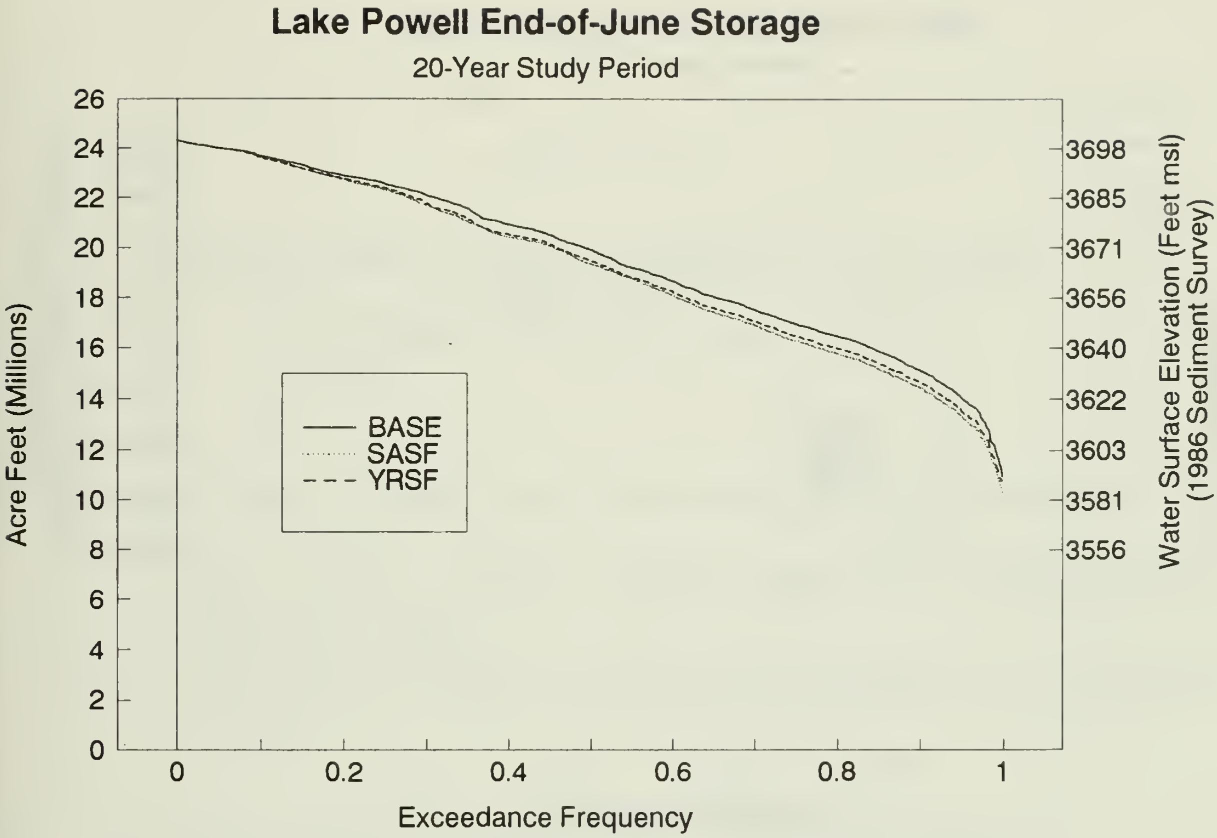
20-Year Study Period

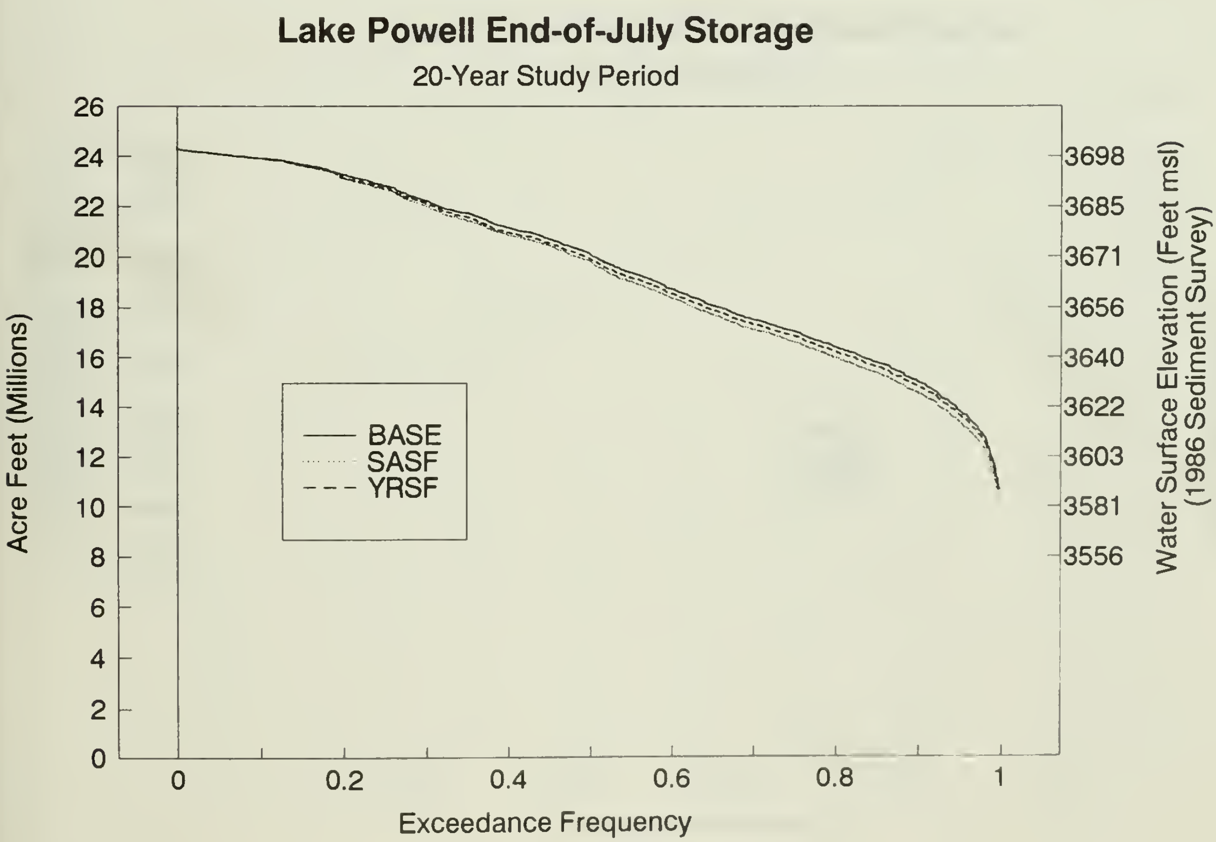



## Lake Powell End-of-May Storage

20-Year Study Period

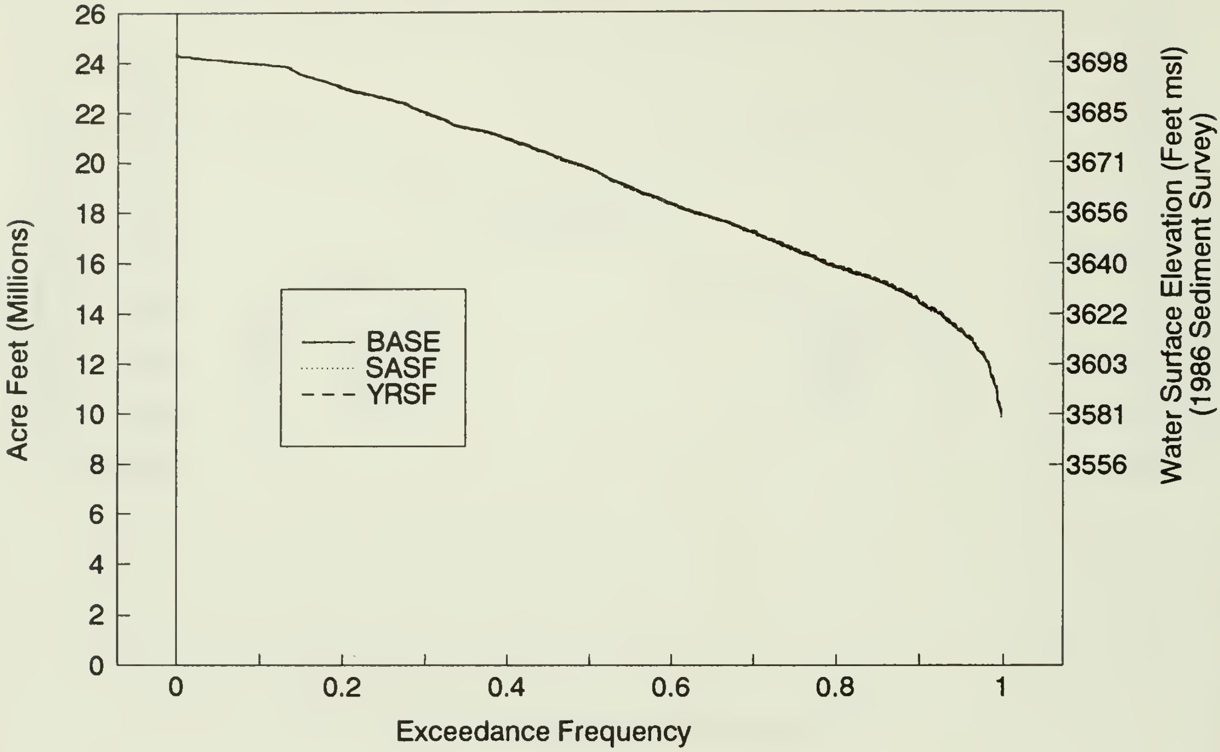



Lake Powell End-of-June Storage
20-Year Study Period
Acre Feet (Millions)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
3698
3685
3671
3656
3640
3622
3603
3581
3556
Water Surface Elevation (Feet msl)
(1986 Sediment Survey)
BASE
SASF
YRSF


Lake Powell End-of-July Storage
20-Year Study Period
Acre Feet (Millions)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency
3698
3685
3671
3656
3640
3622
3603
3581
3556
Water Surface Elevation (Feet msl)
(1986 Sediment Survey)
BASE
SASF
YRSF

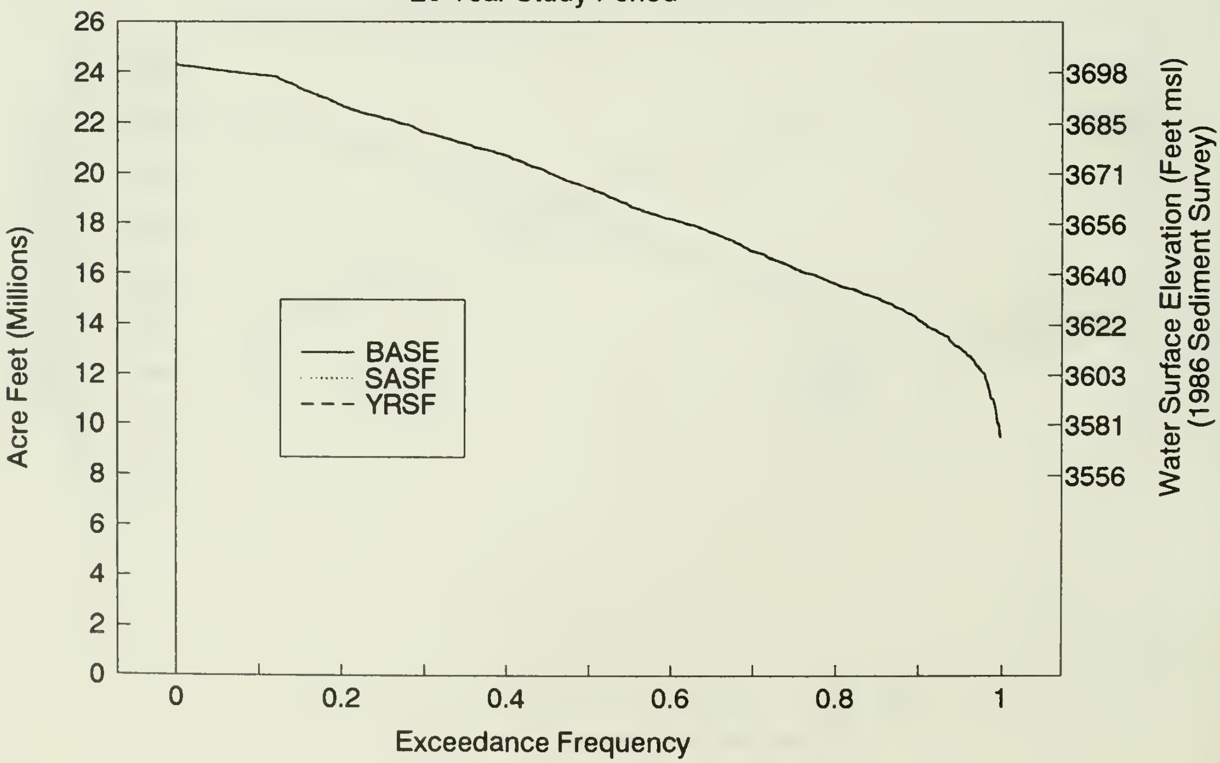
## Lake Powell End-of-August Storage

20-Year Study Period




## Lake Powell End-of-September Storage

20-Year Study Period



Frequencies of

# Projected End-of-Month Storage in Lake Powell (acre-feet)

A. Summary Tables of CRSS Model Results with Several Alternatives

1. With Increased Storage Capacity Method of Reducing Flood Frequency (1 table)
2. With Lower Storage Level Method of Reducing Flood Frequency (1 table)

B. 12 Monthly Frequency Graphs, Each with Several Alternatives

## Lake Mead September 30 Storage (Summary of CRSS Model Results)

With increased storage capacity to reduce frequency of flood flows

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | 20th Year Average & (Median) | FREQUENCY | | | 50th Year Average & (Median) | FREQUENCY | | |
| | | <=10 maf & (Lowest) | >10 maf <=20 maf | >20 maf | | <=10 maf & (Lowest) | >10 maf <=20 maf | >20 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 18,729,000 af (19,002,000 af) | 0.4% (9.4 maf) | 52.1% | 47.5% | 14,045,000 af (11,741,000 af) | 9.7% (8.2 maf) | 52.5% | 37.8% |
| High Fluctuating Flow | 19,082,000 af (19,377,000 af) | 0.3% (9.4 maf) | 50.7% | 49.0% | 14,404,000 af (11,687,000 af) | 9.2% (8.1 maf) | 50.4% | 40.4% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 19,137,000 af (19,409,000 af) | 0.0% (10.1 maf) | 51.0% | * | 14,653,000 af (12,265,000 af) | 6.8% (8.5 maf) | 52.6% | 40.6% |
| Year-Round Steady Flow | 19,102,000 af (19,370,000 af) | 0.5% (9.3 maf) | 51.9% | 48.9% | 14,415,000 af (12,145,000 af) | 9.5% ( * ) | 50.0% | 40.5% |

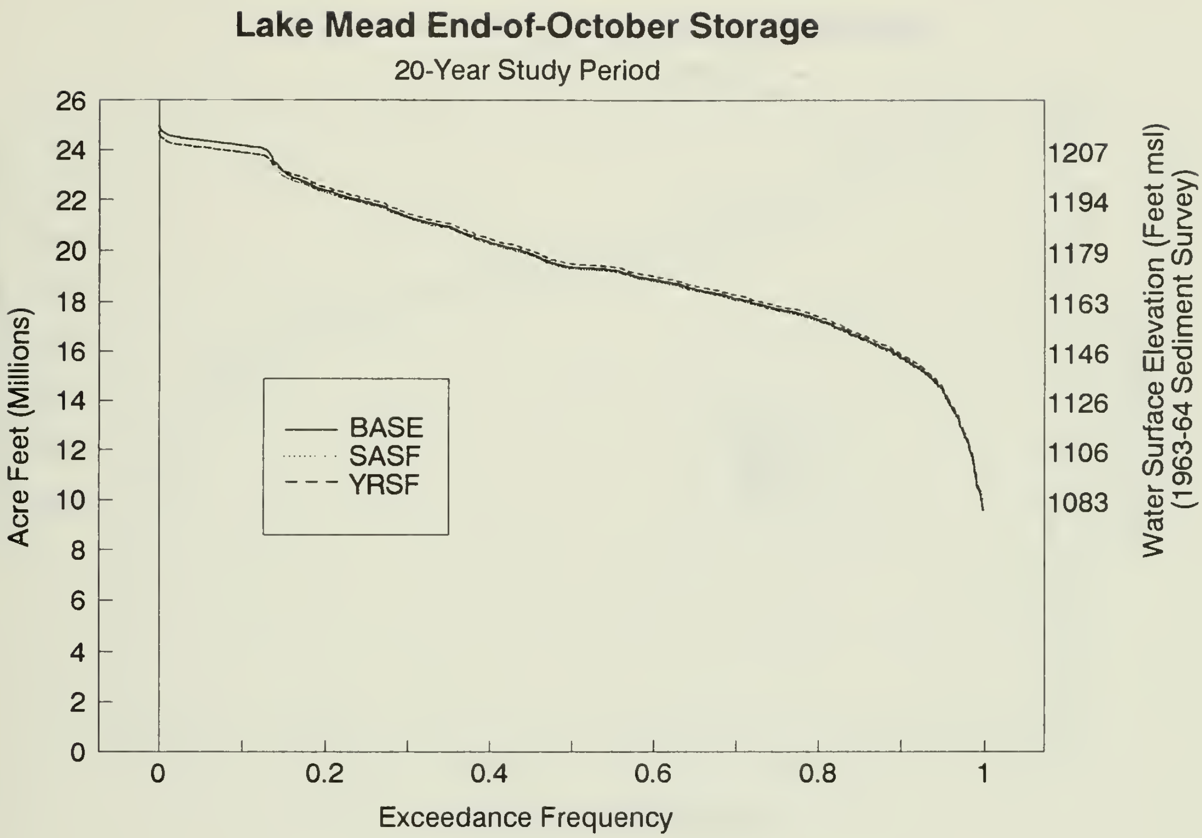
* Same as for High Fluctuating Flow Alternative

With lower reservoir storage to reduce frequency of flood flows

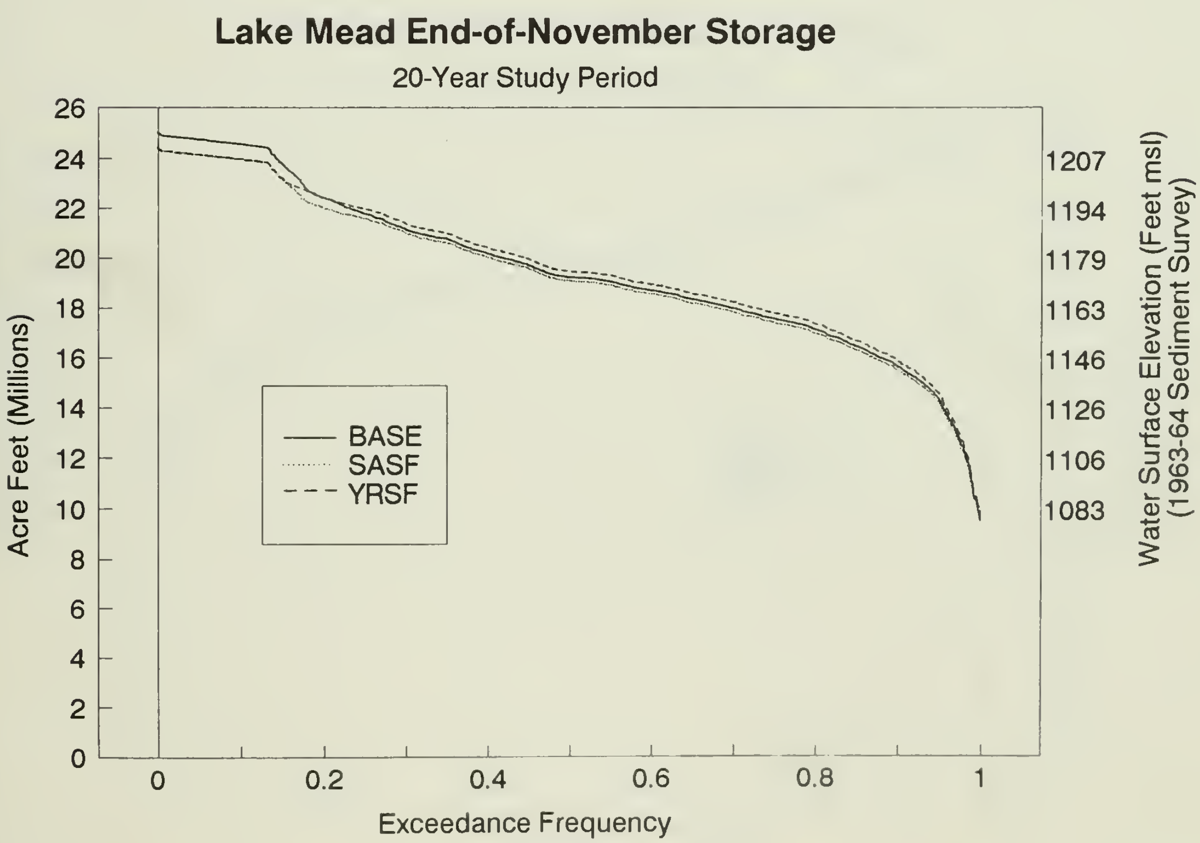
# Lake Mead September 30 Storage (Summary of CRSS Model Results)

| ALTERNATIVE | 20-YEAR ANALYSIS | | | | 50-YEAR ANALYSIS | | | |
|---|---|---|---|---|---|---|---|---|
| | 20th Year Average & (Median) | FREQUENCY | | | 50th Year Average & (Median) | FREQUENCY | | |
| | | <=10 maf & (Lowest) | >10 maf <=20 maf | >20 maf | | <=10 maf & (Lowest) | >10 maf <=20 maf | >20 maf |
| No Action Alternative (and Max. Powerplant Capac.) | 18,729,000 af (19,002,000 af) | 0.4% (9.4 maf) | 52.1% | 47.5% | 14,045,000 af (11,741,000 af) | 9.7% (8.2 maf) | 52.5% | 37.8% |
| High Fluctuating Flow | 18,729,000 af (19,006,000 af) | 0.3% (9.4 maf) | 52.2% | 47.5% | 14,022,000 af (11,675,000 af) | 9.7% (8.2 maf) | 52.4% | 37.9% |
| Moderate Fluctuating Flow | * | * | * | * | * | * | * | * |
| Low Fluctuating Flow (Interim and Preferred) | * | * | * | * | * | * | * | * |
| Existing Monthly Volume Steady Flow | * | * | * | * | * | * | * | * |
| Seasonally-Adjusted Steady Flow | 18,756,000 af (19,002,000 af) | 0.0% (10.1 maf) | 52.4% | 47.6% | 14,209,000 af (11,638,000 af) | 7.6% ( * ) | 54.5% | 37.9% |
| Year-Round Steady Flow | 18,722,000 af (19,010,000 af) | 0.6% (9.3 maf) | 51.9% | 47.6% | 13,966,000 af 11,693,000 af) | 10.1% (8.1 maf) | 52.0% | * |

* Same as for High Fluctuating Flow Alternative



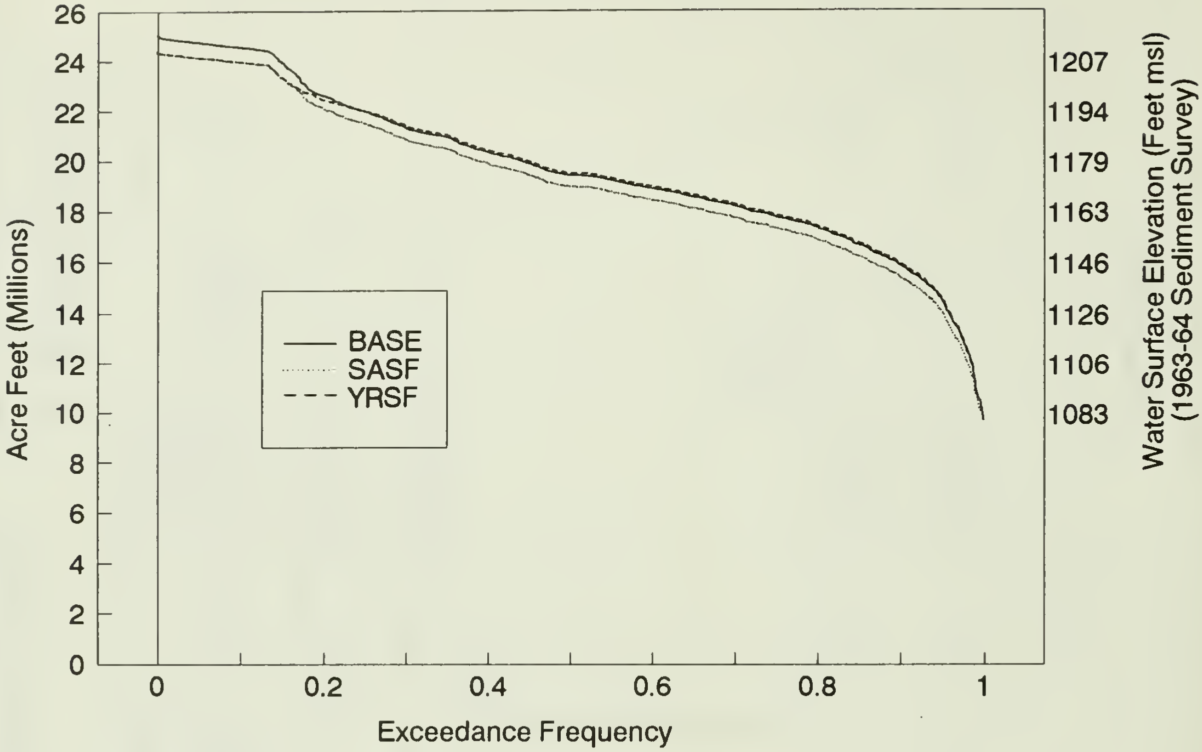
Lake Mead End-of-October Storage
20-Year Study Period
Acre Feet (Millions)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
BASE
SASF
YRSF
Water Surface Elevation (Feet msl)
(1963-64 Sediment Survey)
1207
1194
1179
1163
1146
1126
1106
1083
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

Lake Mead End-of-November Storage
20-Year Study Period
Acre Feet (Millions)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
BASE
SASF
YRSF
Water Surface Elevation (Feet msl)
(1963-64 Sediment Survey)
1207
1194
1179
1163
1146
1126
1106
1083
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

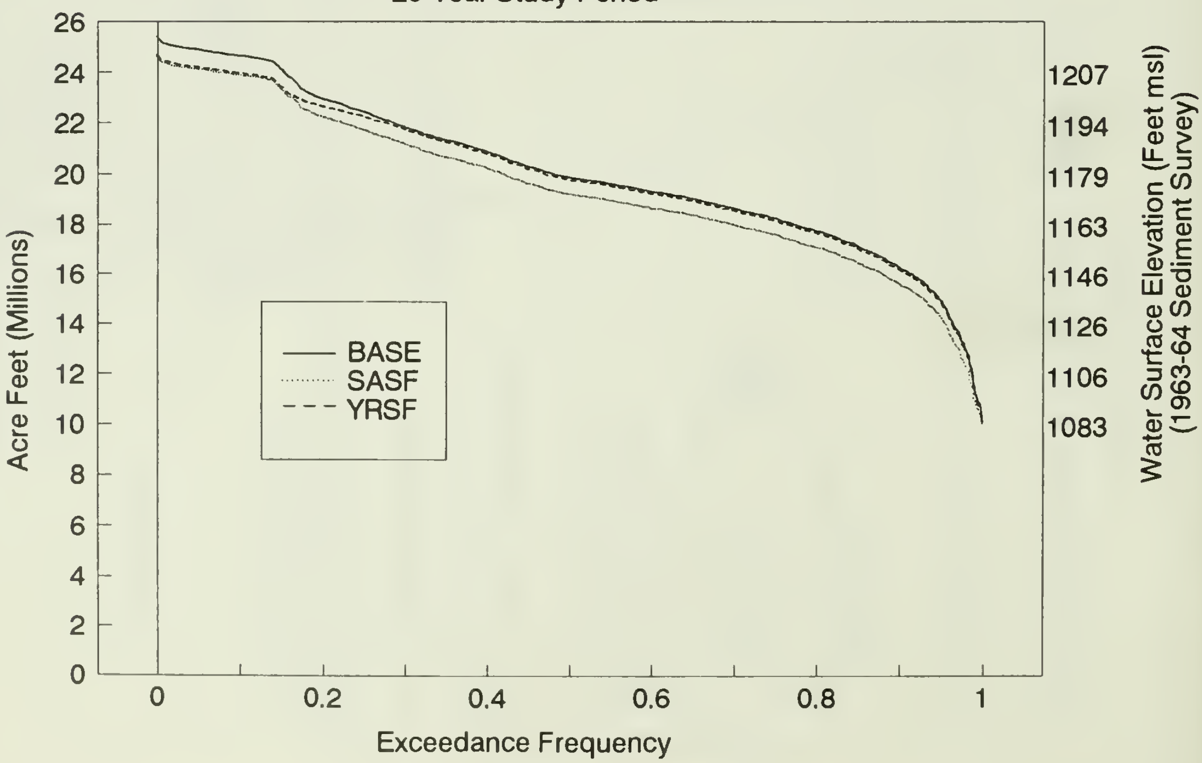
## Lake Mead End-of-December Storage

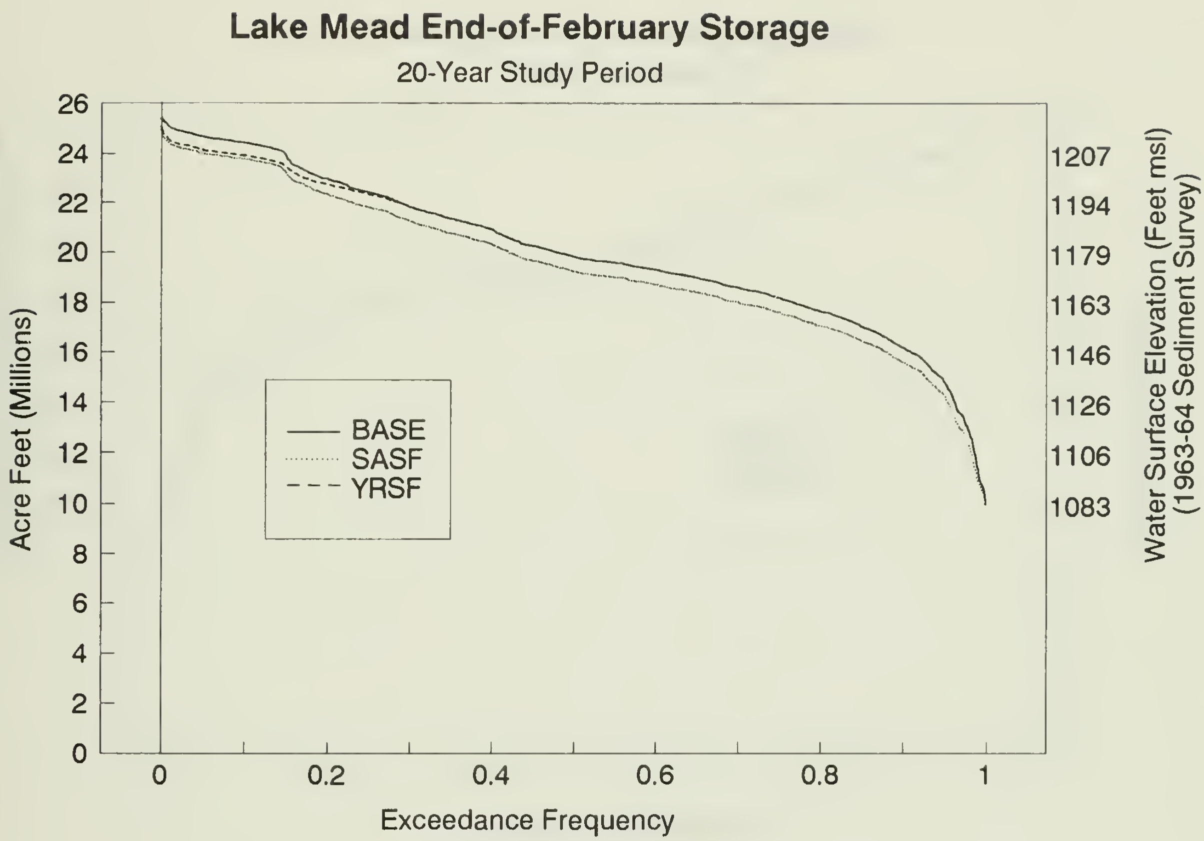
20-Year Study Period



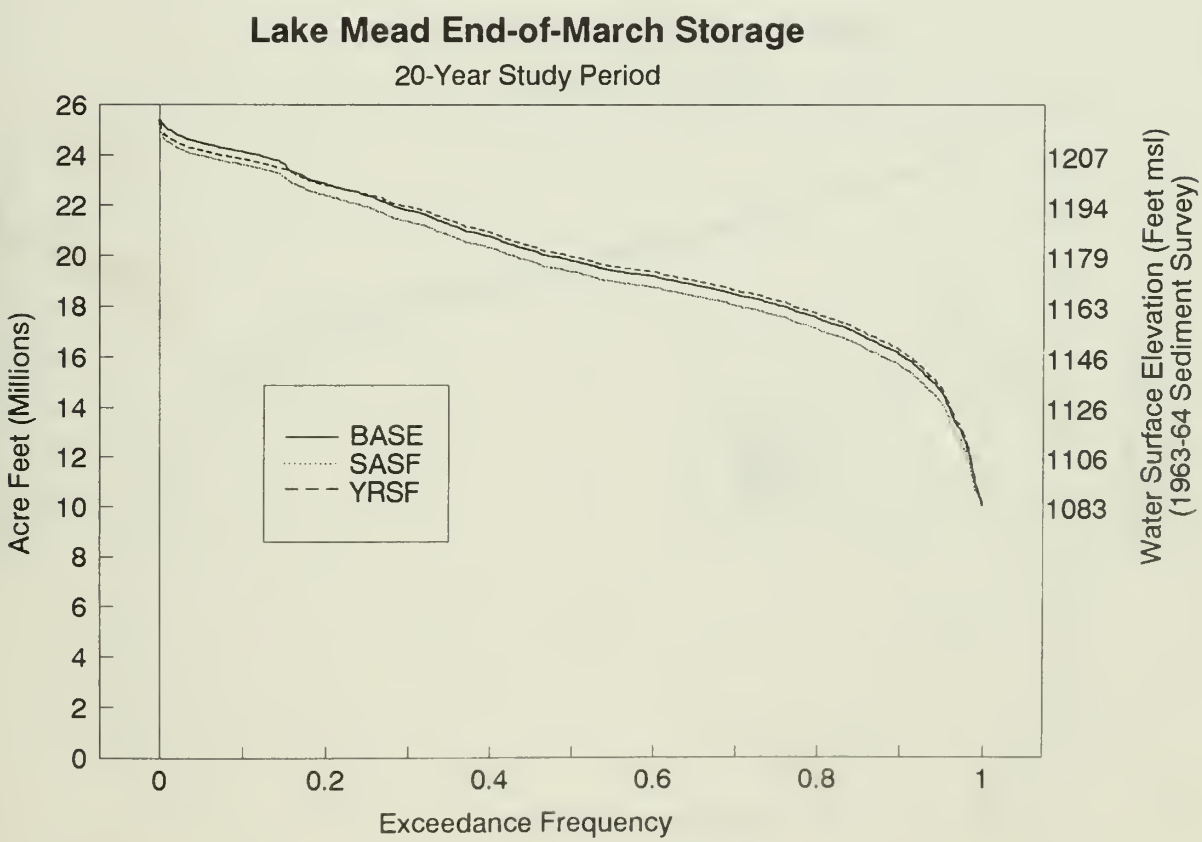

## Lake Mead End-of-January Storage

20-Year Study Period

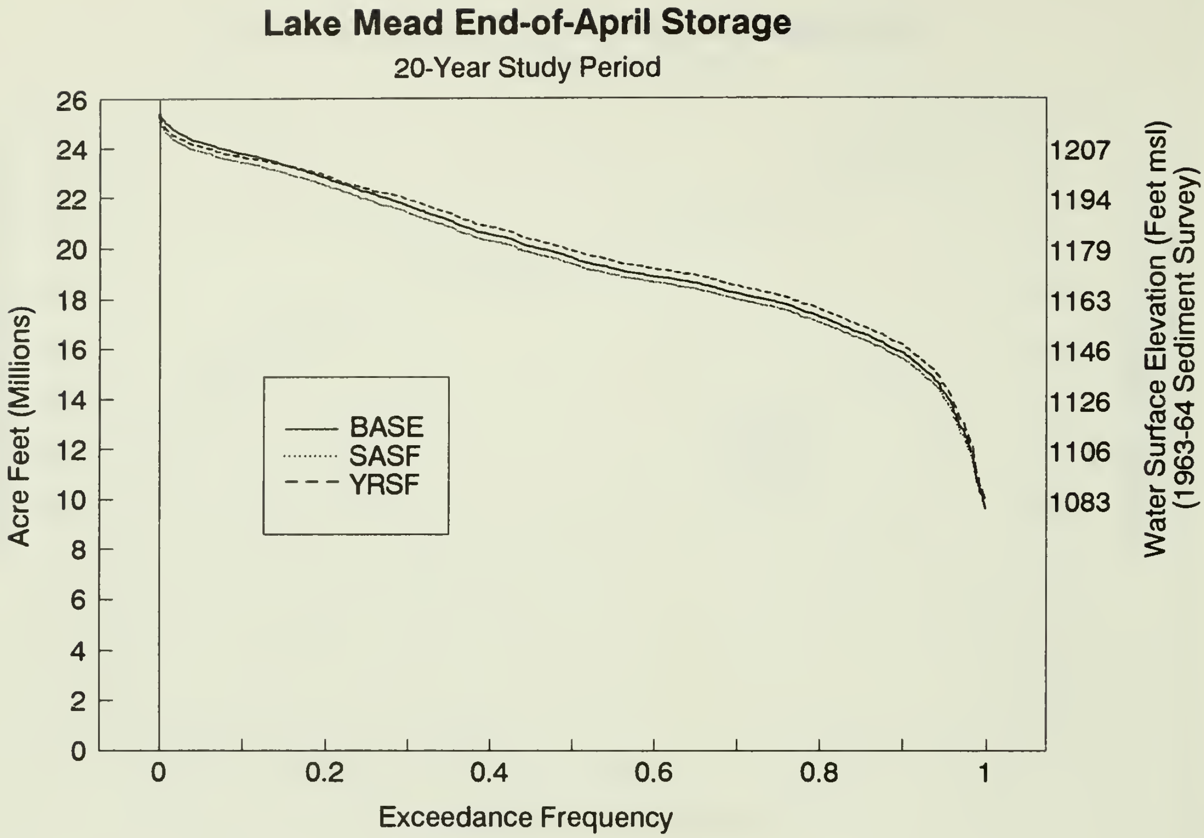


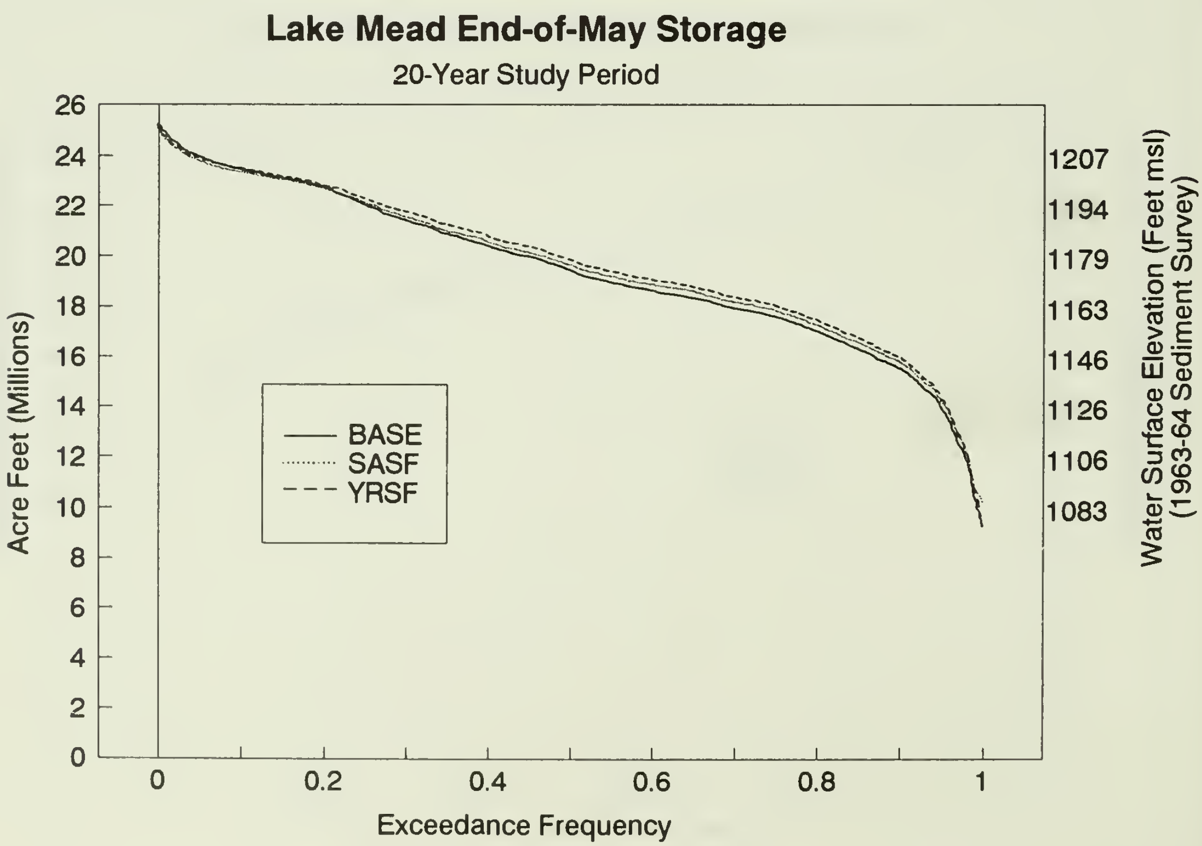


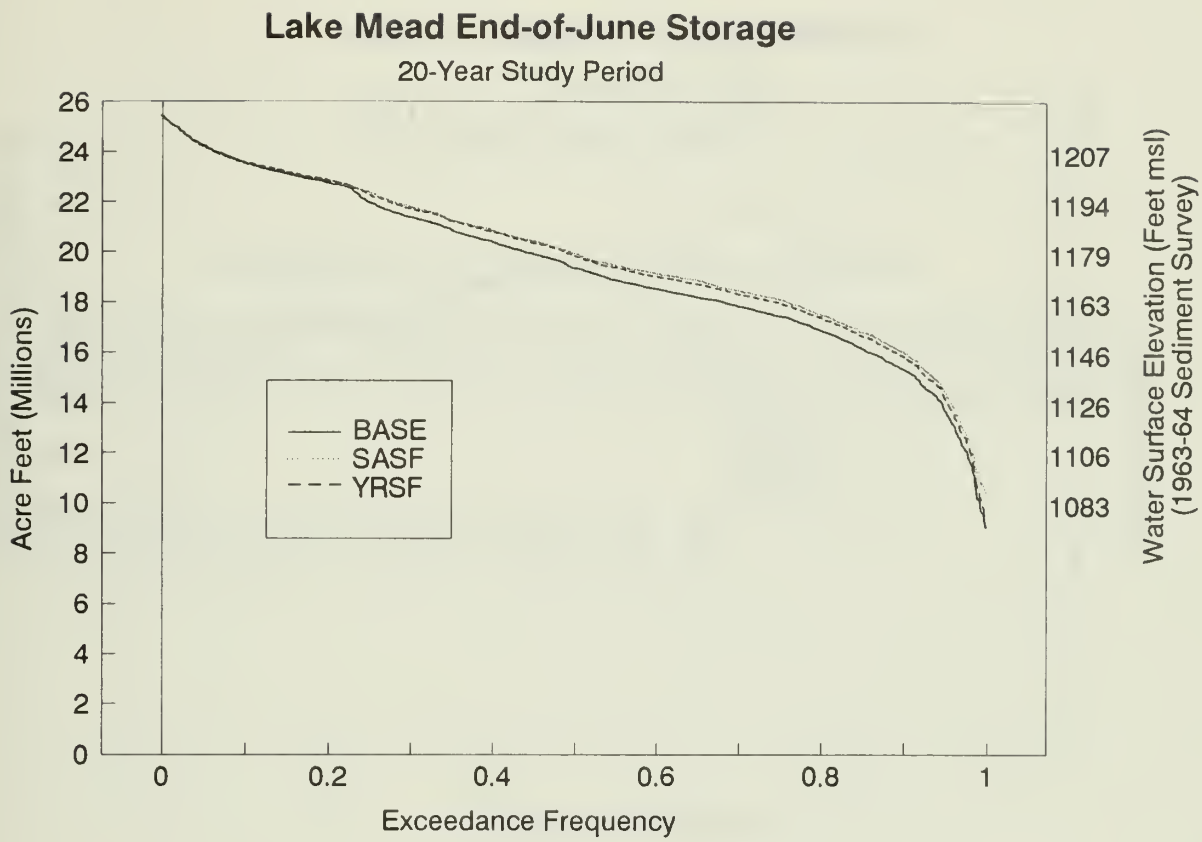
Lake Mead End-of-February Storage
20-Year Study Period
Acre Feet (Millions)
Water Surface Elevation (Feet msl)
(1963-64 Sediment Survey)
Exceedance Frequency
BASE
SASF
YRSF
0
2
4
6
8
10
12
14
16
18
20
22
24
26
1083
1106
1126
1146
1163
1179
1194
1207
0
0.2
0.4
0.6
0.8
1

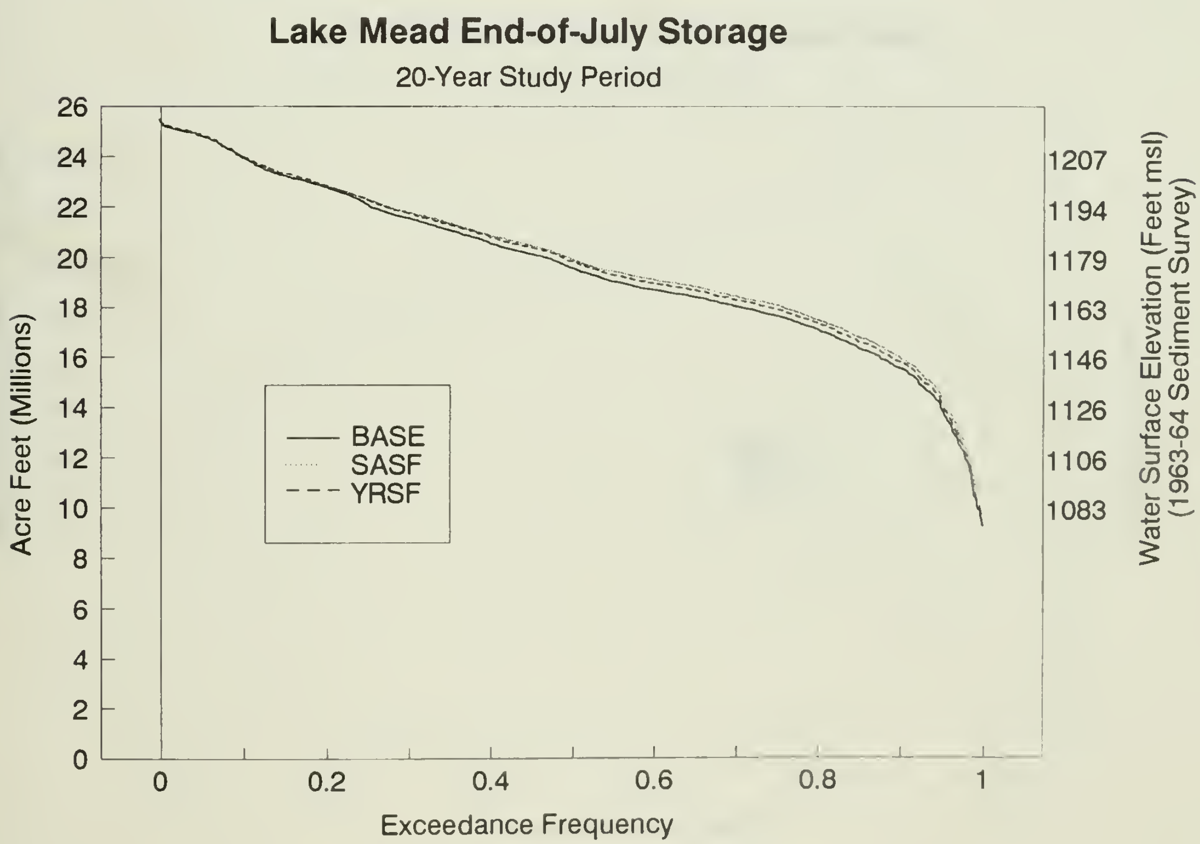



Lake Mead End-of-March Storage
20-Year Study Period
Acre Feet (Millions)
Water Surface Elevation (Feet msl)
(1963-64 Sediment Survey)
Exceedance Frequency
BASE
SASF
YRSF
0
2
4
6
8
10
12
14
16
18
20
22
24
26
1083
1106
1126
1146
1163
1179
1194
1207
0
0.2
0.4
0.6
0.8
1


Lake Mead End-of-April Storage
20-Year Study Period
Acre Feet (Millions)
Water Surface Elevation (Feet msl)
(1963-64 Sediment Survey)
BASE
SASF
YRSF
Exceedance Frequency
0
2
4
6
8
10
12
14
16
18
20
22
24
26
1207
1194
1179
1163
1146
1126
1106
1083
0.2
0.4
0.6
0.8
1

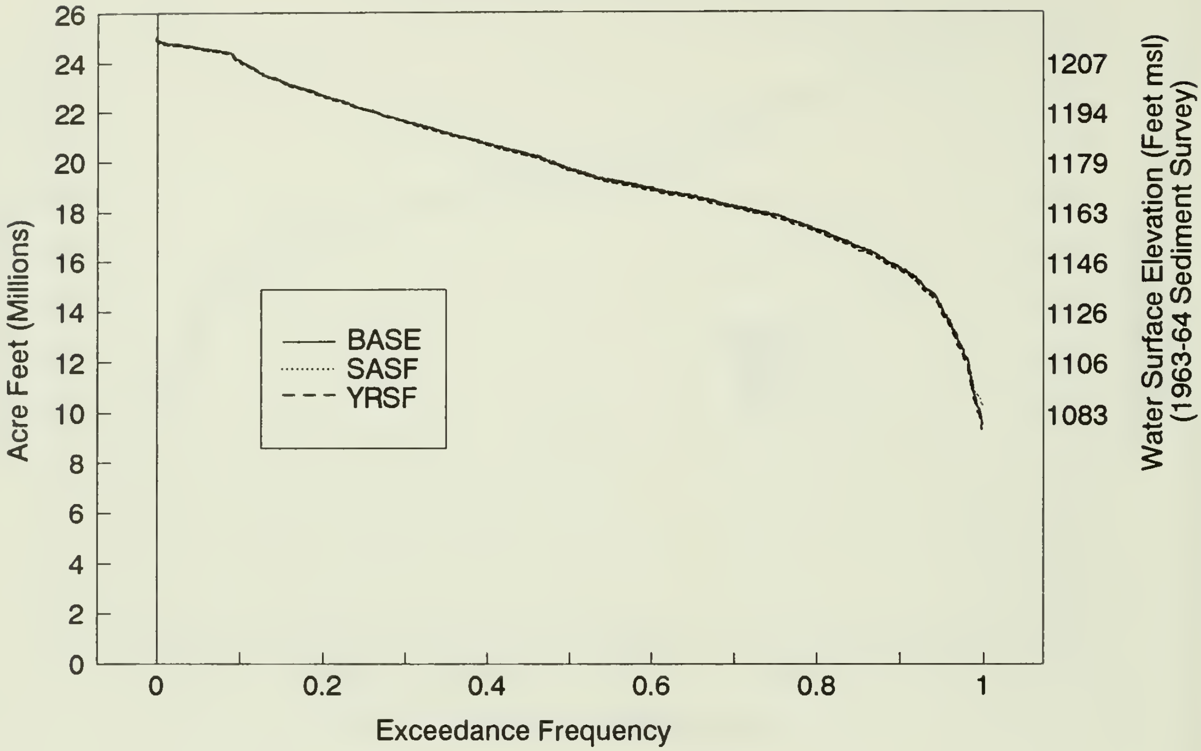

Lake Mead End-of-May Storage
20-Year Study Period
Acre Feet (Millions)
Water Surface Elevation (Feet msl)
(1963-64 Sediment Survey)
BASE
SASF
YRSF
Exceedance Frequency
0
2
4
6
8
10
12
14
16
18
20
22
24
26
1207
1194
1179
1163
1146
1126
1106
1083
0.2
0.4
0.6
0.8
1


Lake Mead End-of-June Storage
20-Year Study Period
Acre Feet (Millions)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Water Surface Elevation (Feet msl)
(1963-64 Sediment Survey)
1207
1194
1179
1163
1146
1126
1106
1083
BASE
SASF
YRSF
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency


Lake Mead End-of-July Storage
20-Year Study Period
Acre Feet (Millions)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Water Surface Elevation (Feet msl)
(1963-64 Sediment Survey)
1207
1194
1179
1163
1146
1126
1106
1083
BASE
SASF
YRSF
0
0.2
0.4
0.6
0.8
1
Exceedance Frequency

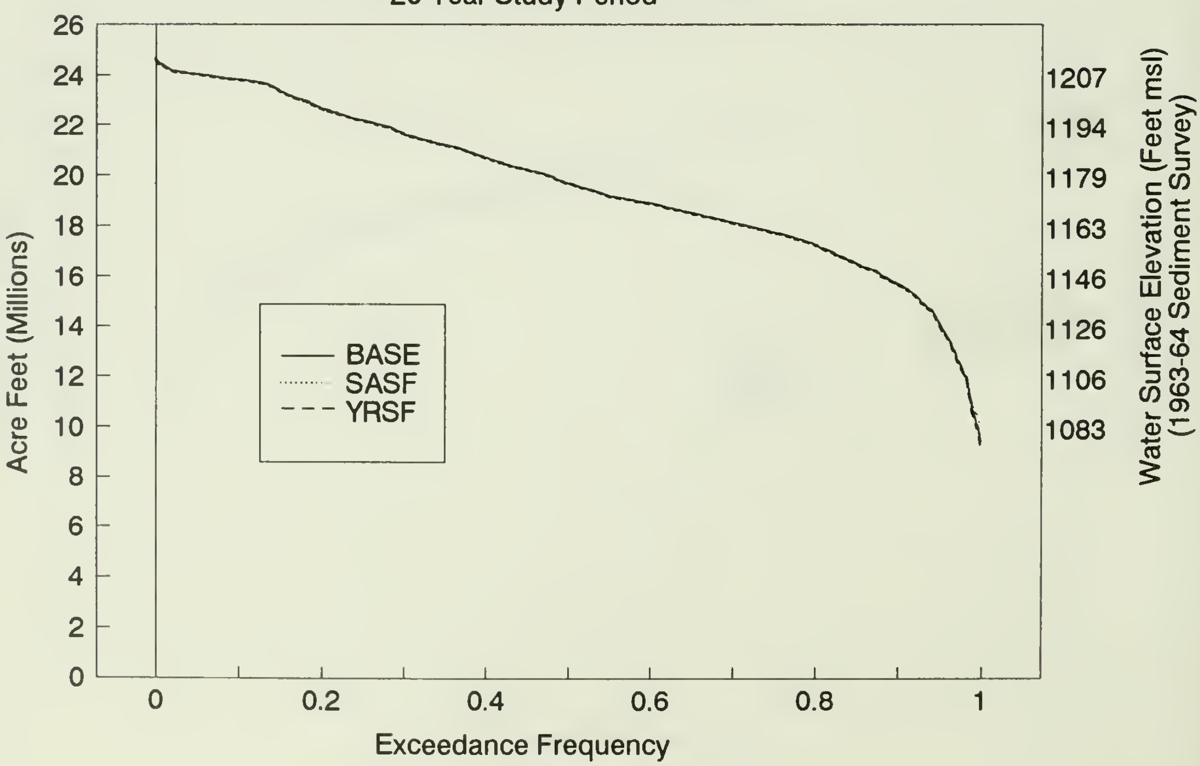
## Lake Mead End-of-August Storage

20-Year Study Period




## Lake Mead End-of-September Storage

20-Year Study Period



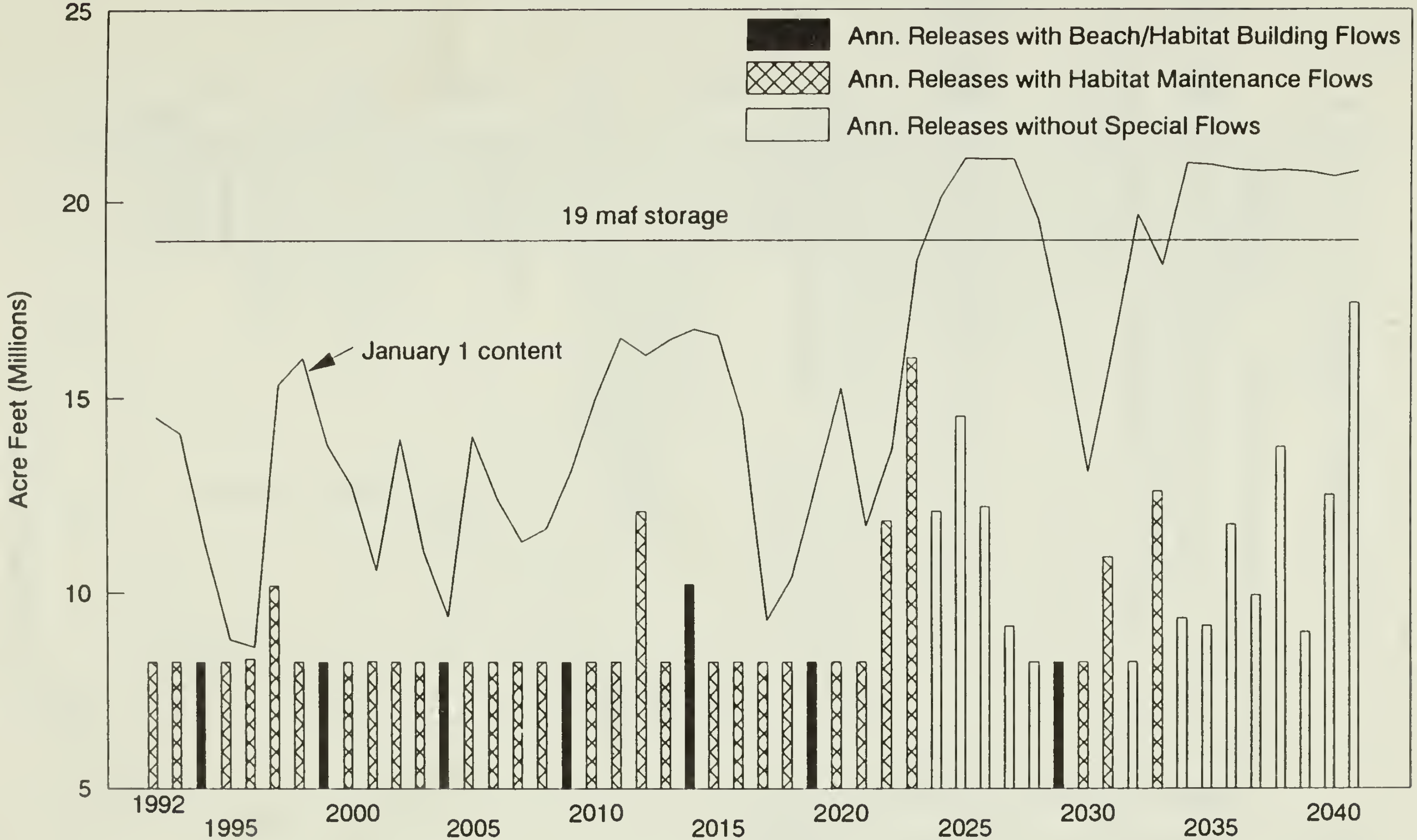
Example Scheduling of

# Habitat Maintenance Flows and Beach/Habitat Building Flows for the Modified Low Fluctuating Flow Alternative

A. CRSS Hydrologic Scenario (Trace) No. 48
B. CRSS Hydrologic Scenario (Trace) No. 60

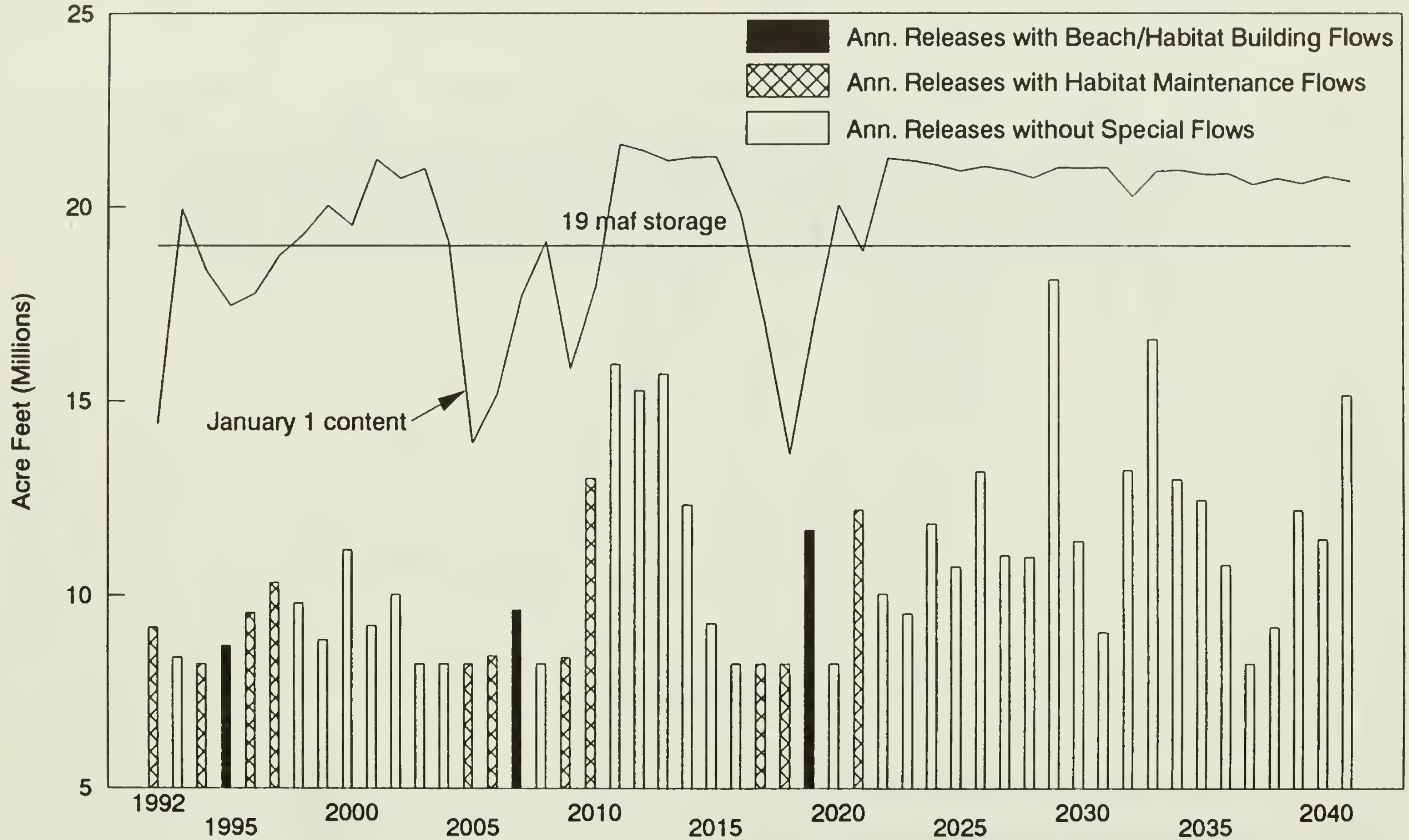
# Example Scheduling of Special Flows

Modified Low Fluctuating Flows — CRSS Hydrologic Trace No. 48



# Example Scheduling of Special Flows

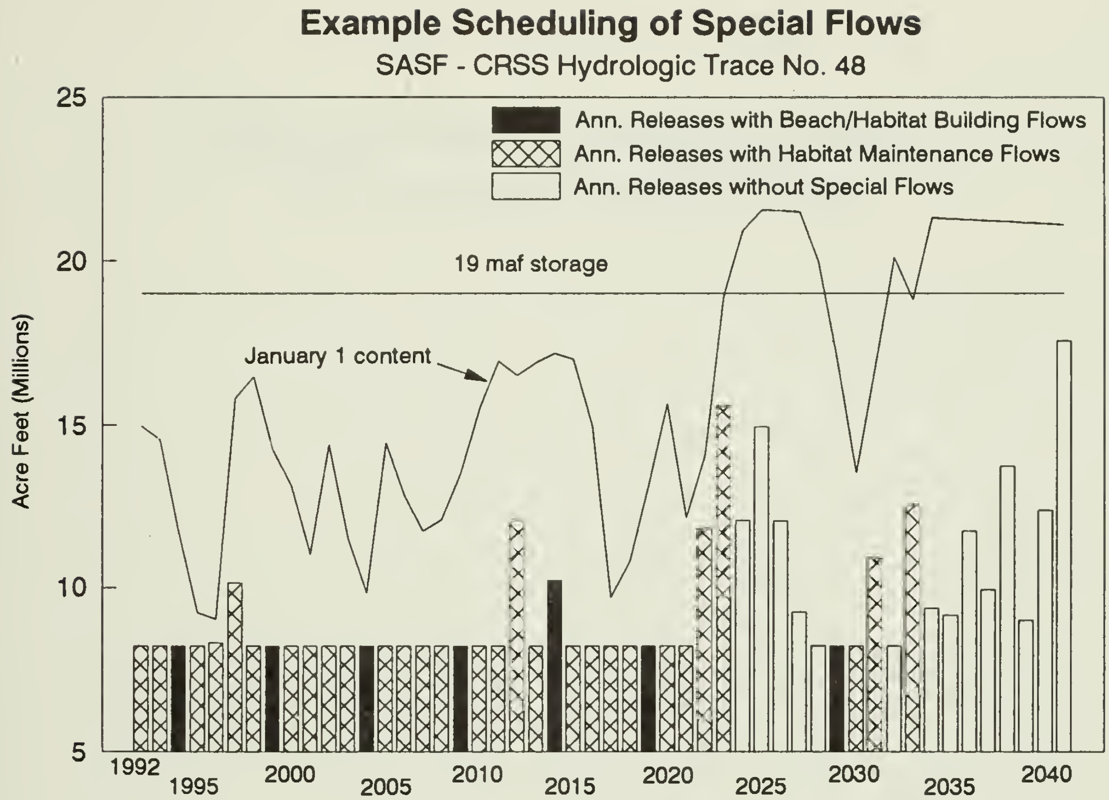
Modified Low Fluctuating Flows — CRSS Hydrologic Trace No. 60

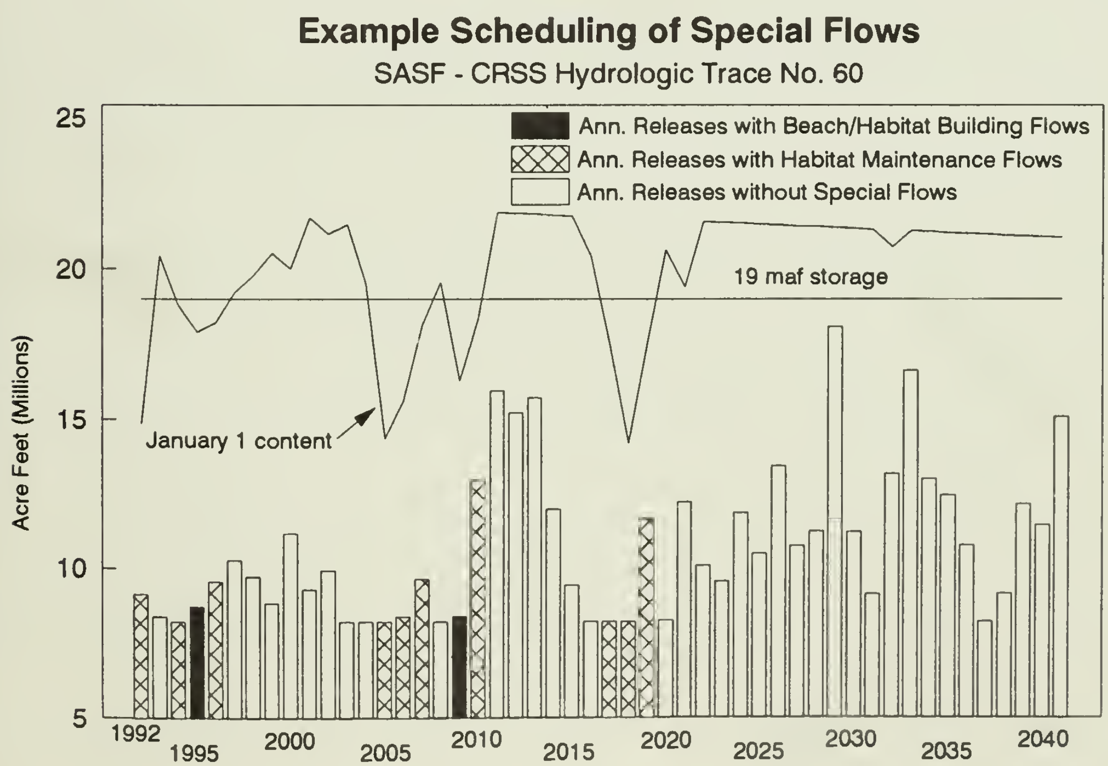


Example Scheduling of

# Habitat Maintenance Flows and Beach/Habitat Building Flows for the Seasonally-Adjusted Steady Flow Alt.

A. CRSS Hydrologic Scenario (Trace) No. 48
B. CRSS Hydrologic Scenario (Trace) No. 60


Example Scheduling of Special Flows
SASF - CRSS Hydrologic Trace No. 48
Ann. Releases with Beach/Habitat Building Flows
Ann. Releases with Habitat Maintenance Flows
Ann. Releases without Special Flows
19 maf storage
January 1 content
Acre Feet (Millions)
25
20
15
10
5
1992
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040


Example Scheduling of Special Flows
SASF - CRSS Hydrologic Trace No. 60
Ann. Releases with Beach/Habitat Building Flows
Ann. Releases with Habitat Maintenance Flows
Ann. Releases without Special Flows
19 maf storage
January 1 content
Acre Feet (Millions)
25
20
15
10
5
1992
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040

# Downstream Transformation of Fluctuating Releases

## Downstream Transformation of Fluctuating Releases

As described in chapter III, WATER, daily fluctuations in releases from Glen Canyon Dam produce long waves that travel the length of the canyon. The waves produced by fluctuating releases transfer the energy of the released water downstream by continuously displacing an equivalent amount of water. As a wave passes a fixed location, an observer sees displaced water, not the released water that initially formed the wave.

Because the fluctuations occur at 24-hour intervals and the wave peaks travel faster than the wave trough, each wave catches up to the one that precedes it. The leading edge of each wave is superimposed on the trailing edge of the preceding wave, and the extent of the overlap increases downstream. The result is a downstream transformation of the wave pattern that is considerably different from the lengthening and flattening that is typical of a single, isolated wave.

The following characteristics of downstream transformation of fluctuating releases are based on studies of Smith and Wiele (written communication, 1992) and examination of several sets of hydrographs of research and normal fluctuating flows:

- Wave peaks and troughs become pointed, regardless of the duration and variability of maximum and minimum releases. Normal fluctuating releases typically have two peaks lasting a few hours each, in response to mid-day and evening electrical demands. Although release rates are highly variable, wave transformation eliminates the variations in the maximum and minimum release patterns, forming a single peak and trough, as shown in figure B-1.

- The shape of the wave becomes triangular. The shape of the wave at Lees Ferry is similar to that below the dam, but by the time the wave reaches the mouth of the LCR, it has transformed to the rounded triangular shape that will be maintained until the wave enters Lake Mead (see figure B-1). This shape probably is established in the reach between RM 36 and the LCR (RM 61).

- Although ramp rates may influence the steepness and shape of the flow pattern between the dam and the LCR, this influence appears to be minimal at sites downstream from the LCR.

- The rate of increase in flow between the trough of one wave and the peak of the next wave (initially, the up ramp rate) tends to increase or remain constant with distance, as shown in figure B-1.

- The rate of decrease in flow between a wave peak and the next trough (initially, the down ramp rate) decreases with distance (see figure B-1).

- Inflows from side canyon streams and springs increase both the maximum and minimum flow in the river.

- Maximum flows (wave peaks) decrease downstream, unless offset by tributary inflows.

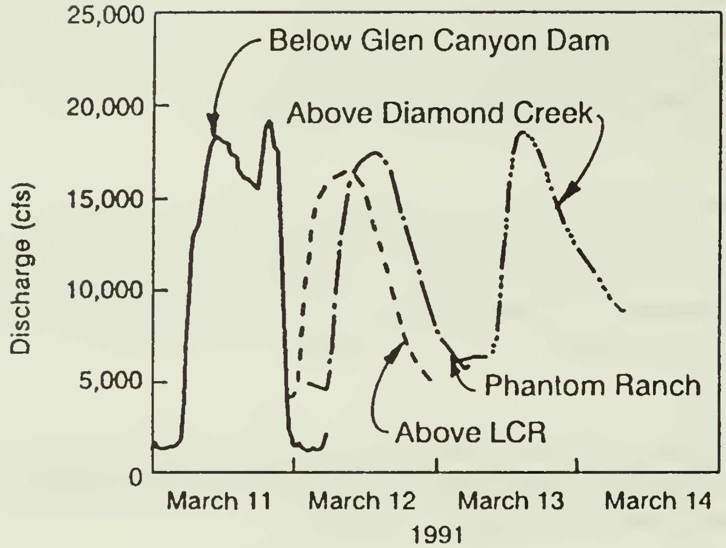



*Figure B-1.—Transformation of the discharge wave during fluctuating flows on March 11, 1991. Minimum discharge increased substantially due to the combined effects of wave transformation and tributary flows. Downstream from the LCR, tributary inflows more than offset the decrease in maximum discharge due to wave transformation. Cumulative tributary inflow between the dam and Diamond Creek is estimated to be approximately 2,000 cfs. (Note: The leading edge—the part of a wave that arrives first at a site—is the left side of a plot of a discharge fluctuation versus time.*

- Minimum flows (wave troughs) increase downstream. The lower the minimum release from the dam, the greater the increase. Also, the greater the range of fluctuations at the dam, the greater the increase in minimum flow. The duration of the minimum flow decreases from several hours at the dam to less than 1 hour downstream from the LCR.

- The waves travel much faster than the released water that forms them (see following discussion under "Travel Time of Water").

- The length of each wave tends to become constant below the LCR. Discharge waves typically are between 50 and 150 miles long.

In contrast with the discharge wave patterns, which gradually transform downstream, river levels (stage) and wave heights (difference between maximum and minimum river stage) vary widely from one location to another, depending on the width, depth, and slope of the channel. River stage data for the two research fluctuating flows described in table B-1 are used to illustrate how wave height and minimum stage vary as a result of local channel geometry and wave pattern transformation. Ramp rates were fairly uniform during these research flows, and minimum and maximum releases had durations of 4 to 6 hours.

Table B-1.—Characteristics of two research fluctuating flows

| Research flow | Date | Minimum release (cfs) | Maximum release (cfs) | Range of flow fluctuations (cfs) |
|---|---|---|---|---|
| B | February 1991 | 5,000 | 14,600 | 9,600 |
| D | May 1991 | 2,700 | 26,500 | 23,800 |

For a given range of flow fluctuations, wave heights are greater in narrow reaches than in wide reaches. Evidence of the wide and narrow reaches, which alternate throughout the canyon, can be seen in figure B-2. The general trend is a decreasing wave height with distance, a result of the increasing minimum flow and more or less constant maximum flow, as described above. The increase in stage of the wave trough, using the 5,000-cfs stage as a reference, is illustrated in figure B-3. Variations in the general trend are caused by variations in channel geometry.

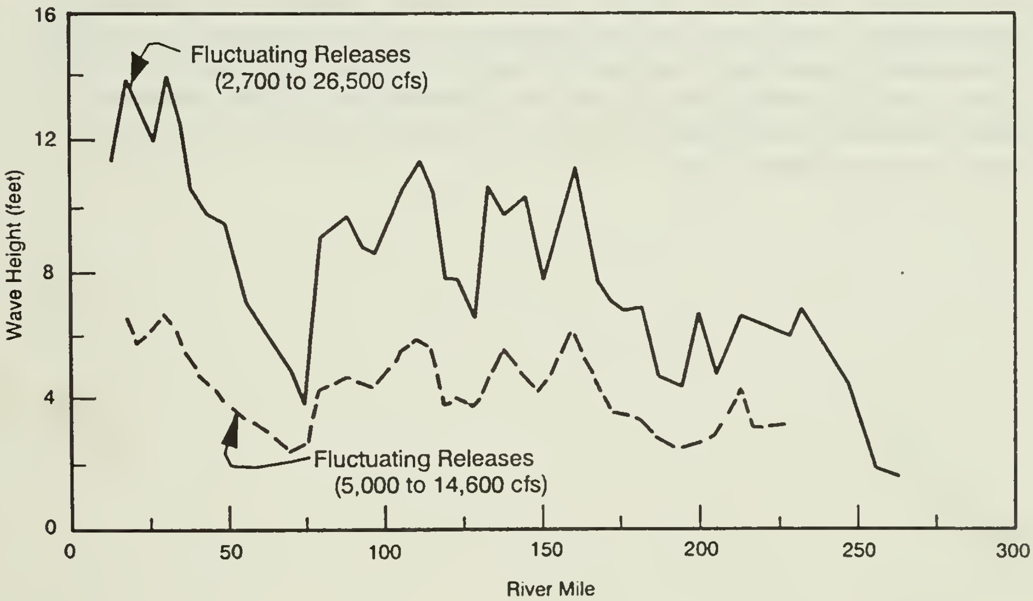



*Figure B-2.—Variations in wave height for two research fluctuating flows. Wave height varies locally as the discharge wave travels through alternating narrow and wide reaches of Grand Canyon. The general trend is a downstream decrease in wave height, because the minimum discharge increases substantially and the maximum discharge decreases or remains about the same, depending on tributary inflow (modified from Smith and Wiele, written communication, 1992).*

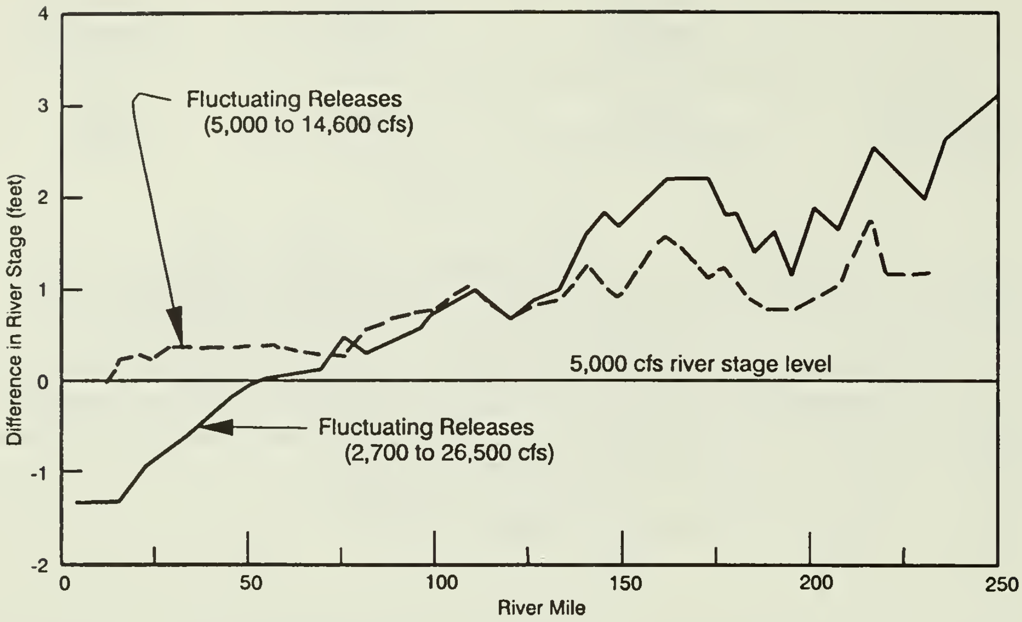



*Figure B-3.—General downstream increase in stage of wave trough for two fluctuating research flows. Local river stage for 5,000 cfs is used for comparison between sites. The increase is caused by downstream increases in minimum discharge and is greater for the higher fluctuations than for the lower fluctuations. Locally, increases are greater in narrow reaches than in wide reaches (modified from Smith and Wiele, written communication, 1992).*

# Travel Time of Water

## Travel Time of Water

Information about travel time of water released from the dam to sites of interest downstream is important for assessing water quality. Travel time is determined by water velocity, which varies with discharge. Dissolved constituents travel at the same velocity as the water, suspended materials travel somewhat slowly, and floating materials more rapidly. The energy waves produced by fluctuating releases from the dam, however, travel at substantially greater velocities than the water that initially forms them, so wave travel times through a given reach are much shorter than travel times of the released water.

Mean travel time of the water through long reaches varies with mean (average) discharge, not with the magnitude of flow fluctuations. As demonstrated by the dye studies of Graf (1991; written communication, 1992), mean travel time of water for the research fluctuating flow of May 6-11, 1991, was nearly identical to that of the research steady flow of May 20-25, 1991; both flows had the same mean daily discharge, about 15,000 cfs. The daily fluctuations for the first test were 2,700 to 26,500 cfs at the dam. In that test, the dye-tagged water took about 104 hours to travel 236 miles downstream from Lees Ferry (about 2.3 miles per hour)—nearly three times the travel time of the wave peak, which took about 37 hours to travel 225 miles (about 6.1 miles per hour). Mean travel times of water for selected releases are given in table B-2.

Table B-2.—Travel times and velocities of water in Glen and Grand Canyons (source: Graf, written communication, 1992)

| Reach | Mean daily discharge (cfs) | Mean travel time (hours) | Mean velocity (mph) |
|---|---|---|---|
| Glen Canyon | 5,000 | [1]20 | 0.80 |
| (RM -16-0) | 15,000 | [1]9.3 | 1.72 |
| | 23,000 | [1]6.7 | 2.39 |
| | 30,000 | [2]5.5 | 2.91 |
| Grand Canyon | 5,000 | [2]240 | 1.0 |
| (RM 0-236) | 8,000 | [3]176 | 1.3 |
| | 15,000 | [1]108 | 2.2 |
| | 30,000 | [3]70 | 3.4 |

[1] Dye measurement.

[2] Graphical extrapolation.

[3] Simulation based on dye measurement.

Appendix C

# *Water Quality*

# Contents



# Table

## WATER QUALITY

Selective withdrawal facilities are structures that allow water to be withdrawn from different elevations in the reservoir with distinct water quality characteristics for the purposes of reservoir and downstream water quality or aquatic habitat management. At Lake Powell, selective withdrawal facilities would be used to withdraw warmer water from nearer the reservoir surface during late spring and summer for discharge downstream to warm the river. Warmer instream temperatures during critical life stages, such as spawning and rearing, may promote recovery of some native fish populations. The establishment of successful spawning and recruitment of native fish in the mainstem may require warmer releases during critical periods approximately once in five years.

Providing warmer release temperatures from Glen Canyon Dam through selective withdrawal has the potential to help recovery of endangered native fish species in Grand Canyon. However, further study is needed because not enough is known about potential corollary and secondary effects to the water quality and aquatic ecology of Lake Powell and the downstream.

The study area for evaluation of water quality related to Glen Canyon Dam includes Lake Powell and the Colorado River with its tributaries between the dam and about Separation Rapids. Separation Rapids is usually considered the inflow area of Lake Mead, yet during extended low inflow periods, Lake Mead may recede, moving the inflow area downstream of Separation Rapids. Chemical, physical, and biological characteristics of the study area, their influence on river system water quality, and potential effects of selective withdrawal operations are presented in this appendix.

Reservoir water quality is always changing for reasons including:

- The reservoir phase, such as the initial filling stage, a full reservoir, and subsequent drawdown and filling cycles,
- Seasonal climatic changes, and
- Variable quantity and quality of reservoir inflow.

The constantly changing nature of reservoir limnology necessitates the collection of data at regular intervals, at representative locations throughout Lake Powell. A complete and comprehensive data base would permit comparisons between the seasons and various years, and provide a history to examine for trends, cycles, and other changes. General characterizations of water quality conditions and predictions of future changes may then be made more confidently.

Lake Powell limnology—or water quality and aquatic ecology—has been studied at various levels of detail since about 1968. Reservoir fisheries have been studied in greatest detail. Since about 1972, Reclamation's water quality data collection program focused on salinity, and temperature, circulation, dissolved oxygen (DO), and pH data were also acquired. Recently, the Lake Powell Monitoring Program has been gathering data at more regular intervals throughout the lake. Short-term and single-event studies, often not conducted reservoir-wide, have provided additional information on nutrients, plankton, sediment chemistry, and trace elements such as mercury, selenium, and lead. The U.S. Fish and Wildlife Service (FWS) collected fish samples for trace chemical analysis. The NPS conducts bacteriological studies in recreation areas for human health concerns.

Lake Powell is a relatively young reservoir that has undergone stages of initial filling, full pool, and drawdown, and each stage has exhibited different water quality characteristics. Historic water quality data for Lake Powell summarized in this appendix provides limited basic background for describing some water quality components and processes at particular stages of reservoir development; however, since data were not collected at regular intervals through all stages of Lake Powell's development, only qualitative predictions can be made. It is difficult and potentially misleading to use discontinuous and limited information to make general statements characterizing water quality of such a large, dynamic water body, and quantitative predictions of future changes and impacts may not be made with confidence.

## Tributaries to Lake Powell

The Colorado River is the major tributary to Lake Powell, followed by the Green and San Juan Rivers, respectively. The Green River joins the Colorado River upstream of Lake Powell, and the junction of the San Juan and Colorado Rivers is inundated by the reservoir. Collectively, the three tributaries contribute approximately 95 percent of the total reservoir inflow (Reynolds and Johnson, 1974). Water quality of each tributary is unique in chemical, physical, and biological composition as a result of diverse basin geology, development, seasonal and annual hydrologic variations, and other factors.

Water quality varies not only among basins, but also within each basin. The headwater regions have had limited human disturbance and are underlain by rock formations that are resistant to weathering, so water from there is quite pristine. Lower in the basins, rock formations are more weatherable, often of marine origin, and greater human development has occurred, contributing to increased input of sediment, dissolved solids, and constituents derived from agriculture, municipalities, and industry. Selenium, mercury, and uranium are naturally occurring elements in the Colorado River basin and tend not to accumulate with sediments in the river, but rather in Lake Powell sediments.

Saline ground water and natural springs within the Colorado River basin also contribute dissolved solids to the river. Isolated discharges of contaminants to or along some tributaries (see next paragraph) have occurred, but are not well-documented, and the fate of the contaminants is unknown. It is suspected that the contaminants were transported down river to Lake Powell and deposited in the delta sediments.

The quality of sediments deposited in Lake Powell is not precisely known. Limited sediment chemistry analyses have been conducted on samples taken from the lake, so insufficient information exists to characterize the quality of sediments or track types of deposition. A water quality specialist for the Bureau of Reclamation expressed the following concerns in a 1990 memorandum (Miller, written communication, 1990):

*Oil spills have occurred in the San Juan River drainage since the 1970's. Mine tailings have contaminated the Animas River (a tributary of the San Juan). Samples of fish tissue from the San Juan River showed petrochemical contamination. Selenium concentrations exceeding 20 parts per billion have been reported in the San Juan River at USGS sampling stations over the past several years. The combination of organics and metals that may now be settling in the San Juan arm of Lake Powell could yield toxins upon resuspension.*

## Lake Powell

### Reservoir Circulation

The Colorado, Green, and San Juan Rivers are the main tributaries to Lake Powell, and their particular water quality characteristics exert chemical and physical compositional control on the lake (Reynolds and Johnson, 1974). Various chemical, physical, and biological processes and characteristics of Lake Powell act on inflow to influence the overall reservoir water quality. Some processes and characteristics include:

- Reservoir circulation and mixing
- Algal growth and respiration
- Chemical reactions
- Changing meteorological conditions
- Variations in inflow quantity and quality
- Retention time in the reservoir
- Reservoir size and shape
- Contaminant retention on sediments

Neither all of the processes listed above occur simultaneously, nor do all of the processes and characteristics have equal effect, so water quality varies throughout the reservoir and over time.

Mixing processes, including currents created by inflow, outflow, and heat distribution, have a major effect on reservoir water quality. There are three distinct seasonal inflows to Lake Powell (Merritt, 1976), and their descriptions are summarized in table C-1.

Table C-1.—Characteristics of inflow to Lake Powell

| Inflow name | Duration | Percent of total inflow | Temperature (°F) | Total dissolved solids (ppm) | Relative sediment concentration (ppm) | Relative density |
|---|---|---|---|---|---|---|
| Spring | April-July | 60 | Warm (57-64) | Low (200-300) | High (1,000-3,000) | < surface water |
| Late summer - early fall | August-October | 12 | Warmer (64-72) | High (≥ 1,100) | Moderate | > surface water but < bottom water |
| Late fall - winter | November-March | 28 | Cold (32-39) | Low (500-600) | Very low | ≥ bottom water |

Spring and late fall-winter inflow currents are the most influential, but affect different areas within the reservoir. Spring inflow is warm, since snowmelt from higher in the basin heats as it travels the great distance across the Colorado Plateau during the long days of spring and summer, and is less dense than reservoir surface water, so it flows near the surface over the cold, dense, deeper water of Lake Powell. Late fall-winter inflow is dense and pervasive, so it flows along the reservoir bottom (Johnson and Page, 1981). The density of late summer inflow is intermediate between that of spring and winter inflows, so it enters and flows through Lake Powell at about mid-depth.

### *Withdrawal Current*

The distinct seasonal inflow currents are further influenced by the withdrawal current produced when reservoir water is drawn through the penstock intakes located at elevation 3470 feet, or about 230 feet below full pool. The vertical extent of the withdrawal current increases with discharge and reaches a maximum of about 100 feet above and below the intakes (Johnson and Merritt, 1979). The withdrawal current is a deep-reaching reservoir current and may extend the length of Lake Powell (Merritt, 1976), depending on the season, discharge magnitude, and other factors. Reservoir profiles (or plots of measurement with depth in the reservoir, of temperature, pH, DO, and conductivity) tend to exhibit pronounced changes from former trends in the vicinity of the withdrawal plume, near the intake elevation.

The intakes are located in the hypolimnion when reservoir elevations are above 3590 feet, although the withdrawal current entrains metalimnetic water before reservoir elevations reach that level. Release water quality changes occur as a result of withdrawing water from the metalimnion and epilimnion, discussed below, and exposing delta sediments as the lake recedes. Exposed sediments are vulnerable to resuspension by inflow and wave action, which facilitate release of constituents associated with sediments back into the water. Reservoir elevations of 3590 feet or below are considered rare events, likely to occur less than 5 percent of the time.

### Heat Distribution

Uneven heat distribution throughout Lake Powell also creates currents. Lake Powell typically stratifies annually into three layers that differ in temperature: the epilimnion, metalimnion (thermocline), and the hypolimnion. Sunlight penetrates and warms the upper part of the reservoir, called the epilimnion. Summer surface temperatures reach about 80 °F, and winter temperatures may drop to 45 °F. The thickness of the epilimnion ranges between 30-50 feet, but may extend to 80 feet. The metalimnion is the zone below the epilimnion, also ranging between 30-50 feet, and extending to 80 feet in depth where sunlight is limited and water temperatures decrease with depth. Temperatures continue to decrease in the metalimnion until a level is reached below which temperatures cease to change. The hypolimnion is the deepest region where essentially no light reaches, and water temperatures of about
46 °F persist throughout the year.

Lake Powell is typically thermally stratified for much of the year, but from about October through December, the epilimnion cools, becoming more dense and sinks, mixing with layers below. This primarily vertical mixing process, or turnover, blends the quality of water in the reservoir to about penstock intake elevation, but not to the reservoir bottom. Vertical mixing within the reservoir modifies the thermal regime, creating more uniform temperature, or isothermal, conditions with depth from about January through March. The temperature in the mixed region of Lake Powell is about 46 °F during that period. Generally by late March thermal stratification begins as the reservoir surface warms, and is fully developed by July. The effects of high inflow or extended drought conditions induce different reservoir dynamics. During recent extended low inflow conditions, Lake Powell was drawn down over 80 feet from full pool, and development of isothermal conditions was less extensive than observed in other years prior, perhaps due to a weak turnover and less reservoir mixing. Contrastingly, high inflows of 1983 and 1984 necessitated the release of reservoir water from both the spillways and river outlets, flushing the reservoir out at two levels. Combining two levels of outflow with the large mass of inflow created extensive mixing reservoir-wide, preventing prominent stratification for over a year.

Removing warmer water from Lake Powell by selectively withdrawing may decrease reservoir temperatures, and in turn potentially:

- Reduce reservoir productivity,
- Diminish the threadfin shad population,
- Change reservoir circulation strength and patterns, and
- Reduce reservoir evaporation.

### Dissolved Oxygen

The epilimnion is where most biological activity and atmospheric reaeration occurs, so it is well oxygenated, averaging 8.0 milligrams per liter (mg/L) of dissolved oxygen. DO concentrations are highest in the summer, primarily due to photosynthesis, but vary with circulation and biological activity. Concentrations generally decrease with increasing reservoir depth. In the metalimnion, DO concentrations typically range between 5-10 mg/L, however the DO concentrations in the metalimnetic oxygen minimum layer, discussed below, may be as low as 2 mg/L. Concentrations at the bottom of the hypolimnion become very low, 2-4 mg/L (Johnson and Page, 1981), and turnover mixing, which would bring oxygenated water from upper reservoir strata, does not reach the reservoir bottom. DO concentrations below 2 mg/L have not been recorded at that depth, perhaps due to the relatively oxygen-rich winter underflow density current. The underflow density current flows along the reservoir bottom, lifting low-oxygen bottom water and carrying it to the dam, where it is eventually discharged from the reservoir.

Although most of the nutrient-rich sediments settle out in the deltas, as discussed below, sufficient nutrients and organic material remain in surface inflows for aquatic growth. Algae, bacteria, and chemical process of organic decay consume DO in the water, which may cause development of a dissolved oxygen minimum layer that is theorized to form near the lake surface, then sinks toward the metalimnion, about 45-60 feet below the surface (Johnson and Page, 1981). The dissolved oxygen minimum layer, with concentrations as low as 2 mg/L, reaches its maximum size by September, potentially extending the full length of Lake Powell, and is more prominent in tributary bays (Johnson and Page, 1981). This DO deficient layer may impact fishery distributions by presenting a formidable barrier to vertical migration during late summer and early fall (Wood and Kimball, 1987), even though hypolimnion DO concentrations are generally adequate to support fisheries (Johnson and Page, 1981). Vertical mixing in the reservoir, beginning in about October, breaks up the low DO layer.

Selective withdrawal operations may intercept the metalimnetic DO minimum layer, since timing of development partially overlaps the critical period when withdrawals from the metalimnion or higher would be required. Lower DO concentrations in releases would depress river concentrations, predominantly in the Glen Canyon reach, but data have shown that releases with relatively low DO content approach saturation by Lees Ferry.

### Nutrients

Spring inflows carry large amounts of nutrient-rich sediment and organic material (see table C-1), most of which settles out in the deltas (see chapter III, SEDIMENT). The river may be turbid through Cataract Canyon, the headwater area of Lake Powell but about 30 miles downstream at the Hite Marina, the river may clear considerably. An estimated 98 percent of total phosphorus and 46 percent of total nitrogen entering Lake Powell is trapped in the reservoir, probably associated with sediments (Paulson and Baker, 1984). Overall, nutrient concentrations in Lake Powell are low since most of the nutrients are bound to sediments. Bound nutrients do not contribute to lake productivity because they are biologically unavailable. Since Lake Powell is long, narrow, and deep with many canyons, wind and wave action have less effect on resuspending bottom sediments than sediments in shallow water or on exposed beaches or deltas. Sediment resuspension may facilitate release of nutrients back into the water column (Miller et al., 1983).

Although nutrient concentrations appear low in the main body of Lake Powell, potentially restricting primary productivity (Maddux et al., 1988; Angradi et al., 1992) (see chapter III, Aquatic Food Base), tributary inflow areas benefit from nutrient-rich sediment inflow, and as a result, have higher levels of productivity. Agitated flow resuspends some sediment, facilitating disassociation of nutrients from sediment particles, thereby increasing the physical and biological availability of nutrients. Algal blooms occur occasionally in the shallow, warm, clear, nutrient-rich inflow areas in late summer, and may occur more frequently during low reservoir conditions. Under low reservoir conditions, water temperatures increase in shallow areas of the reservoir, such as coves or inflow areas, and nutrient concentrations also increase, perhaps due to resuspended sediments by wave action and inflow. Since most of the sediment settles out in the delta, little particulate matter remains to cloud the water in Lake Powell. Particulates limit the depth that light can penetrate water, thereby limiting aquatic productivity. Preliminary light penetration studies have determined that the depth light reaches in the forebay, or area near the dam, is about 82 to 113 feet.

Extracting water from the metalimnion or higher with selective withdrawal operations may induce movement of nutrient plumes from inflow areas out into the reservoir, potentially modifying reservoir nutrient distribution. Impacts to the reservoir may be influenced by the rate of nutrient cycling in the reservoir, or uptake of nutrients by aquatic organisms and the eventual return of nutrients to the system through death or wastes. More rapid nutrient cycling rates may intensify the metalimnetic DO minimum layer, thus potentially increasing the possibility of withdrawing from DO minimum layer during selective withdrawal operations. Slower nutrient cycling rates in the reservoir may result in withdrawing water of somewhat higher nutrient content from the metalimnion and epilimnion, thereby increasing downstream concentrations.

Phosphorus availability is influenced by factors including:

- Input sources,
- Sediment/nutrient relationships,
- Mixing processes within the lake,
- The shape and form of the reservoir, affecting reservoir circulation (Miller et al., 1983),
- Hydraulic retention time (the intervening time between when a volume of inflow enters and leaves the lake), and
- Intake depth.

Paulson and Baker (1984) found phosphorus concentrations in Lake Powell to be low, ranging from below the detection limit to about 0.010 mg/L, of which an estimated 10 to 30 percent is biologically available (Evans and Paulson, 1981). These findings are consistent with preliminary results of a 1990-1991 water quality survey conducted in Lake Powell forebay. Additionally, the preliminary results indicated that nitrogen concentrations were also low (less than 0.02 mg/L to over 0.50 mg/L), with nitrate being the primary form of nitrogen, which is beneficial to aquatic productivity.

Concentrations of both nitrogen and phosphorus increased with reservoir depth. Stewart and Blinn (1976) found phosphate concentrations (ortho-phosphate) to be over six times as high in the summer (June through August) as those recorded throughout the remainder of the year. Nitrogen concentrations in the hypolimnion are relatively high (0.30 to 0.40 mg/L of nitrate), averaging about three to five times epilimnetic concentrations (Vernieu, verbal communication, 1991). Silica, an essential nutrient for diatoms and other planktonic organisms, averaged about 8.0 mg/L throughout Lake Powell forebay.

Selectively withdrawing water from the metalimnion or higher, where nutrient concentrations are lower than in the hypolimnion, would leave water with higher nutrient concentrations in the reservoir, and over time, concentrations would tend to increase.

### Productivity

Variables affecting lake primary productivity fall into three main groups :

- Solar energy input variables, such as temperature and light,
- Nutrient supply and relationships to sediments, and
- The shape and form of the reservoir which affect circulation (Miller et al., 1983).

Other influencing factors include hydraulic retention time, or the intervening time between when a volume of inflow enters and leaves the lake, intake depth, and mixing processes within the lake. These variables influence availability of phosphorus.

Several variables influencing primary productivity change throughout the year, such as the amount of solar energy input and forms and strength of circulation patterns, so definite patterns of seasonal algal succession have been observed in Warm Creek Bay (Stewart and Blinn, 1976). In the spring, there was a rapid increase in the diatom population. During the warm summer, a phytoplankton community composed of a variety of species developed. Initiation of reservoir overturn stimulated a late autumn diatom increase, and colder winter temperatures effected a pronounced decline in phytoplankton. Water temperature appeared to be a very important regulator of phytoplankton density in Warm Creek Bay, and concentrations of nitrogen compounds often correlated significantly with both total number of phytoplankton and individual species.

Periphytic organisms, or those that grow on submerged terrestrial vegetation, along the shores of Lake Powell share some of the same influencing factors and variations as planktonic, or floating, communities. Studies have shown that the relative diversities and densities of periphytic organisms indicate that development of the aquatic community in Lake Powell is similar to that of other manmade lakes. Both variations in reservoir level, which redistribute unstable reservoir soils, and the inflow sediment load produce changes in bottom substrate, which in turn influence the type and density of aquatic vegetation and other organisms inhabiting the area (Potter and Louderbough, 1977).

Changes in composition and density patterns of the periphytic organisms in Lake Powell were related to depth and time, as is typical of aquatic communities subject to changing water levels (Potter and Louderbough, 1977). Diatoms near the shore of the reservoir exhibited similar seasonal successions as diatoms of Warm Creek Bay, described above. Diatom diversity appeared to be inversely related to density; diatom density was usually greatest when diversity was lowest.

Chironomid larvae comprised approximately 95 percent of the macroinvertebrates and were the major food source of maturing fish in the lake (Potter and Louderbough, 1977). Population density of Chironomids decreased with depth, possibly a function of temperature and food supply since both temperature and available food decrease with depth.

Selective withdrawals from the metalimnion or epilimnion, the most productive strata, may entrain phytoplankton and zooplankton, reducing reservoir productivity.

### Salinity

Total dissolved solids (TDS) concentrations, or salinity, are also unevenly distributed in Lake Powell. Under normal hydrologic conditions, salinity concentrations near the surface tended to remain high in the vicinity of the dam for most of the year since fresh spring inflows may not reach the dam before fall turnover mixes higher salinity water from lower depths with water in the upper reservoir levels. Exceptions may occur during high spring inflows or extended drought. Typically, spring inflows are low in salinity, and large inflows may reach the dam within two months. Weak winter turnovers, observed during the recent drought, produce limited mixing of deep saline water with less saline above. A zone of increasing salinity concentrations with depth generally develops between the epilimnion and hypolimnion, and below this zone, salinity concentrations vary due to differing inflow characteristics and uneven circulation.

The lower part of the hypolimnion maintains a fairly constant 600 mg/L salinity concentration. Fall turnover, extending to about penstock elevation, brings high salinity water up from the hypolimnion and mixes it with strata above. The degree of mixing between reservoir strata depends on the strength of the turnover. A strong fall turnover blends strata more completely.

Turnover mixing during recent extended low reservoir conditions has been relatively incomplete, so winter reservoir temperature distributions have not been isothermal, and a salinity concentration gradient has persisted. High spring inflows, such as those of 1983, temporarily destratify the reservoir. The amount of destratification depends on the inflow magnitude.

Surface evaporation from Lake Powell removes heat and lowers the overall reservoir temperature. The estimated average net evaporative loss from Lake Powell is 500,000 acre-feet annually (Jacoby et al., 1977), although it is felt that it may be an over-estimate. Reservoir evaporation may be reduced due to lowering of water temperatures during selective withdrawal operations. Evaporation influences reservoir salinity concentrations by removing water and concentrating salts. Past salinity analyses on Lake Powell have tended to overpredict salinity, perhaps due to over-estimating evaporation.

High salinity concentrations reduce the suitability of water for drinking, irrigation, municipal, and industrial purposes. Irrigation in the Colorado River Basin has increased salinity concentrations in the river, and by 1970, salinity had become a major concern in the basin. The Colorado River Basin Salinity Control Act of 1974 (CRBSC Act) was implemented in response to amendments to the Federal Water Pollution Control Act of 1972 (FWPCA, 1972), requiring establishment of instream standards for water quality. The Colorado River Basin states set salinity standards at 1972 average concentrations, establishing a nondegradation policy for the Colorado River (Moody and Mueller, 1984).

Reservoirs are recognized as important features in meeting CRBSC Act objectives. Unregulated streams exhibit a relationship between magnitude of flow and salinity concentrations, but reservoirs allow inflow mixing, so regulated outflow from reservoirs and salinity concentration no longer exhibit the same relationship as the inflow. Annual predam salinity concentration ranges observed at downstream gauging stations have narrowed, and the total annual input, or load, downstream has been reduced. A reduction in downstream salinity loads, without concurrent load reductions upstream of the dam, indicates that Lake Powell retains part of the salinity load. Salinity budget studies show that reservoirs are effective in salinity control, but the estimated level of effectiveness is not reliable because of loss of salts by precipitation and degree of model accuracy.

Since salinity concentrations increase with depth in Lake Powell, selectively withdrawing water from the metalimnion or higher would remove lower salinity water, and leave higher salinity water in the reservoir. Over time, salinity concentrations in Lake Powell would tend to increase. However, a reduction in reservoir evaporation may consequently reduce the amount of salinity increase. Consequently, more variability in salinity concentrations may be observed.

### *Sediment Chemistry*

A baseline water quality study conducted for Lake Powell included an analysis of tributary delta sediments and surface and bottom waters for lead, mercury, and selenium among other constituents (Potter and Drake, 1989). Results indicated that Lake Powell acts as a trap for most of the elements investigated, except lead. More dissolved lead left the reservoir than came in, and this was attributed to input from recreational boating and gas spills in Lake Powell (Potter and Drake, 1989). Based on limited data collected, the results indicated that mercury and selenium, both naturally occurring in the Colorado River basin, were at higher concentrations in lake sediments than combined concentrations from tributary sediments. Both mercury and selenium accumulate in tissues of living organism (Wood and Kimball, 1987).

In 1988, reservoir bottom material was collected at three sites—near Hite, Utah; in Zahn Bay (San Juan Arm); and near Glen Canyon Dam—and analyzed only for various metals, for the purpose providing some insight into sources and distributions of metals in Lake Powell. Provisional results indicate general concentration reductions in the downstream direction of Lake Powell, perhaps partly due to sediments with attached metals settling out in the deltas. In cases where concentrations increased from upstream to downstream, the San Juan River may have been the source. Zahn Bay bottom materials, for instance, had elevated concentrations over those upstream at Hite, indicating probable contributions from the San Juan River.

Withdrawals from nearer the reservoir surface during selective withdrawal operations would entrain water with higher lead concentrations, but lower selenium and mercury concentrations. Resultingly, downstream concentrations of lead would increase, and selenium and mercury would decrease. Lake Powell selenium and mercury concentrations would tend to increase, but lead concentrations may decrease.

Preliminary 1990 and 1991 water quality survey results indicated that many of the remaining element concentrations were within National Interim Primary Drinking Water Regulations (EPA-570/9-76-003). Lake Powell is a drinking water source for the city of Page, Arizona, and for Hite Marina at the upper end of the reservoir. Neither the city of Page nor the marina discharges wastewater into Lake Powell. Other marinas and area water users obtain water from ground-water wells. The cooling water supply for Navajo Powerplant is also from Lake Powell, and the cooling water is recycled and discharged to holding ponds, but not returned to the reservoir.

## Water Quality below Glen Canyon Dam

Lake Powell has had a major influence on water quality below Glen Canyon Dam. Release water quality is dependent on the reservoir strata (hypolimnion, metalimnion, or epilimnion) from which water is withdrawn, which in turn is contingent on two factors:

- level of the intakes and
- reservoir elevation.

The elevation of the intakes is fixed at 3470 feet, which has been within the hypolimnion, the strata with nearly constant temperature and chemical characteristics. Selective withdrawal facilities at Glen Canyon Dam would extend withdrawals from the hypolimnion, up into the metalimnion and epilimnion, where water differs in temperature and other water quality characteristics.

Reservoir elevation influences release water quality particularly when Lake Powell is drawn down below 3590 feet; large areas of delta sediments are exposed, and the metalimnion and epilimnion descend toward the intakes. Changes in release water quality that may potentially arise stem from resuspension of sediments and withdrawing water from different reservoir strata, and are discussed above.

In general, regulated releases have reduced the range of downstream riverflow, turbidity, temperature, salinity, and other water quality parameters. Figure III-5 (chapter III, WATER) illustrates changes in riverflow since regulation at Glen Canyon Dam. River temperatures below the damsite varied with seasons and ranged from 32 to 82 °F (Carothers and Minckley, 1981). Today, releases from Glen Canyon Dam range between 43 and 54 °F, and average about 46 °F. River temperatures at Lees Ferry, about 15 miles downstream, vary only about 6 °F throughout the year.

### *River Temperatures*

River temperature surveys conducted in 1978 below Glen Canyon Dam (Brickler and Tunnicliff, 1980) showed downstream temperature as a function of:

- Reservoir temperature in strata (hypolimnion, metalimnion, or epilimnion) where water is withdrawn,
- River water level, which depends on discharge magnitude, and
- Distance downstream from the dam.

Since construction of the dam, river temperatures increase gradually with distance downstream at an approximate rate of 2 °F per 35 miles during the months of July and August. The greatest amount of instream warming occurs from June through August. Provisional data collected in 1990 showed that the average downstream temperature is about 55 °F, and actual river temperatures deviate very little from the average (Sartoris, 1990). Temperature of the river at Lees Ferry is inversely related to Lake Powell water surface elevations; the lower the reservoir, the warmer the releases (Lechleitner, written communication, 1991). River temperatures at Diamond Creek, about 240 miles below the dam, are seldom higher than 60 °F.

Warmer releases due to selective withdrawal operations during late spring and summer would increase river temperatures below the dam. Warmer river temperatures may benefit some life stage of both native and non-native fish. As warm releases continue to warm as they flow downstream, a section of river may become sufficiently warm to induce spawning in native fish species, and promote survival of young. Although warmer instream temperatures may stimulate productivity, individual species' limits and tolerances to temperature change are not completely known. Increased temperatures in the river and in Lake Mead may increase evaporation rates.

### *Salinity*

Salinity concentrations in Colorado River in the area of Lake Powell prior to the dam ranged from over 300 mg/L in the summer to approximately 1200 mg/L in the fall, but the average was about 600 mg/L (Johnson and Merritt, 1979). Lake Powell has had a dampening effect on concentration variations below the dam. Salinity concentrations in the river since Lake Powell filled in 1980 have ranged between 492 and 645 mg/L (Liebermann et al., 1989), but the average has remained nearly the same as prior to the dam, approximately 600 mg/L. Mean river salinity concentrations exhibit an increasing trend downstream, due primarily to tributary input (Sartoris, 1990). Historically, salinity has been relatively high in the Colorado River, and the U.S. Public Health Drinking Water Standard (1962) of 500 mg/L has been exceeded occasionally.

Salinity concentrations of water selectively withdrawn from the metalimnion or higher in Lake Powell may be lower than withdrawals from the hypolimnion, and consequently, downstream salinity concentrations may be reduced.

### Dissolved Oxygen

Dissolved oxygen concentrations below Glen Canyon Dam range from approximately 6 mg/L in the winter to 9 mg/L in the summer. Concentrations generally increase slightly with distance downstream, depending on the season. Releases from the dam that may be low in DO are reaerated and typically reach near-saturation concentrations by Lees Ferry.

Selective withdrawal operations would generally withdraw water of greater dissolved oxygen content from the metalimnion or above, although the DO minimum layer that develops occasionally in the metalimnion may be intercepted.

### Nutrients

Releases from Glen Canyon Dam are relatively clear and low in nutrient content, particularly phosphorus, due to retention of nutrient-rich sediment in Lake Powell, as discussed earlier (Paulson and Baker, 1980). Although nutrient concentrations are low, sunlight reaches deeper in clear water and enhances productivity. Studies have shown that nutrients (nitrogen and phosphorus) exhibited different downstream trends. Nitrogen (nitrate-nitrogen) concentrations ranged between 0.32 and 0.35 mg/L with no apparent downstream trend. Phosphorus, both soluble reactive and total phosphorus, concentrations increased with downstream distance and ranged between about 0.01 and 0.17 mg/L and 0.02 and 0.29 mg/L, respectively (Maddux et al., 1988).

Nutrient concentration of releases may be reduced during selective withdrawal operations when water is withdrawn from the upper reservoir strata, which would decrease downstream nutrient concentrations. Lower nutrient concentrations in the river may decrease productivity, yet increased river temperatures may lessen nutrient-related reductions in productivity.

### Metals and Trace Elements

Preliminary studies (Hart and Sherman, 1992) have shown that concentrations of lead and selenium in the Colorado River below the dam tend to increase in the summer and with distance downstream. Mercury concentrations in the mainstem do not appear to change significantly with distance downstream.

Selective withdrawals from the reservoir metalimnion and epilimnion may have higher lead concentrations, but lower selenium and mercury concentrations, so releases will exhibit similar concentrations trends.

## Water Quality of Downstream Tributaries to the Colorado River

Colorado River tributaries below Glen Canyon Dam vary considerably among each other in water quality, each reflecting the chemical composition of its watershed (Brickler and Tunnicliff, 1980). Downstream tributaries flow mainly during spring and summer, contributing sediment and nutrients to the river system. The majority of the tributaries with appreciable streamflows have lower salinity concentrations than the mainstem. Tributaries with only intermittent streamflow, or pools, have high salinity concentrations, possibly due to high evaporation rates in the pools, or inflow from saline springs. Tributary temperatures are generally warmer in the summer and colder in the winter than those of the Colorado River mainstem, depending on discharge, and exhibit seasonal temperature trends, ranging from near freezing to about 79 °F (Sartoris, 1990). Dissolved oxygen concentrations in the tributaries differ little from the Colorado River mainstem below Lees Ferry (Sartoris, 1990). Nutrient concentrations, particularly nitrogen (nitrate-nitrogen) and phosphorus (ortho-phosphorus) are generally low in the tributaries, but concentrations are not atypical of those found elsewhere in the Colorado River corridor (Brickler and Tunnicliff, 1980).

Nutrient concentrations are generally low in the side creeks, although somewhat higher than in the mainstem. Natural sources of nutrients accumulate in some watersheds over the winter and are flushed out by high spring runoff, creating short-term high concentrations.

Selective withdrawal operations at Glen Canyon Dam will not affect tributaries to the Colorado River below the dam.

## Summary

Potential effects of selective withdrawal operations at Glen Canyon Dam to water quality and aquatic ecology in Lake Powell, the Colorado River below the dam, and Lake Mead were briefly described throughout this appendix; however, further investigations are required to verify the feasibility and potential success of selective withdrawal at Glen Canyon Dam, and determine corollary and secondary effects of such operations on reservoir and river limnology. Identified analyses and research areas may fall into one of five categories:

- River temperature ranges suitable to the life stages of the humpback chub
- Possible release temperatures from Lake Powell
- Potential downstream warming rates
- Structural feasibility—Can a suitable facility be built for Glen Canyon Dam?
- Potential effects of selective withdrawal operations

The identified analyses and research are summarized under each of the five categories below.

A. River temperature ranges suitable to the life stages of the humpback chub

Identify the thermal requirements and tolerances per life stage of native fish, particularly the humpback chub.

B. Possible release temperatures from Lake Powell

Estimate release temperatures from Glen Canyon Dam with selective withdrawal capabilities.

C. Potential downstream warming rates

Estimate the increase in river temperature with distance downstream during selective withdrawal operations.

D. Structural feasibility—Can a suitable facility be built for Glen Canyon Dam?

Determine what type of facility may best accomplish release temperature objectives at Glen Canyon Dam.

E. Potential effects of selective withdrawal operations

Selective withdrawal operations at Glen Canyon Dam may effect the water quality and aquatic biology of Lake Powell, the Colorado River below the dam, and Lake Mead.

Impacts to Lake Powell may include changes in reservoir:

- Heat budget (temperature),
- Water budget,
- Nutrient budget,
- Salinity budget,
- Dissolved oxygen content,
- Sport fisheries,
- Spatial variability, and
- Primary and secondary productivity.

Potential downstream impact issues are similar to those in Lake Powell, but generally are opposite in effect, and include:

- Increased river temperature,
- Decrease in nutrient input,
- Decrease in salinity input,
- Change in dissolved oxygen content below the dam,
- Non-native fisheries, including trout and upstream migration of species from lower in the river and Lake Mead,
- Primary and secondary productivity, inclusive Cladophora, diatoms, Oscillatoria, Gammarus, and aquatic insects.

Changes due to selective withdrawal operations at Glen Canyon Dam may also be observed in Lake Mead, and include:

- Increased inflow temperature,
- Decrease in nutrient input,
- Decrease in salinity input,
- Upstream migration of non-native fisheries, and
- Primary and secondary productivity.

Appendix D

# *Sediment*

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# SEDIMENT HIGHLIGHTS

*Riverbed Sand*

**Annual sand supply and the Colorado River's capacity to transport sand have been greatly reduced since closure of Glen Canyon Dam**

**Sand loss from the Glen Canyon reach is irreversible**

**Sand stored upstream of the Little Colorado River decreased during 1966-89; downstream it increased**

**As riverflow increases, the river's capacity to transport sand increases exponentially**

**The amount of sand stored in the river increases as flow fluctuations decrease**

**About 70 percent of the postdam sand load in the Colorado River is delivered by the Paria and Little Colorado Rivers**

**Floodflows have a tremendous capacity to transport sand and, if they occur too frequently, can upset the long-term sand balance**

*Sandbars*

**Sandbars (beaches) are dependent on sand stored within the river**

**Nearly all sandbars are associated with eddies**

**Cycles of sandbar deposition and erosion are a natural process**

**Eroded sandbars are likely to rebuild during periiods of higher flows**

**Fluctuating flows build higher sandbars than steady flows, but the higher bars are less stable**

**Rapidly falling river stage is the primary cause of sandbar erosion from fluctuating flows; the greater the range in stage change, the greater the erosion potential**

**Sandbar erosion has not been linked to up ramp rates**

**Backwaters form within a small range of flows and have little or no velocity**

**Deposition of silt and clay, important for establishment of riparian marshes, depends mainly on tributary floods and river level**

### *High Terraces*

High terraces were deposited in wide reaches of Grand Canyon by large sediment-laden floods over the last 2,000 years

Many high terraces contain buried archaeological remains which may be exposed or destroyed by erosion

Arroyos cause substantial erosion of many high terraces; a few terraces also are susceptible to erosion by floods

Erosion of high terraces will continue regardless of dam operations

### *Debris Fans and Rapids*

Debris fans and rapids create sand-storage areas along the Colorado River

Debris flows from side canyons are independent of dam operations

The river channel becomes narrower and steeper at rapids as new debris flows aggrade debris fans

River flows much greater than powerplant capacity are needed to remove boulders and maintain channel width and slope at major rapids

### *Lake Deltas*

Deltas have formed in tributary mouths by sediment trapped in Lakes Powell and Mead

The sizes of deltas in Lake Powell are independent of dam operations

Growth of the Colorado River delta in Lake Mead has slowed since closure of Glen Canyon Dam

Where the river is affected by Lake Mead, sediment deposits exposed along the channel margins have steep banks that are easily eroded.

When the lake level is low, exposed deltas become substrate for riparian vegetation, and navigation becomes more difficult

# RIVERBED SAND

- Methods used to analyze riverbed sand
- Figure D-1—Typical profile of the Colorado River in Grand Canyon
- Table D-1—Summary of tributary sand supply to the Colorado River
- Table D-2—Computed sand loads for steady and fluctuating releases of the same volume
- Table D-3—Sand transport capacity of the Colorado River between Lees Ferry and the Little Colorado River, for a low, moderate, and high release year, by alternative

## Methods Used To Analyze Riverbed Sand

This discussion was drawn from Randle, Strand, and Streifel (1993). It describes the methods and assumptions used in the analysis of riverbed sand in chapter IV, SEDIMENT.

Future changes in the quantity of riverbed sand storage depend on tributary sand supply and the daily and seasonal operation of Glen Canyon Dam. A sand mass-balance model was developed to estimate the impacts to riverbed sand from various operating criteria at Glen Canyon Dam. This model uses the following basic equation:

*Riverbed sand change = Tributary sand supply*
*+ Upstream reach sand supply*
*- Downstream sand load*

This equation was used to compute net changes in riverbed sand storage for two reaches of the Colorado River between the USGS gauging stations at Lees Ferry (RM 0), above the LCR (RM 61), and near Phantom Ranch (RM 87). Changes in sand mass may occur locally at sandbars, eddies, or main channel pools, and changes would not necessarily be uniform throughout the reach. Historic changes were computed for the period 1965-89 for both reaches. Changes over a future 20- and 50-year period were computed for the reach between Lees Ferry and the LCR for each alternative.

The Paria and Little Colorado Rivers were assumed to be the only sources of sand. The future patterns of tributary sand supply were assumed to be the same as historical estimates for the period 1941-90. These sand loads were computed from the mean daily flows and the sand-load discharge rating curves developed by Randle and Pemberton (1987).

Contributions of sand to the Colorado River between the dam and the Paria River at Lees Ferry were assumed to be zero, since that reach has no substantial source of sand. Ungauged tributaries downstream from the Paria can supply large amounts of sediment during flash floods and debris flows; however, these are relatively infrequent events, and no general models exist to predict their occurrence. Therefore, sand contributions from ungauged tributaries also were assumed to be zero. (R.H. Webb and T.S. Melis, U.S. Geological Survey, are studying side canyon floods and debris flows, including sand contribution, as part of the Glen Canyon Environmental Studies.)

Colorado River sand loads were computed using the sand-discharge equations developed by Pemberton (1987) and estimates of future monthly release volumes. The original equations developed by Pemberton were adjusted for each fluctuating flow alternative to account for the variations in hourly releases. Future hourly release patterns were projected by S. Rosekrans (Environmental Defense Fund) using the Environmental Defense Fund's peak-shaving model (see chapter IV, WATER). For each alternative, a relationship between sand transport and monthly release volume was developed by computing sand transport for each hour of the month and then performing a regression analysis between the computed monthly sand transport and monthly release volumes.

Future water-release scenarios (50 years of monthly release volumes) were computed by C. Phillips (Bureau of Reclamation) using the Colorado River Simulation Model discussed in chapter IV, WATER. For each operational alternative, 85 water release scenarios were developed using natural flow data for 1906-90. Existing levels of the Upper Colorado Basin reservoirs were used for the initial conditions for all scenarios. The 85 scenarios included all wet and dry cycles of the historic record; the sequence of annual data was not altered, but the relative position of a given year was different in each scenario.

Sand loads computed from each water-release scenario were matched with the historical sand loads from the Paria and Little Colorado Rivers (1941-90), as demonstrated by Smillie, Jackson, and Tucker (1993), to estimate changes in riverbed sand over the next 20 and 50 years for a given alternative. Cumulative frequency curves were prepared using the 85 computed net changes in riverbed sand storage at the end of the 20- and 50-year periods for each alternative. Each scenario was assumed to have an equal chance of occurring. The frequencies of a net gain in riverbed sand at the end of the 20- and 50-year periods are used in chapter IV, SEDIMENT, as the probabilities of having a net gain in riverbed sand.

The relationship between sand load and discharge over time was assumed to be constant. This would tend to overestimate either long-term deposition or erosion. Downstream transformation of discharge waves from fluctuating releases were not accounted for, because calibrated models to reliably predict this were not available (J.D. Smith and S.M. Wiele, U.S. Geological Survey, are developing such a model under the Glen Canyon Environmental Studies). Therefore, computed sand loads are somewhat overestimated, and riverbed sand storage is somewhat underestimated under high fluctuating flows, such as the No Action, Maximum Powerplant Capacity, and High Fluctuating Flow Alternatives.

The sand mass balance model could be improved by developing more accurate methods to predict sand transport and also by using synthetic hydrographs to estimate future flow conditions.

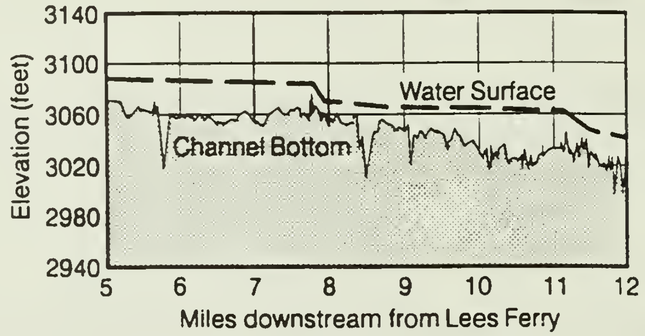



*Figure D-1.—Typical profile of the Colorado River in Grand Canyon. Changes in the water-surface profile are evident where the channel bottom is aggraded by debris flows at Badger Creek Rapid (RM8) and Soap Creek Rapid (RM11).*

Table D-1.—Summary of tributary sand supply to the Colorado River [Modified from Randle and Pemberton (1987); shown graphically in chapter III, SEDIMENT]

| | | Average annual sand supply (thousands of tons) | |
|---|---|---|---|
| Reach | River mile | Gauged tributaries | Ungauged tributaries[1] |
| Glen Canyon Dam to Lees Ferry | -16 to 0 | -- | 38.6 |
| Lees Ferry to Little Colorado River | 0 to 61 | 785[2] | 150 |
| Little Colorado River to Phantom Ranch | 61 to 87 | 1,610[3] | 35.6 |
| Phantom Ranch to National Canyon | 87 to 166 | 318[4] | 316 |
| National Canyon to Diamond Creek | 166 to 225 | -- | 183 |
| Totals | | 2,713 | 723.2 |

[1] Estimated on basis of drainage area
[2] Paria River, 1941-90
[3] Little Colorado River, 1948-89
[4] Kanab Creek, 1964-80

Table D-2.—Computed sand loads in the Colorado River for steady and fluctuating releases of the same volume

| Flow type | At Lees Ferry (tons/day) | Above the Little Colorado River (tons/day) | At Phantom Ranch (tons/day) |
|---|---|---|---|
| Steady flow (15,700 cfs) | 200 | 1,500 | 3,100 |
| Fluctuating flow (3,600 to 23,700 cfs) | 340 | 2,500 | 5,100 |
| Percent increase (from steady to fluctuating flow) | 70 | 67 | 65 |
| Percent decrease (from fluctuating to steady flow) | 41 | 40 | 39 |

Table D-3—Sand transport capacity of the Colorado River between Lees Ferry and the Little Colorado River, for a low, moderate, and high release year, by alternative. Probability of net gain in sand storage is computed using the record of sand delivery from the Paria River. [HMF, habitat-maintenance flow]

| Year | Dam release (maf) | Sand transport capacity (1,000 tons) | Probability of net gain in sand storage (percent) |
|---|---|---|---|
| **NO ACTION** | | | |
| 1989 | 8.2 | 481 | 53 |
| 1987 | 13.6 | 1,595 | 15 |
| 1984 | 21.1 | 5,042 | <1 |
| **MAXIMUM POWERPLANT CAPACITY** | | | |
| 1989 | 8.2 | 492 | 51 |
| 1987 | 13.6 | 1,641 | 14 |
| 1984 | 21.1 | 5,106 | <1 |
| **HIGH FLUCTUATING FLOW** | | | |
| 1989 | 8.2 | 423 | 58 |
| 1987 | 13.6 | 1,546 | 15 |
| 1984 | 21.1 | 5,041 | <1 |
| **MODERATE FLUCTUATING FLOW** | | | |
| 1989 (w/o HMF) | 8.2 | 278 | 73 |
| 1989 (w/HMF) | 8.2 | 397 | 63 |
| 1987 | 13.6 | 1,325 | 17 |
| 1984 | 21.1 | 4,884 | <1 |
| **MODIFIED AND INTERIM LOW FLUCTUATING FLOW [1]** | | | |
| 1989 (w/o HMF) | 8.2 | 266 | 76 |
| 1989 (w/HMF) | 8.2 | 386 | 64 |
| 1987 | 13.6 | 1,312 | 17 |
| 1984 | 21.1 | 4,879 | <1 |
| **EXISTING MONTHLY VOLUME STEADY FLOW** | | | |
| 1989 | 8.2 | 218 | 80 |
| 1987 | 13.6 | 1,231 | 17 |
| 1984 | 21.1 | 4,823 | <1 |
| **SEASONALLY ADJUSTED STEADY FLOW** | | | |
| 1989 (w/o HMF) | 8.2 | 264 | 73 |
| 1989 (w/HMF) | 8.2 | 388 | 64 |
| 1987 | 13.6 | 1,040 | 19 |
| 1984 | 21.1 | 5,018 | <1 |
| **YEAR-ROUND STEADY FLOW** | | | |
| 1989 | 8.2 | 196 | 82 |
| 1987 | 13.6 | 1,051 | 19 |
| 1984 | 21.1 | 5,015 | <1 |

[1] Interim Low Fluctuating Flow Alternative has no HMF; otherwise same.

# SANDBARS (BEACHES AND BACKWATERS)

- Empirical results from research flows
- Table D-4—Hydraulic characteristics of geologic reaches
- Figure D-2—Comparison of sandbar change during the last century
- Figure D-3—Downstream increase in minimum discharge for alternatives with fluctuating flows
- Table D-5—Range in river stage at the two USGS gauging stations in reach 0 (Glen Canyon), by alternative
- Table D-6—Differences in potential sandbar heights from no action, by alternative, for a minimum release year
- Tables of reach-averaged range in river stage and reach-averaged active sandbar widths in reaches 1 through 11, by alternative

## Empirical Results from Research Flows

Special research flows and data-collection programs were conducted from June 1990 through July 1991 as part of the Glen Canyon Environmental Studies (GCES). The research flows included a variety of both steady and fluctuating releases, lasting a minimum of 11 days and preceded by 3 days of 5,000 cfs steady flow. Some of the fluctuating flows were uniform (same daily pattern), and some varied in response to changes to electrical load (normal releases). The following information is summarized from preliminary results of the GCES Sand Bar Stability Team (Beus and Avery, written communication, 1992). Component studies were described by Beus, Avery, and Cluer (1991); Budhu and Contractor (1991); Carpenter, Carruth, and Cluer (1991); Cluer (1991); Stevens, Schmidt, and Brown (1991); and Werrell, Inglis, and Martin (1991).

Sandbars were observed to be more dynamic downstream from the LCR. Many sandbars underwent cycles of substantial deposition and substantial erosion, with little net change. Main-current erosion dominated over seepage-induced erosion during high flows and high flow fluctuations. Reattachment bars were more susceptible to erosion than separation bars.

Sandbar volume changes were measured at 29 sites over the course of 16 different research flows. The changes were measured in the hydrologically active zone—the part of the sandbar between river stages corresponding to 5,000 and 31,500 cfs. The findings are:

- 3 sandbars had eroded
- 11 sandbars remained relatively unchanged
- 15 sandbars had aggraded

Overall, measured sandbar volumes increased by an average of 2.9 percent between October 27, 1990 and July 31, 1991. The total sand volume for all 29 sites decreased by 1.2 percent, because of substantial erosion at a few sites.

Steady and low fluctuating flows resulted either in net erosion or negligible change. Three of the five high uniform fluctuating flows resulted in systemwide deposition, and the other two resulted in systemwide erosion.

Fall and winter flows during 1990-91 generally were erosive, whereas some spring and summer flows were depositional. Recreation intensity did not appear to be correlated with sandbar erosion or deposition. Periods of deposition usually were followed by erosion, particularly when high fluctuating flows were followed by low fluctuating flows or steady flows.

Cycles of gradual deposition and rapid erosion were documented by daily photographs at five of the six sandbars equipped with automatic cameras (Cluer, written communication, 1992). Most of the sandbars rebuilt to nearly the same area or larger, following the return to high fluctuating flows. One deposit, however, eroded rapidly during December 1990 and remained greatly reduced in size throughout the remainder of the study. When low fluctuating releases followed erosion events, little deposition occurred.

Table D-4.—Hydraulic characteristics of geologic reaches.

| Reach No.[1] | River miles | Reach name | Width type |
|---|---|---|---|
| 1 | 0-11 | Permian Section | Wide |
| 2 | 11-22 | Supai Gorge | Narrow |
| 3 | 22-36 | Redwall Gorge | Narrow |
| 4 | 36-61 | Lower Marble Canyon | Wide |
| 5 | 61-77 | Furnace Flats | Wide |
| 6 | 77-118 | Upper Granite Gorge | Narrow |
| 7 | 118-126 | Aisles | Narrow |
| 8 | 126-140 | Middle Granite Gorge | Narrow |
| 9 | 140-160 | Muav Gorge | Narrow |
| 10 | 160-214 | Lower Canyon | Wide |
| 11 | 214-235 | Lower Granite Gorge | Narrow |

[1] See map in chapter III, SEDIMENT.

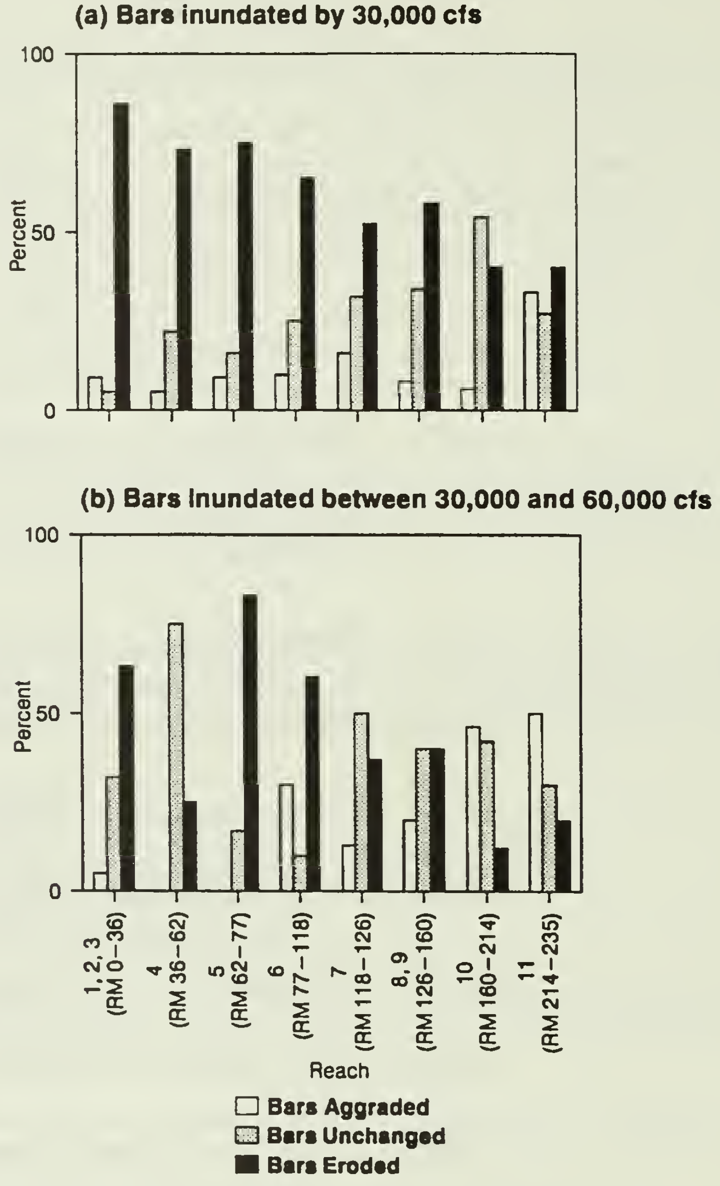



*Figure D-2.—Comparison of sandbar change by reach during the last century, for (a) low-elevation sandbars, and (b) high-elevation sandbars. Reaches are described in table D-4. Upstream from RM118 (reaches 1-6), more sandbars (both high-elevation and low-elevation) have eroded than have aggraded or remained unchanged. Between RM0 and RM36, 86 percent of low-elevation sandbars have eroded; downstream from RM118 (reaches 7-11), more sandbars have aggraded or remained unchanged. These conclusions are based on comparison of photographs taken 100 years apart and do not account for short-term changes in sandbars. (After Webb, written communication, 1992.)*

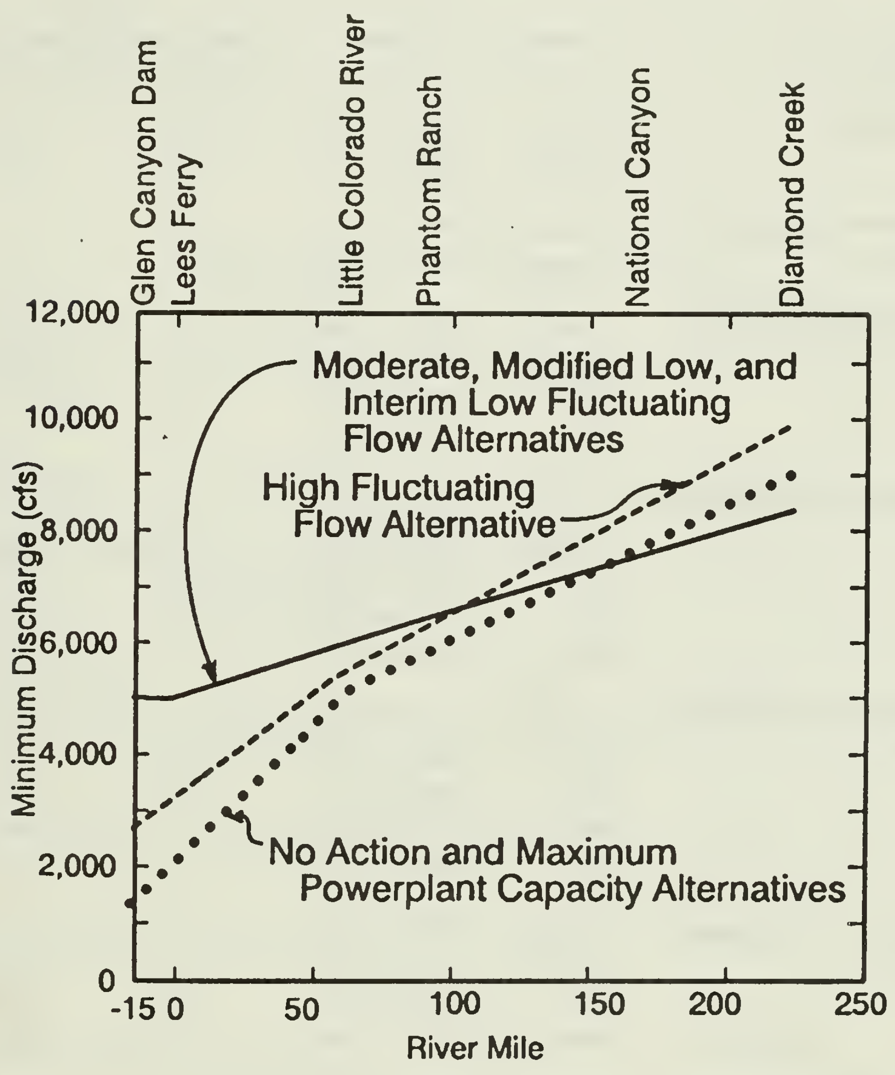



*Figure D-3.—Downstream increase in minimum discharge for alternatives with fluctuating flows. Not adjusted for tributary inflows. Rate of increase generally is greater for lower initial minimum releases, but also depends on the range in fluctuations (see Downstream Transformation of Fluctuating Releases in appendix B, Water).*

Table D-5.—Range in river stage at the two USGS gauging stations in reach 0 (Glen Canyon), by alternative [Source: USGS rating tables; BBF, beach/habitat-building flow; HMF, habitat-maintenance flow]

| Alternative | Release type | Range in discharge (cfs) | Difference in stage (ft) Below dam (RM -14.5) | Difference in stage (ft) At Lees Ferry (RM 0) |
|---|---|---|---|---|
| **No Action** | Daily | 1,000-24,000 | 9.2 | 6.5 |
| | Annual | 1,000-31,500 | 11.0 | 7.5 |
| **Maximum Powerplant Capacity** | Daily | 1,000-24,000 | 9.2 | 6.5 |
| | Annual | 1,000-33,200 | 13.1 | 7.7 |
| **High Fluctuating Flow** | Daily | 3,000-23,000 | 7.6 | 4.9 |
| | Annual | 3,000-31,500 | 9.7 | 6.1 |
| | BBF | 31,500-41,500 | 3.9 | 1.1 |
| | BBF | 31,500-45,000 | 4.8 | 1.5 |
| **Moderate Fluctuating Flow** | Daily | 5,000-13,200 | 3.5 | 2.3 |
| | Annual | 5,000-22,300 | 6.3 | 3.9 |
| | HMF | 5,000-30,000 | 8.3 | 5.0 |
| | BBF | 22,300-40,000 | 6.0 | 2.2 |
| | BBF | 22,300-45,000 | 7.1 | 2.8 |
| **Modified Low Fluctuating Flow** | Daily | 5,000-10,000 | 2.3 | 1.5 |
| | Annual | 5,000-20,000 | 5.7 | 3.5 |
| | HMF | 5,000-30,000 | 8.3 | 5.0 |
| | BBF | 20,000-40,000 | 6.7 | 2.5 |
| | BBF | 20,000-45,000 | 7.8 | 3.1 |
| **Interim Low Fluctuating Flow** | Daily | 5,000-10,000 | 2.3 | 1.5 |
| | Annual | 5,000-20,000 | 5.7 | 3.5 |
| | BBF | 20,000-30,000 | 2.6 | 1.4 |
| | BBF | 20,000-45,000 | 7.8 | 3.1 |
| **Existing Monthly Volume Steady Flow** | Annual | 9,200-16,300 | 2.6 | 1.6 |
| | BBF | 16,300-26,300 | 2.8 | 1.6 |
| | BBF | 16,300-45,000 | 8.9 | 3.8 |
| **Seasonally Adjusted Steady Flow** | Annual | 8,000-18,000 | 3.6 | 2.2 |
| | HMF | 8,000-30,000 | 6.8 | 4.0 |
| | BBF | 18,000-40,000 | 7.3 | 2.9 |
| | BBF | 18,000-45,000 | 8.4 | 3.5 |
| **Year-Round Steady Flow** | Annual | 10,900-11,900 | 0.4 | 0.2 |
| | BBF | 11,900-21,900 | 3.2 | 1.8 |
| | BBF | 11,900-45,000 | 10.4 | 4.7 |

Table D-6—Differences in potential sandbar heights from no action (NA), by alternative, for a minimum release year (8.23 maf). Values are ranges for 11 reaches, from tables of reach-averaged change in river stage, p. D-17 through D-26)

[BBF, beach/habitat-building flows; NA, no action; HMF, habitat-maintenance flows]

| Alternative | Without BBF (difference from NA) | With beach/habitat-building flows | | 45,000 cfs BBF (difference from NA) |
|---|---|---|---|---|
| | | Discharge (cfs) | Difference from NA | |
| **Maximum Powerplant Capacity** | 0-1 ft higher | — | — | — |
| **High Fluctuating Flow** | same as NA | 41,500 | 3-4 ft higher | 4-5 ft higher |
| **Moderate Fluctuating Flow** | 0-1 ft lower (3-4 ft lower w/o HMF) | 40,000 | 3-4 ft higher | ↓ |
| **Modified Low Fluctuating Flow** | 0-1 ft lower (4-6 ft lower w/o HMF) | 40,000 | 3-4 ft higher | ↓ |
| **Interim Low Fluctuating Flow** | 4-6 ft lower | 30,000 | 0-1 ft lower | ↓ |
| **Existing Monthly Volume Steady Flow** | 5-8 ft lower | 26,300 | 1-3 ft lower | ↓ |
| **Seasonally Adjusted Steady Flow** | 0-1 ft lower (5-7 ft lower w/o HMF) | 40,000 | 3-4 ft higher | ↓ |
| **Year-Round Steady Flow** | 6-11 ft lower | 21,900 | 3-5 ft lower | ↓ |

**Tables of reach-averaged range in river stage and reach-averaged active sandbar widths in reaches 1 through 11, by alternative (p. D-18 through D-26). Values are listed for daily and annual ranges in flow, habitat-maintenance flows, and selected beach/habitat-building flows, for a minimum release year (8.23 maf).**

Information from these tables is used in chapter IV to summarize impacts of alternatives on sediment, fish, and vegetation. The sandbar area between river stages corresponding to the maximum and minimum flows is referred to in chapters III and IV as the hydrologically active zone or fluctuating zone. Sand within this zone is considered to be unstable.

The 11 reaches are described in table D-4 (p. D-12). Local minimum flows, obtained from research flows, are shown in figure D-3 (p. D-14). Range in stage was calculated by extension of the model of Randle and Pemberton (1987), as discussed in chapter IV, SEDIMENT. Active width of sandbar was calculated using range in river stage and a barface slope of 11°, as suggested by Budhu (written communication, 1992; see chapters III and IV, SEDIMENT).

Local maximum flows, habitat-maintenance flows, and beach/habitat-building flows were not adjusted for inflows from tributaries and springs. Inspection of hydrographs for a variety of research flows suggests that, in the absence of side canyon floods, normal downstream decrease in maximum flow is approximately offset by normal gains from inflows from tributaries and springs (see Downstream Transformation of Fluctuating Releases, appendix B, Hydrology). Although the decrease in maximum flow caused by wave transformation rarely is identical to the increase caused by inflows, this assumption is believed to be valid for comparing the relative differences between alternatives.

Steady flows, which are not affected by wave translation, also were not adjusted locally for inflows from tributaries and springs. It was assumed that such increases apply equally to both the minimum and the maximum flows indicated in the tables and, therefore, the differences in river stage are essentially the same with or without the flow increases.

In order to calculate differences in potential sandbar height (i.e., differences in river stage) for comparing alternatives by specific reaches, a common local base discharge is needed. Values for a local flow of 5,000 cfs are listed in the tables for habitat-maintenance and beach/habitat-building flows. A summary of the differences, by alternative, is given in table D-6, p. D-16.

## NO ACTION ALTERNATIVE

Reach-averaged range in stage and active sandbar width

*Normal operations—minimum release year (8.23 maf)*

| | | Daily discharge range (1,000 to 24,000 cfs at dam) | | | Annual discharge range (1,000 to 31,500 cfs at dam) | | |
|---|---|---|---|---|---|---|---|
| Reach | Local minimum flow [1] (cfs) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) |
| 1 | 2,400 | 11 | 51 | 9 | 14 | 65 | 12 |
| 2 | 2,900 | 12 | 58 | 10 | 15 | 74 | 14 |
| 3 | 3,600 | 11 | 54 | 10 | 14 | 68 | 13 |
| 4 | 4,500 | 9 | 40 | 8 | 11 | 52 | 11 |
| 5 | 5,400 | 7 | 32 | 7 | 10 | 44 | 10 |
| 6 | 6,100 | 11 | 54 | 12 | 15 | 72 | 16 |
| 7 | 6,700 | 10 | 47 | 12 | 13 | 63 | 15 |
| 8 | 7,000 | 9 | 41 | 11 | 12 | 57 | 14 |
| 9 | 7,300 | 10 | 48 | 12 | 14 | 65 | 16 |
| 10 | 8,200 | 9 | 42 | 12 | 12 | 59 | 15 |
| 11 | 9,000 | 9 | 39 | 12 | 12 | 55 | 15 |

[1] Increase in minimum flow estimated on the basis of hydrographs of normal fluctuating flows of March 12, 1991. Range of fluctuations was 1,300-18,500 cfs. Inflow from streams and springs between Glen Canyon Dam and RM225 not estimated.

## MAXIMUM POWERPLANT CAPACITY ALTERNATIVE

Reach-averaged range in stage and active sandbar width

*Normal operations—minimum release year (8.23 maf)*

| | | Daily discharge range (1,000 to 24,000 cfs at dam) | | | Annual discharge range (1,000 to 33,200 cfs at dam) | | |
|---|---|---|---|---|---|---|---|
| Reach | Local minimum flow [1] (cfs) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) |
| 1 | 2,400 | 11 | 51 | 9 | 14 | 67 | 12 |
| 2 | 2,900 | 12 | 58 | 10 | 16 | 77 | 14 |
| 3 | 3,600 | 11 | 54 | 10 | 15 | 71 | 14 |
| 4 | 4,500 | 9 | 40 | 8 | 12 | 54 | 11 |
| 5 | 5,400 | 7 | 32 | 7 | 10 | 47 | 10 |
| 6 | 6,100 | 11 | 54 | 12 | 16 | 76 | 17 |
| 7 | 6,700 | 10 | 47 | 12 | 14 | 66 | 15 |
| 8 | 7,000 | 9 | 41 | 11 | 13 | 60 | 14 |
| 9 | 7,300 | 10 | 48 | 12 | 14 | 69 | 16 |
| 10 | 8,200 | 9 | 42 | 12 | 13 | 62 | 16 |
| 11 | 9,000 | 9 | 39 | 12 | 12 | 59 | 16 |

[1] Increase in minimum flow estimated on the basis of hydrographs of normal fluctuating flows of March 12, 1991. Range of fluctuations was 1,300-18,500 cfs. Inflow from streams and springs between Glen Canyon Dam and RM225 not estimated.

## HIGH FLUCTUATING FLOW ALTERNATIVE

Reach-averaged range in stage and active sandbar width

*Normal operations—minimum release year (8.23 maf)*

| | | Daily discharge range (3,000 to 23,000 cfs at dam) | | | Annual discharge range (3,000 to 31,500 cfs at dam) | | |
|---|---|---|---|---|---|---|---|
| Reach | Local minimum flow [1] (cfs) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) |
| 1 | 3,500 | 10 | 45 | 9 | 13 | 60 | 12 |
| 2 | 3,900 | 11 | 51 | 10 | 14 | 69 | 14 |
| 3 | 4,400 | 10 | 48 | 10 | 14 | 65 | 13 |
| 4 | 5,000 | 8 | 36 | 8 | 11 | 50 | 11 |
| 5 | 5,700 | 7 | 30 | 7 | 10 | 44 | 10 |
| 6 | 6,500 | 11 | 50 | 12 | 15 | 70 | 16 |
| 7 | 7,100 | 9 | 43 | 11 | 13 | 61 | 15 |
| 8 | 7,400 | 8 | 38 | 10 | 12 | 55 | 14 |
| 9 | 7,900 | 9 | 43 | 12 | 13 | 63 | 16 |
| 10 | 8,900 | 8 | 37 | 11 | 12 | 56 | 15 |
| 11 | 10,000 | 7 | 33 | 11 | 11 | 52 | 15 |

[1] Increase in minimum flow estimated on the basis of hydrographs of research fluctuating flows of May 7, 1991. Range of fluctuations was 2,700-26,500 cfs. Estimated inflow from streams and springs between Glen Canyon Dam and RM225 is 1,550 cfs.

*Selected beach/habitat-building flows*

| | 41,500 cfs at dam | | 45,000 cfs at dam | |
|---|---|---|---|---|
| Reach | Range in stage above 5,000 cfs (ft) | Range in stage above 31,500 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 31,500 cfs (ft) |
| 1 | 15 | 3 | 16 | 4 |
| 2 | 17 | 4 | 18 | 5 |
| 3 | 16 | 3 | 17 | 4 |
| 4 | 14 | 3 | 14 | 4 |
| 5 | 13 | 3 | 14 | 4 |
| 6 | 20 | 4 | 21 | 5 |
| 7 | 18 | 4 | 19 | 5 |
| 8 | 17 | 3 | 18 | 5 |
| 9 | 19 | 4 | 21 | 5 |
| 10 | 19 | 4 | 20 | 5 |
| 11 | 19 | 4 | 20 | 5 |

## MODERATE FLUCTUATING FLOW ALTERNATIVE

Reach-averaged range in stage and active sandbar width

*Normal operations—minimum release year (8.23 maf)*

| | | Daily discharge range (5,000 to 13,200 cfs at dam) | | | Annual discharge range (5,000 to 22,300 cfs at dam) | | |
|---|---|---|---|---|---|---|---|
| Reach | Local minimum flow [1] (cfs) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) |
| 1 | 5,100 | 4 | 18 | 5 | 8 | 37 | 8 |
| 2 | 5,300 | 5 | 21 | 5 | 9 | 44 | 10 |
| 3 | 5,500 | 5 | 19 | 5 | 9 | 42 | 10 |
| 4 | 5,800 | 4 | 14 | 4 | 7 | 32 | 8 |
| 5 | 6,200 | 3 | 10 | 4 | 6 | 28 | 7 |
| 6 | 6,600 | 5 | 20 | 6 | 10 | 47 | 12 |
| 7 | 7,000 | 4 | 17 | 6 | 9 | 42 | 11 |
| 8 | 7,100 | 4 | 14 | 5 | 8 | 37 | 10 |
| 9 | 7,300 | 4 | 16 | 6 | 9 | 43 | 11 |
| 10 | 7,800 | 4 | 14 | 6 | 9 | 40 | 11 |
| 11 | 8,400 | 3 | 12 | 6 | 8 | 37 | 11 |

[1] Increase in minimum flow estimated on the basis of hydrographs of research fluctuating flows of Jan. 29, 1991. Range of fluctuations was 5,000-14,600 cfs. Estimated inflow from streams and springs between Glen Canyon Dam and RM225 is 1,400 cfs.

| | *Habitat-maintenance flow* | | | *Selected beach/habitat-building flows* | | | |
|---|---|---|---|---|---|---|---|
| | Annual discharge range (5,000 to 30,000 cfs at dam) | | | 40,000 cfs at dam | | 45,000 cfs at dam | |
| Reach | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 22,300 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 22,300 cfs (ft) |
| 1 | 11 | 52 | 11 | 15 | 7 | 16 | 7 |
| 2 | 13 | 60 | 13 | 17 | 7 | 18 | 9 |
| 3 | 12 | 58 | 13 | 16 | 6 | 17 | 8 |
| 4 | 10 | 45 | 10 | 14 | 6 | 14 | 7 |
| 5 | 9 | 41 | 9 | 13 | 6 | 14 | 7 |
| 6 | 14 | 66 | 15 | 20 | 8 | 21 | 10 |
| 7 | 12 | 59 | 14 | 18 | 7 | 19 | 9 |
| 8 | 11 | 54 | 13 | 17 | 7 | 18 | 8 |
| 9 | 13 | 62 | 15 | 19 | 8 | 21 | 9 |
| 10 | 12 | 57 | 15 | 19 | 8 | 20 | 9 |
| 11 | 12 | 55 | 14 | 19 | 8 | 20 | 9 |

## MODIFIED LOW FLUCTUATING FLOW ALTERNATIVE

Reach-averaged range in stage and active sandbar width

*Normal operations—minimum release year (8.23 maf)*

| | | Daily discharge range (5,000 to 10,000 cfs at dam) | | | Annual discharge range (5,000 to 20,000 cfs at dam) | | |
|---|---|---|---|---|---|---|---|
| Reach | Local minimum flow [1] (cfs) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) |
| 1 | 5,100 | 3 | 10 | 3 | 7 | 33 | 7 |
| 2 | 5,300 | 3 | 12 | 3 | 8 | 38 | 9 |
| 3 | 5,500 | 3 | 10 | 3 | 8 | 37 | 9 |
| 4 | 5,800 | 2 | 7 | 3 | 6 | 28 | 7 |
| 5 | 6,200 | 2 | 4 | 2 | 6 | 24 | 6 |
| 6 | 6,600 | 3 | 9 | 4 | 9 | 41 | 10 |
| 7 | 7,000 | 2 | 6 | 4 | 8 | 36 | 10 |
| 8 | 7,100 | 2 | 5 | 4 | 7 | 32 | 9 |
| 9 | 7,300 | 2 | 5 | 4 | 8 | 37 | 10 |
| 10 | 7,800 | 2 | 3 | 4 | 8 | 34 | 10 |
| 11 | 8,400 | 1 | 1 | 4 | 7 | 31 | 10 |

[1] Increase in minimum flow estimated on the basis of hydrographs of research fluctuating flows of Jan. 29, 1991. Range of fluctuations was 5,000-14,600 cfs. Estimated inflow from streams and springs between Glen Canyon Dam and RM225 is 1,400 cfs.

| | *Habitat-maintenance flow* | | | *Selected beach/habitat-building flows* | | | |
|---|---|---|---|---|---|---|---|
| | Annual discharge range (5,000 to 30,000 cfs at dam) | | | 40,000 cfs at dam | | 45,000 cfs at dam | |
| Reach | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 20,000 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 20,000 cfs (ft) |
| 1 | 11 | 52 | 11 | 15 | 8 | 16 | 8 |
| 2 | 13 | 60 | 13 | 17 | 8 | 18 | 10 |
| 3 | 12 | 58 | 13 | 16 | 7 | 17 | 9 |
| 4 | 10 | 45 | 10 | 14 | 7 | 14 | 7 |
| 5 | 9 | 41 | 9 | 13 | 7 | 14 | 7 |
| 6 | 14 | 66 | 15 | 20 | 10 | 21 | 11 |
| 7 | 12 | 59 | 14 | 18 | 8 | 19 | 10 |
| 8 | 11 | 54 | 13 | 17 | 8 | 18 | 9 |
| 9 | 13 | 62 | 15 | 19 | 9 | 21 | 11 |
| 10 | 12 | 57 | 15 | 19 | 9 | 20 | 10 |
| 11 | 12 | 55 | 14 | 19 | 9 | 20 | 10 |

## INTERIM LOW FLUCTUATING FLOW ALTERNATIVE

Reach-averaged range in stage and active sandbar width

*Normal operations—minimum release year (8.23 maf)*

| | | Daily discharge range (5,000 to 10,000 cfs at dam) | | | Annual discharge range (5,000 to 20,000 cfs at dam) | | |
|---|---|---|---|---|---|---|---|
| Reach | Local minimum flow [1] (cfs) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above local minimum flow (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) |
| 1 | 5,100 | 3 | 10 | 3 | 7 | 33 | 7 |
| 2 | 5,300 | 3 | 12 | 3 | 8 | 38 | 9 |
| 3 | 5,500 | 3 | 10 | 3 | 8 | 37 | 9 |
| 4 | 5,800 | 2 | 7 | 3 | 6 | 28 | 7 |
| 5 | 6,200 | 2 | 4 | 2 | 6 | 24 | 6 |
| 6 | 6,600 | 3 | 9 | 4 | 9 | 41 | 10 |
| 7 | 7,000 | 2 | 6 | 4 | 8 | 36 | 10 |
| 8 | 7,100 | 2 | 5 | 4 | 7 | 32 | 9 |
| 9 | 7,300 | 2 | 5 | 4 | 8 | 37 | 10 |
| 10 | 7,800 | 2 | 3 | 4 | 8 | 34 | 10 |
| 11 | 8,400 | 1 | 1 | 4 | 7 | 31 | 10 |

[1] Increase in minimum flow estimated on the basis of hydrographs of research fluctuating flows of Jan. 29, 1991. Range of fluctuations was 5,000-14,600 cfs. Estimated inflow from streams and springs between Glen Canyon Dam and RM225 is 1,400 cfs.

*Selected beach/habitat-building flows*

| | 30,000 cfs at dam | | 45,000 cfs at dam | |
|---|---|---|---|---|
| Reach | Range in stage above 5,000 cfs (ft) | Range in stage above 20,000 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 20,000 cfs (ft) |
| 1 | 11 | 4 | 16 | 8 |
| 2 | 13 | 4 | 18 | 10 |
| 3 | 10 | 4 | 17 | 9 |
| 4 | 9 | 3 | 14 | 7 |
| 5 | 15 | 3 | 14 | 7 |
| 6 | 24 | 5 | 21 | 11 |
| 7 | 13 | 4 | 19 | 10 |
| 8 | 15 | 4 | 18 | 9 |
| 9 | 14 | 5 | 21 | 11 |
| 10 | 13 | 5 | 20 | 10 |
| 11 | 14 | 5 | 20 | 10 |

## EXISTING MONTHLY VOLUMES STEADY FLOW ALTERNATIVE

Reach-averaged range in stage and active sandbar width

*Normal operations—minimum release year (8.23 maf)*

| | Annual discharge range (9,200 to 16,300 cfs at dam) | | |
|---|---|---|---|
| Reach | Range in stage above 9,200 cfs (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) |
| 1 | 3 | 12 | 6 |
| 2 | 4 | 15 | 7 |
| 3 | 4 | 15 | 7 |
| 4 | 3 | 11 | 6 |
| 5 | 3 | 10 | 5 |
| 6 | 5 | 19 | 8 |
| 7 | 4 | 17 | 8 |
| 8 | 4 | 15 | 7 |
| 9 | 5 | 19 | 8 |
| 10 | 5 | 18 | 8 |
| 11 | 4 | 18 | 8 |

*Selected beach/habitat-building flows*

| | 26,300 cfs at dam | | 45,000 cfs at dam | |
|---|---|---|---|---|
| Reach | Range in stage above 5,000 cfs (ft) | Range in stage above 16,300 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 16,300 cfs (ft) |
| 1 | 10 | 4 | 16 | 10 |
| 2 | 11 | 4 | 18 | 11 |
| 3 | 11 | 4 | 17 | 11 |
| 4 | 9 | 4 | 14 | 9 |
| 5 | 8 | 3 | 14 | 9 |
| 6 | 14 | 5 | 21 | 13 |
| 7 | 13 | 5 | 19 | 12 |
| 8 | 12 | 4 | 18 | 11 |
| 9 | 13 | 5 | 21 | 13 |
| 10 | 13 | 5 | 20 | 12 |
| 11 | 13 | 5 | 20 | 12 |

## SEASONALLY ADJUSTED STEADY FLOW ALTERNATIVE

Reach-averaged range in stage and active sandbar width

*Normal operations—minimum release year (8.23 maf)*

| | Annual discharge range (8,000 to 18,000 cfs at dam) | | |
|---|---|---|---|
| Reach | Range in stage above 8,000 cfs (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) |
| 1 | 5 | 20 | 7 |
| 2 | 6 | 23 | 8 |
| 3 | 5 | 23 | 8 |
| 4 | 4 | 18 | 6 |
| 5 | 4 | 16 | 5 |
| 6 | 7 | 29 | 9 |
| 7 | 6 | 27 | 9 |
| 8 | 6 | 24 | 8 |
| 9 | 7 | 29 | 9 |
| 10 | 6 | 28 | 9 |
| 11 | 6 | 27 | 9 |

| | *Habitat-maintenance flow* | | | *Selected beach/habitat-building flows* | | | |
|---|---|---|---|---|---|---|---|
| | Annual discharge range (8,000 to 30,000 cfs at dam) | | | 40,000 cfs at dam | | 45,000 cfs at dam | |
| Reach | Range in stage above 8,000 cfs (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 18,000 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 18,000 cfs (ft) |
| 1 | 9 | 43 | 11 | 15 | 8 | 16 | 9 |
| 2 | 11 | 49 | 13 | 17 | 9 | 18 | 11 |
| 3 | 11 | 49 | 13 | 16 | 8 | 17 | 10 |
| 4 | 9 | 39 | 10 | 14 | 8 | 14 | 8 |
| 5 | 8 | 37 | 9 | 13 | 8 | 14 | 8 |
| 6 | 13 | 60 | 15 | 20 | 11 | 21 | 12 |
| 7 | 12 | 55 | 14 | 18 | 9 | 19 | 11 |
| 8 | 11 | 50 | 13 | 17 | 9 | 18 | 10 |
| 9 | 13 | 59 | 15 | 19 | 10 | 21 | 12 |
| 10 | 12 | 57 | 15 | 19 | 10 | 20 | 11 |
| 11 | 12 | 56 | 14 | 19 | 10 | 20 | 11 |

## YEAR-ROUND STEADY FLOW ALTERNATIVE

Reach-averaged range in stage and active sandbar width

*Normal operations—minimum release year (8.23 maf)*

| | Annual discharge range (10,900 to 11,900 cfs at dam) | | |
|---|---|---|---|
| Reach | Range in stage above 10,900 cfs (ft) | Active sandbar width (ft) | Range in stage above 5,000 cfs (ft) |
| 1 | 1 | 0 | 4 |
| 2 | 1 | 0 | 5 |
| 3 | 1 | 0 | 4 |
| 4 | 0 | 0 | 4 |
| 5 | 0 | 0 | 3 |
| 6 | 1 | 0 | 5 |
| 7 | 1 | 0 | 5 |
| 8 | 1 | 0 | 5 |
| 9 | 1 | 0 | 5 |
| 10 | 1 | 0 | 5 |
| 11 | 1 | 0 | 5 |

*Selected beach/habitat-building flows*

| | 21,900 cfs at dam | | 45,000 cfs at dam | |
|---|---|---|---|---|
| Reach | Range in stage above 5,000 cfs (ft) | Range in stage above 11,900 cfs (ft) | Range in stage above 5,000 cfs (ft) | Range in stage above 11,900 cfs (ft) |
| 1 | 8 | 4 | 16 | 12 |
| 2 | 10 | 5 | 18 | 14 |
| 3 | 9 | 5 | 17 | 13 |
| 4 | 8 | 4 | 14 | 11 |
| 5 | 7 | 4 | 14 | 11 |
| 6 | 11 | 6 | 21 | 16 |
| 7 | 11 | 5 | 19 | 14 |
| 8 | 10 | 5 | 18 | 13 |
| 9 | 11 | 6 | 21 | 15 |
| 10 | 11 | 6 | 20 | 15 |
| 11 | 11 | 6 | 20 | 15 |

## LAKE DELTAS

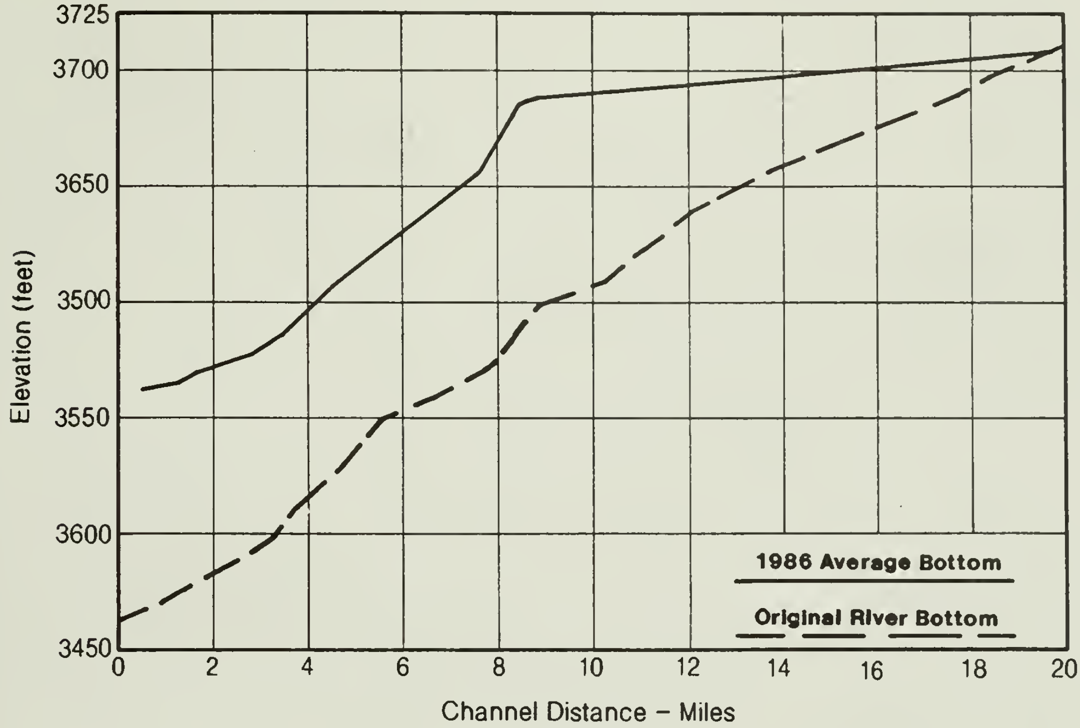



*Figure D-4.—Profile along Dirty Devil Canyon showing original river surface and 1986 average bottom profile (from Ferrari, 1988b).*

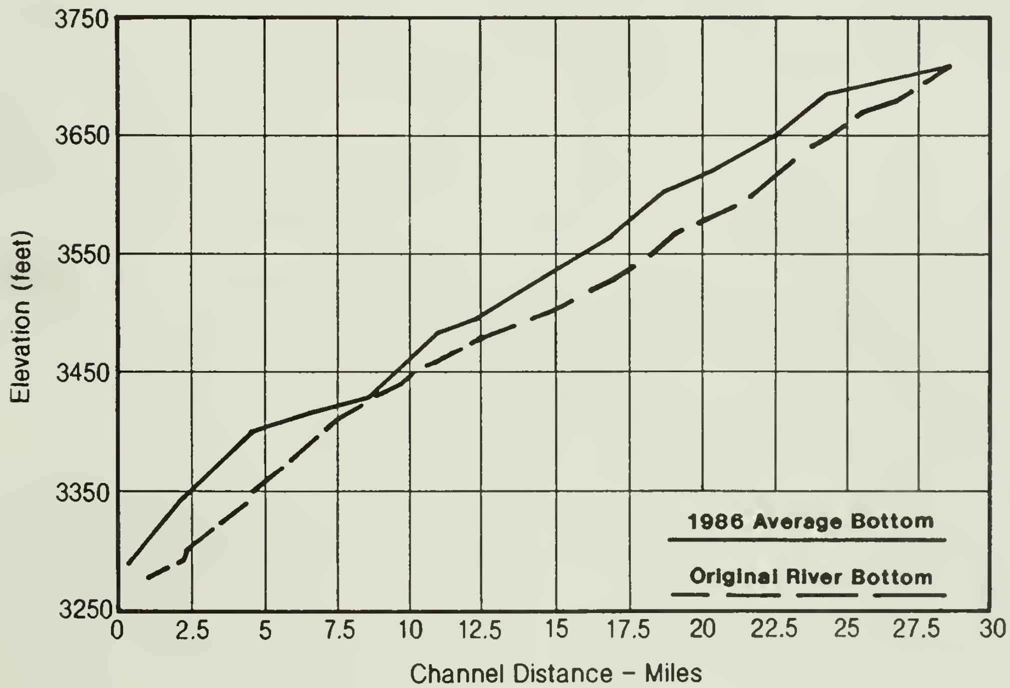



*Figure D-5.—Profile along Escalante Canyon showing original river surface and 1986 average bottom profile (from Ferrari, 1988b).*

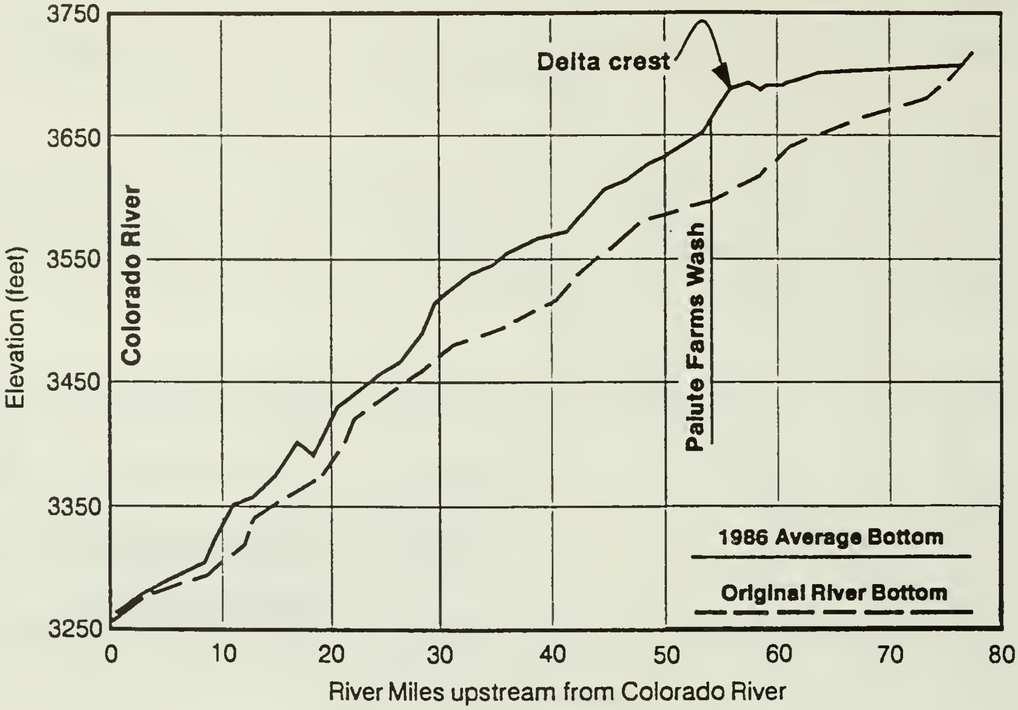



*Figure D-6.—Profile along San Juan River showing original river surface and 1986 average bottom profile (from Ferrari, 1988b).*

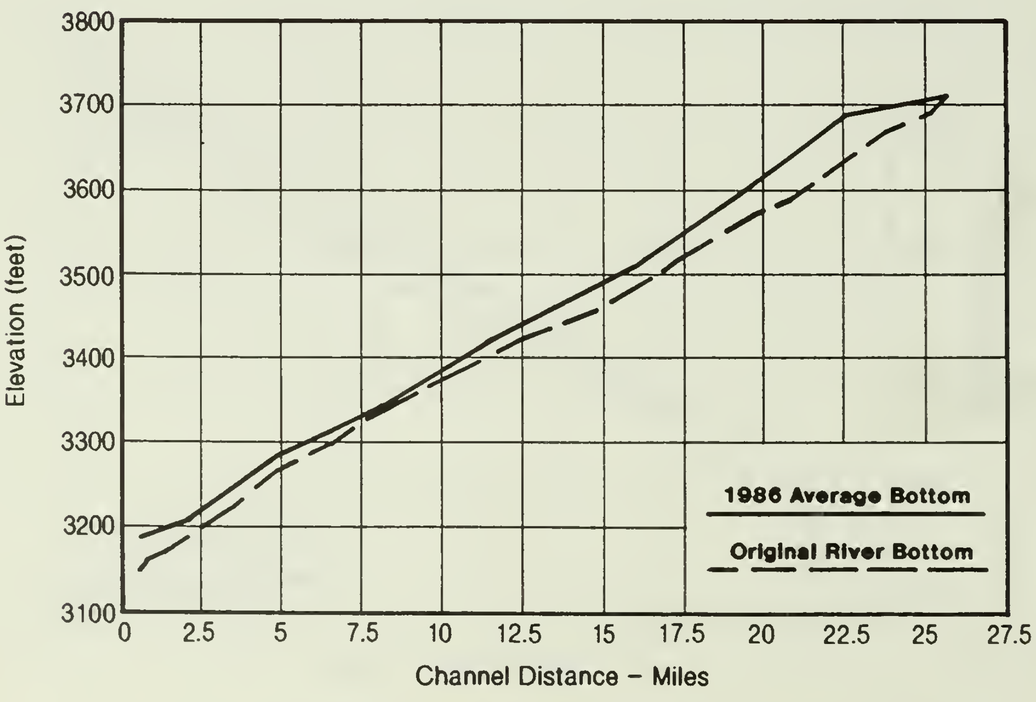



*Figure D-7—Profile along Navajo Canyon showing original river surface and 1986 average bottom profile (from Ferrari, 1988b).*

Appendix E

# Hydropower

# Contents



# Figures



# Tables



# Maps

# HYDROPOWER

Federal Projects of the Colorado River Storage Project from which Western's SLCA Markets Power

Colorado River Storage Project
- Glen Canyon Powerplant
- Flaming Gorge Powerplant
- Blue Mesa Powerplant
- Crystal Powerplant
- Morrow Point Powerplant
- Fontenelle Powerplant

Seedskadee Project (CRSP Participating Project)
- Fontenelle Powerplant

Collbran Project
- Upper Molina Powerplant
- Lower Molina Powerplant

Rio Grande Project
- Elephant Butte Powerplant

Falcon and Amistad Powerplants

Dolores Project (CRSP Participating Project)
- Towaoc Powerplant
- McPhee Powerplant

Provo River Project
- Deer Creek Powerplant

## Table E-1.—Operational Characteristics of SLCA/IP

| Plant Name | No. of Units | Maximum Operating Capacity (MW)[1] | 10-Year Annual Average (1980-90) Gross Generation (MWh) | Minimum Flow Below Powerplant (cfs) | Maximum Power Release (cfs) | Under Automated Generation Control |
|---|---|---|---|---|---|---|
| Glen Canyon | 8 | 1,356[2] | 5,800,000 | 3,000 Summer<br>1,000 Winter | 31,500 | Yes |
| Flaming Gorge | 3 | 152 | 540,000 | 400 Winter<br>800 Summer | 4,700[3] | Yes |
| Blue Mesa | 2 | 96 | 292,000 | 0 | 3,000 | Yes |
| Morrow Point | 2 | 174[4] | 398,000 | 0 | 5,000 | Yes |
| Crystal | 1 | 31 | 189,000 | 300 | 1,700 | No |
| Fontenelle | 1 | 13 | 52,000 | 400 | 1,700 | No |
| Elephant Butte | 3 | 24 | 112,000 | 0 | 2,200 | No |
| Upper Molina | 1 | 9 | 37,000 | Not Applicable | 52 | Yes |
| Lower Molina | 1 | 5 | 22,000 | Not Applicable | 52 | Yes |
| Deer Creek | 2 | 5 | 27,000 | 85 | 600 | No |
| Towaoc | 1 | 11.5 | 30,318[5] | Not Applicable | 375 | No |
| McPhee | 1 | 1 | 7,170[2] | 20 | 75 | No |

[1] Generator operating capacity is dependent upon reservoir elevations.
[2] Installed capacity is 1,356 MW. Capacity has been limited to less than 1,300 MW because maximum allowable water release for power is 31,500 cfs.
[3] Releases restricted to 2,400 cfs maximum in August and September.
[4] Morrow Point is limited to 156 MW due to transformer capacity.
[5] Projected annual generation.

## Colorado River Basin Fund

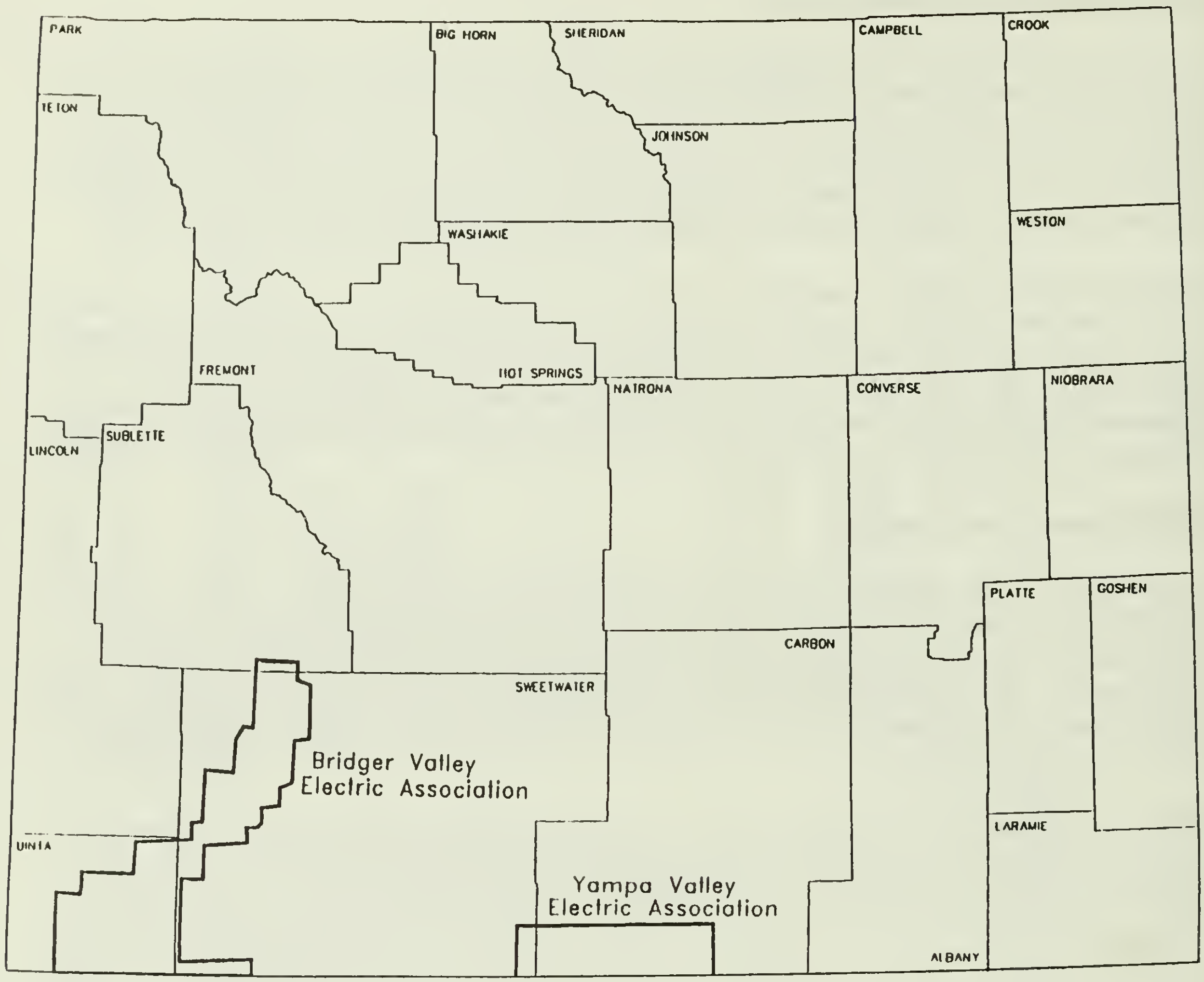
The Reclamation Act of 1902 authorized construction of dams and associated water systems for irrigating the arid western United States. The act also authorized establishment of a Reclamation Fund designed to be financially self-sufficient by receiving revenues from the sale of public lands in the west, plus various user fees and congressional appropriations for specific purposes. Reclamation was empowered to use money from the fund to construct Federal irrigation projects, with repayment by those benefiting from use of the water.

This repayment procedure was followed until it was determined that water revenues would not be sufficient to repay irrigation investments. The Town Sites and Power Development Act of 1906 authorized sale of Federal hydropower surplus to irrigation needs and application of net power sales to repay irrigators' obligations beyond their ability to repay. Additionally, power revenues pay all costs associated with power development including operation and maintenance procedures.

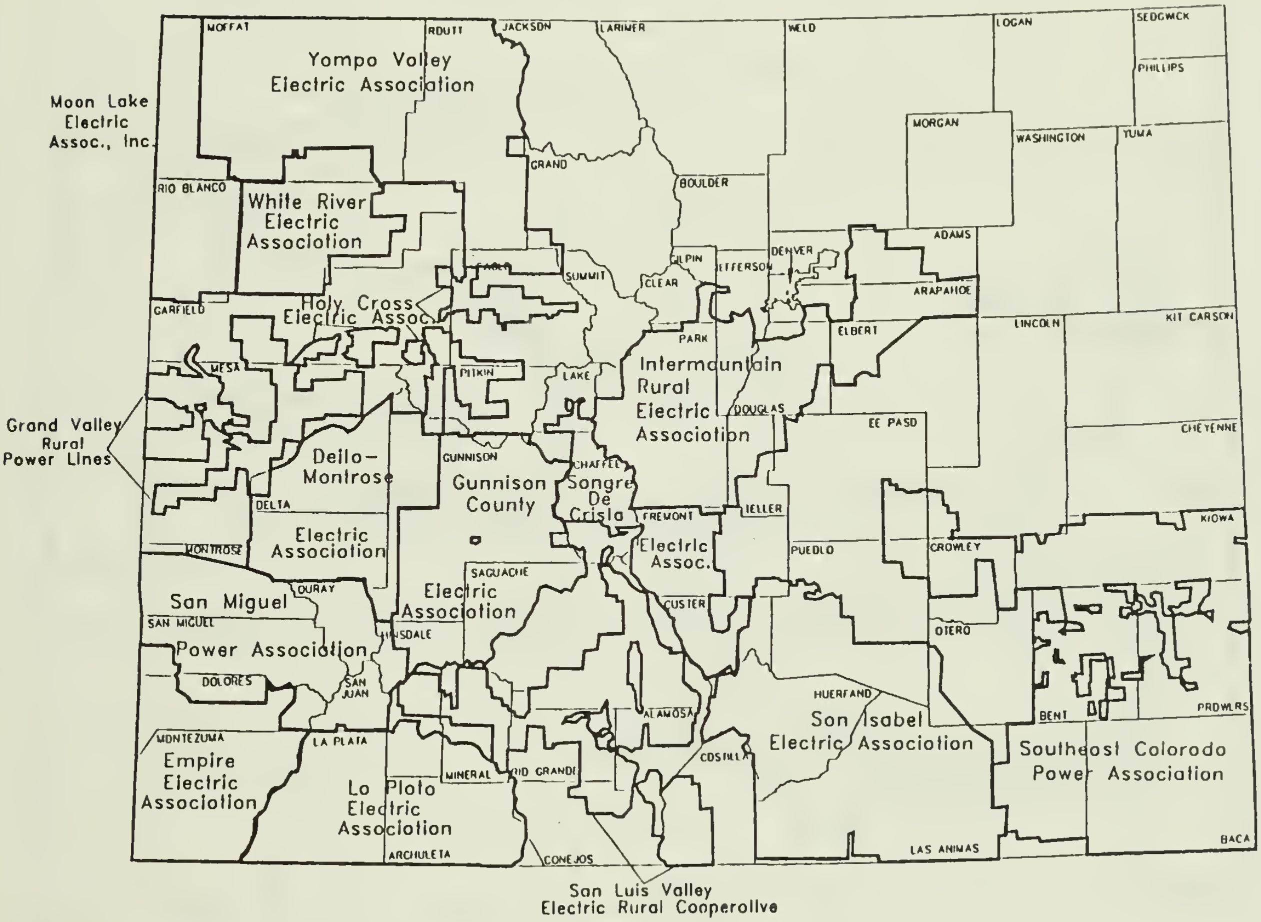
### *Multipurpose Cost Allocation*

The Colorado River Project Act incorporated the concept of multipurpose water resource project development to include not only irrigation and hydropower generation but also municipal and industrial water use, flood control, fish and wildlife mitigation and enhancement, water quality improvement, and recreation. Costs were allocated among these various uses, with hydroelectric power paying both its share and a major portion of the amount assigned to irrigation.

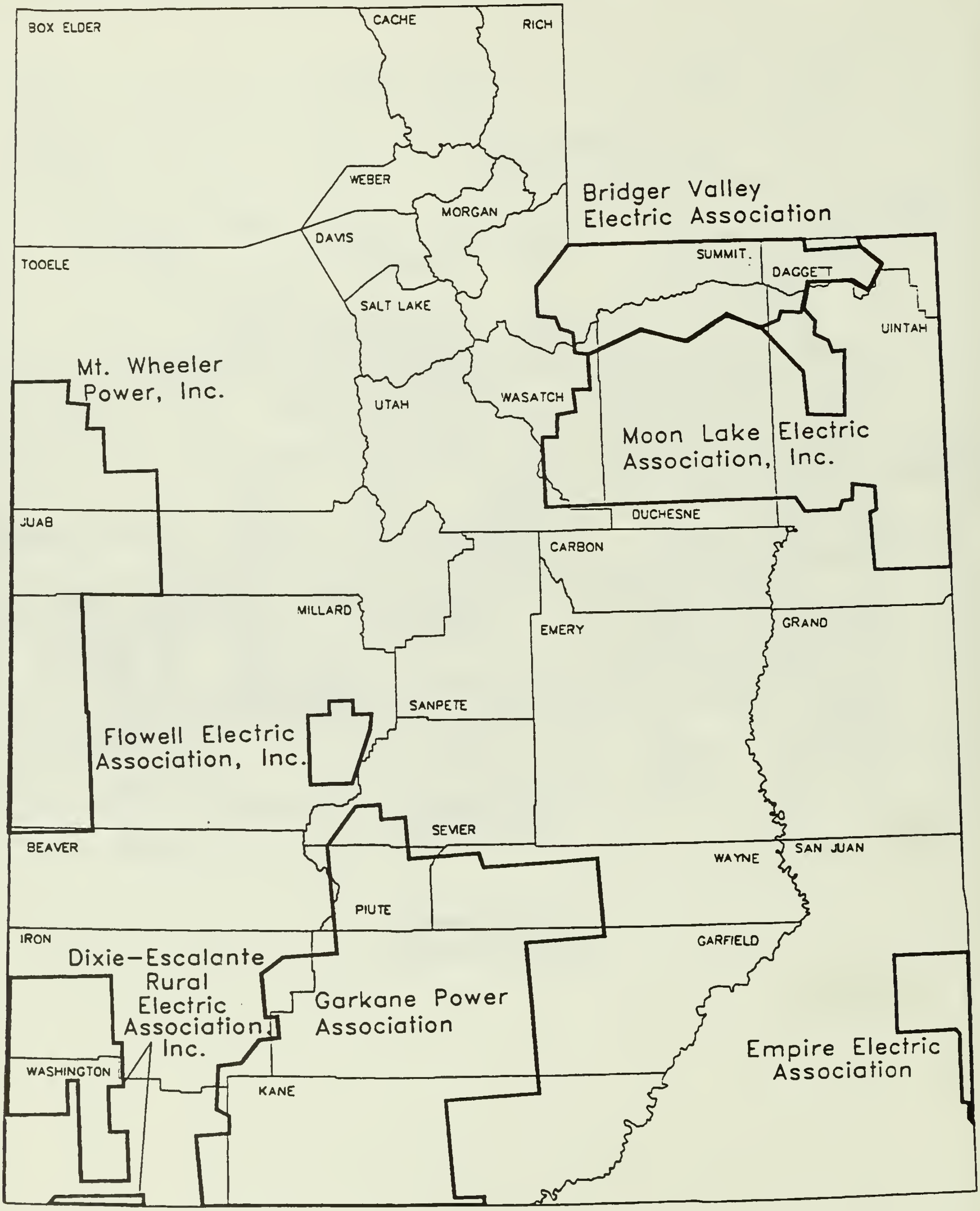
After construction of an irrigation project is completed, Reclamation prepares a final cost allocation report. This report allocates repayment requirements to each project purpose. Reclamation used the "separable cost-remaining benefits" method for cost allocation of the CRSP. Under this method, costs that can be specifically identified with a particular project purpose are assigned to that project purpose. For example, cost of Glen Canyon Powerplant would be assigned to the power function for repayment purposes, while cost of a boat ramp would be assigned to recreation. Costs that cannot be identified with a particular project purpose, such as the actual concrete structure of the dam, are allocated among the project purposes, based on the percentage of benefits each project receives from these "joint" costs. Reclamation completed the *Report of Allocation of Costs - Colorado River Storage Project* in 1974.



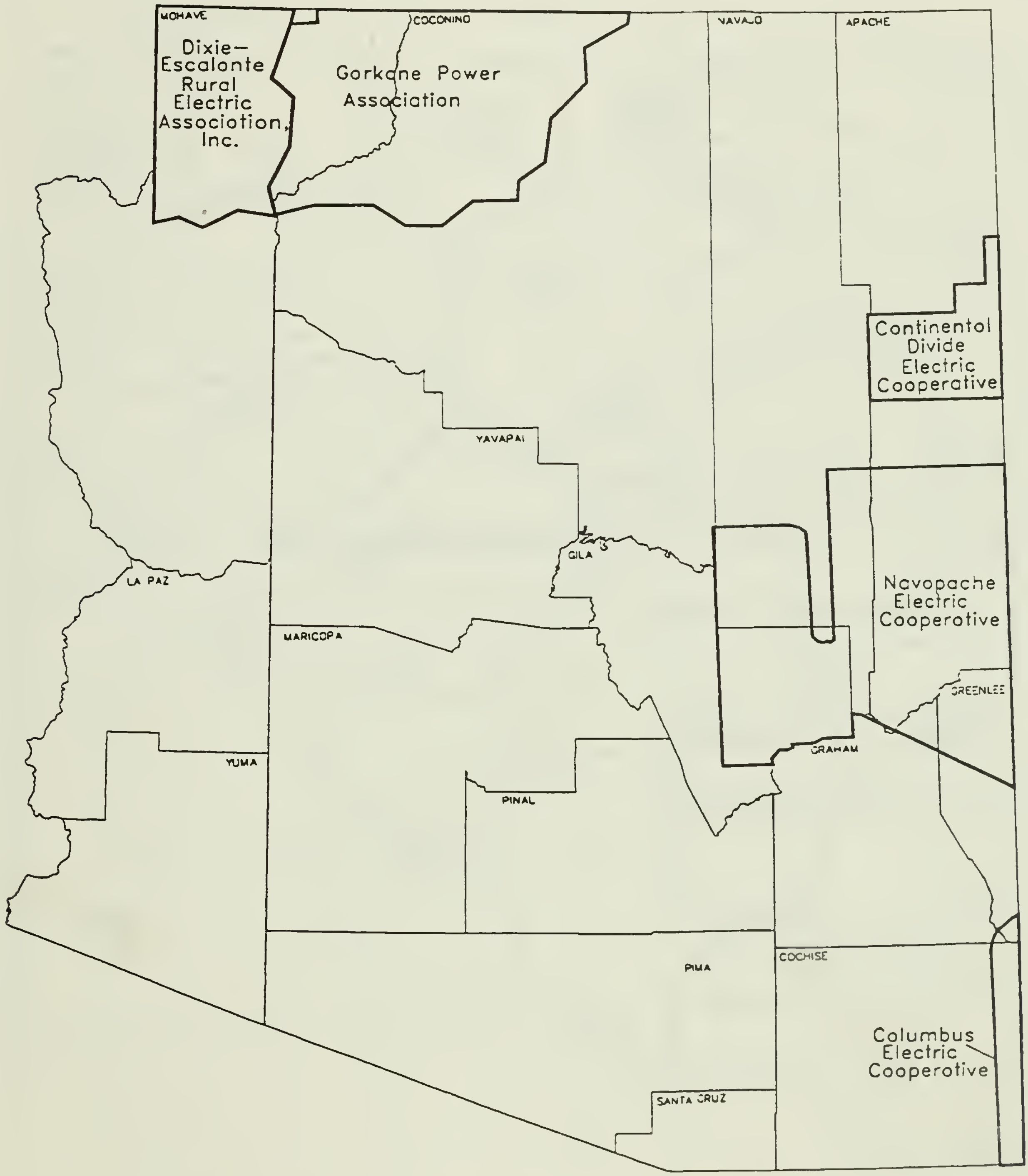

State of Wyoming
Customer Service Map



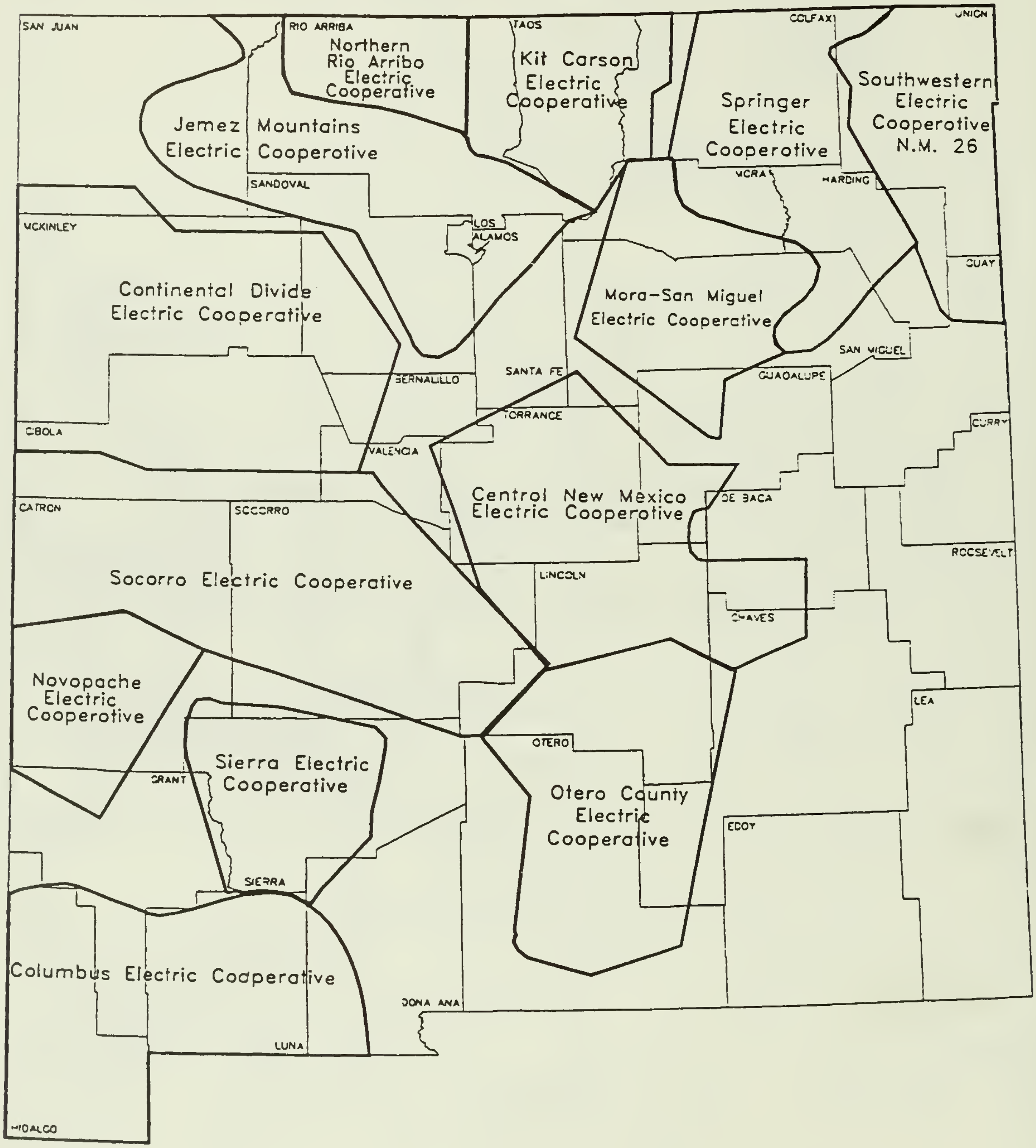

State of Colorado
Customer Service Map



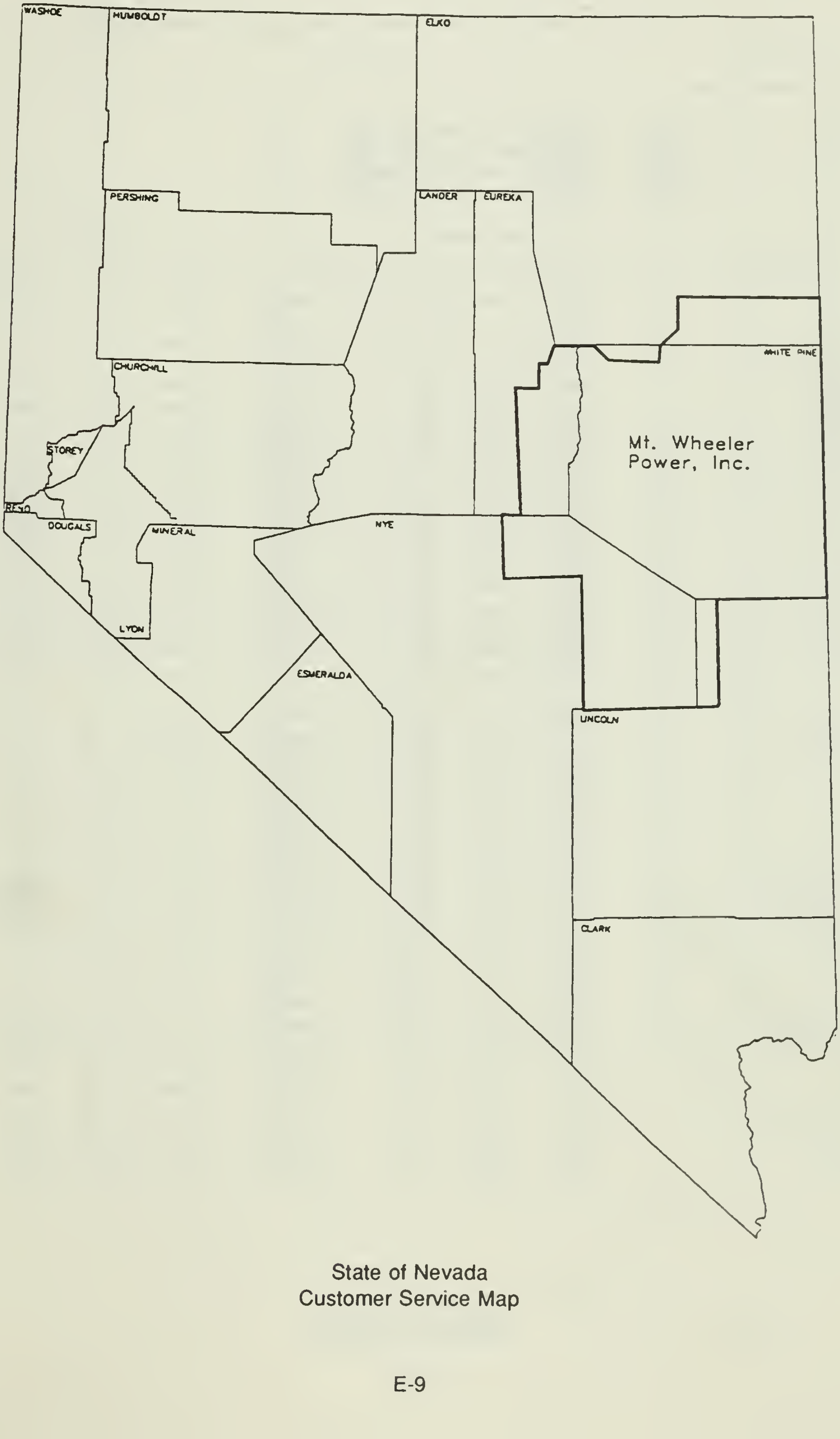

State of Utah
Customer Service Map




State of Arizona
Customer Service Map




State of New Mexico
Customer Service Map




State of Nevada
Customer Service Map

# Table E-2.—SLCA/IP Power Allocations (firm capacity and energy)

No-Action Alternative Allocations (7/6/92)

| | |
|---|---|
| 1,407.227 | = Marketable Winter Capacity Total (MW) |
| 3,105,848.030 | = Marketable Winter Energy Total (MWh) |
| 1,314.863 | = Marketable Summer Capacity Total (MW) |
| 2,904,402.851 | = Marketable Summer Energy Total (MWh) |

| | Winter Season | | | | Summer Season | | | |
|---|---|---|---|---|---|---|---|---|
| CUSTOMER | % | Cap | % | Eng | % | Cap | % | Eng |
| PAGE | 0.57% | 8.040 | 0.57% | 17,604.906 | 0.51% | 6.687 | 0.51% | 14,737.305 |
| ASPEN | 0.12% | 1.677 | 0.14% | 4,234.809 | 0.08% | 1.062 | 0.09% | 2,714.455 |
| Colorado Ute Members | | | | | | | | |
| DELTA-MONTROSE | 0.27% | 3.851 | 0.36% | 11,054.425 | 0.33% | 4.377 | 0.41% | 11,888.560 |
| EMPIRE ELECTRIC | 0.24% | 3.419 | 0.32% | 9,968.712 | 0.23% | 2.971 | 0.28% | 8,171.027 |
| GRAND VALLEY | 0.19% | 2.699 | 0.25% | 7,887.689 | 0.15% | 2.029 | 0.19% | 5,580.985 |
| GUNNISON COUNTY | 0.23% | 3.234 | 0.30% | 9,458.521 | 0.15% | 2.027 | 0.19% | 5,574.966 |
| HOLY CROSS | 0.32% | 4.500 | 0.41% | 12,684.785 | 0.38% | 4.978 | 0.46% | 13,347.800 |
| IREA | 1.68% | 23.693 | 1.92% | 59,496.928 | 1.42% | 18.736 | 1.57% | 45,509.434 |
| LA PLATA | 0.27% | 3.755 | 0.35% | 10,814.055 | 0.31% | 4.124 | 0.39% | 11,273.402 |
| S.DE CRISTO | 0.01% | 0.155 | 0.01% | 387.030 | 0.02% | 0.218 | 0.02% | 527.561 |
| SAN ISABEL | 0.03% | 0.357 | 0.03% | 896.622 | 0.04% | 0.488 | 0.04% | 1,185.391 |
| SAN LUIS VLY | 0.02% | 0.221 | 0.02% | 554.212 | 0.12% | 1.631 | 0.14% | 3,963.504 |
| SAN MIGUEL | 0.24% | 3.433 | 0.32% | 10,003.498 | 0.24% | 3.118 | 0.30% | 8,573.556 |
| SOUTHEAST | 0.02% | 0.302 | 0.02% | 756.793 | 0.06% | 0.851 | 0.07% | 2,066.360 |
| WHITE RIVER | 0.15% | 2.162 | 0.20% | 6,319.461 | 0.13% | 1.734 | 0.16% | 4,768.739 |
| YAMPA VLY | 0.30% | 4.221 | 0.39% | 11,985.109 | 0.36% | 4.718 | 0.44% | 12,716.603 |
| DELTA | 0.12% | 1.721 | 0.13% | 3,935.517 | 0.11% | 1.510 | 0.12% | 3,486.750 |
| GLENWOOD SPRINGS | 0.12% | 1.689 | 0.14% | 4,243.525 | 0.09% | 1.246 | 0.11% | 3,182.500 |
| GUNNISON | 0.51% | 7.225 | 0.51% | 15,821.430 | 0.37% | 4.812 | 0.37% | 10,605.277 |
| OAK CREEK | 0.03% | 0.485 | 0.03% | 1,014.500 | 0.02% | 0.320 | 0.02% | 702.204 |
| TOTAL COLORADO | 4.89% | 68.799 | 5.84% | 181,517.621 | 4.64% | 60.950 | 5.37% | 155,839.074 |
| AZTEC | 0.20% | 2.778 | 0.20% | 6,082.158 | 0.16% | 2.039 | 0.15% | 4,494.653 |
| CANNON AFB | 0.10% | 1.419 | 0.12% | 3,573.678 | 0.11% | 1.387 | 0.12% | 3,545.692 |
| CENTRAL VLY ELEC COOP | 0.22% | 3.081 | 0.29% | 9,048.805 | 0.20% | 2.612 | 0.31% | 9,092.366 |
| COUNTY OF LOS ALAMOS | 0.11% | 1.569 | 0.13% | 3,951.530 | 0.08% | 1.056 | 0.09% | 2,701.693 |
| DOE-ALBUQ. OPER. OFF | 2.57% | 36.127 | 1.49% | 46,260.616 | 2.65% | 34.883 | 1.55% | 45,077.648 |
| FARMERS ELEC COOP | 0.17% | 2.353 | 0.22% | 6,887.176 | 0.20% | 2.576 | 0.27% | 7,983.671 |
| FARMINGTON | 1.34% | 18.866 | 1.48% | 45,931.000 | 1.48% | 19.523 | 1.52% | 44,283.860 |
| GALLUP | 0.26% | 3.592 | 0.29% | 9,048.805 | 0.26% | 3.439 | 0.30% | 8,795.248 |
| HOLLOMAN AFB | 0.15% | 2.065 | 0.17% | 5,386.666 | 0.15% | 1.925 | 0.17% | 4,933.272 |
| LEA COUNTY ELEC COOP | 0.17% | 2.335 | 0.29% | 9,048.805 | 0.20% | 2.570 | 0.31% | 9,092.366 |
| NAVAJO TRIBAL UT ATH | 1.68% | 23.677 | 1.99% | 61,940.167 | 1.66% | 21.802 | 1.96% | 57,034.083 |
| PLAINS G&T | 12.63% | 177.722 | 11.98% | 372,222.505 | 10.82% | 142.303 | 10.74% | 312,070.292 |
| RATON | 0.12% | 1.637 | 0.13% | 4,077.916 | 0.08% | 1.078 | 0.09% | 2,737.564 |
| ROOSEVELT CO ELEC COOP | 0.18% | 2.517 | 0.25% | 7,769.264 | 0.22% | 2.869 | 0.30% | 8,788.350 |
| SANDIA/KIRTLAND | 0.26% | 3.592 | 0.29% | 9,048.805 | 0.27% | 3.555 | 0.31% | 9,092.366 |
| TRUTH OR CONSEQ | 0.46% | 6.506 | 0.46% | 14,234.333 | 0.46% | 6.025 | 0.46% | 13,285.367 |
| TOTAL NEW MEXICO | 20.60% | 289.836 | 19.79% | 614,512.229 | 18.99% | 249.642 | 18.70% | 543,008.491 |

SUBJECT TO REVISION

| CUSTOMER | Winter Season % | Cap | % | Eng | Summer Season % | Cap | % | Eng |
|---|---|---|---|---|---|---|---|---|
| BLANDING | 0.05% | 0.765 | 0.06% | 1,926.300 | 0.04% | 0.500 | 0.04% | 1,278.588 |
| BRIGHAM CITY | 0.89% | 12.594 | 0.89% | 27,577.770 | 0.68% | 8.932 | 0.68% | 19,650.298 |
| CUWCD | 0.01% | 0.095 | 0.01% | 285.651 | 0.02% | 0.237 | 0.02% | 607.009 |
| DEFENSE DEPOT OGDEN | 0.25% | 3.532 | 0.25% | 7,734.000 | 0.24% | 3.169 | 0.24% | 6,984 667 |
| HELPER | 0.03% | 0.472 | 0.04% | 1,181.057 | 0.02% | 0.304 | 0.03% | 773.637 |
| HILL AFB | 0.26% | 3.592 | 0.29% | 9,048.805 | 0.27% | 3.555 | 0.31% | 9,092.366 |
| ICPA Members | | | | | | | | |
| DESERET G&T | 7.84% | 110.346 | 7.43% | 230,865.569 | 7.73% | 101.616 | 7.53% | 218,834 447 |
| DIXIE-ESCALANTE | 1.71% | 24.085 | 1.61% | 50,110.977 | 1.45% | 19.072 | 1.41% | 40,956.172 |
| ENTERPRISE | 0.09% | 1.292 | 0.09% | 2,945.890 | 0.08% | 0.992 | 0.08% | 2,265.232 |
| HURRICANE | 0.28% | 3.882 | 0.28% | 8,851.348 | 0.13% | 1.716 | 0.13% | 3,918.486 |
| ST GEORGE | 2.27% | 31.915 | 2.13% | 66,005.078 | 1.50% | 19.673 | 1.45% | 42,118 273 |
| UAMPS | 11.35% | 159.714 | 10.71% | 332,700.063 | 7.89% | 103.718 | 7.67% | 222,853.999 |
| KANAB | 0.04% | 0.611 | 0.05% | 1,539.732 | 0.04% | 0.476 | 0.04% | 1,216.504 |
| PRICE | 0.12% | 1.702 | 0.14% | 4,287.107 | 0.09% | 1.119 | 0.10% | 2,861.732 |
| SANTA CLARA | 0.02% | 0.331 | 0.03% | 828.047 | 0.02% | 0.300 | 0.03% | 764 669 |
| TOOELE ARMY DEPOT | 0.09% | 1 307 | 0.11% | 3,291.706 | 0.07% | 0.920 | 0.08% | 2,352.298 |
| UMPA | 6.65% | 93.566 | 6.60% | 204,880.060 | 6.02% | 79.126 | 6.00% | 174,385.170 |
| UNIVERSITY OF UTAH | 0.25% | 3.461 | 0.29% | 8,944 220 | 0.24% | 3.104 | 0.28% | 8,021.611 |
| UTAH ST. UNIVERSITY | 0.08% | 1.152 | 0.10% | 3,017.143 | 0.09% | 1.124 | 0.10% | 2,881.047 |
| WASHINGTON | 0.05% | 0.691 | 0.06% | 1,728.876 | 0.04% | 0.556 | 0.05% | 1,417.587 |
| WEBER BASIN CONS. DST | 0.00% | 0.000 | 0.00% | 0.000 | 0.39% | 5.144 | 0.10% | 2,855.143 |
| TOTAL UTAH | 32.34% | 455.105 | 31.16% | 967,749.399 | 27.03% | 355.353 | 26.38% | 766,088 935 |
| **TOTAL SALT LAKE CITY AREA OFFICE** | 58.40% | 821.780 | 57.36% | 1,781,384.155 | 51.16% | 672.632 | 50.95% | 1,479,673.805 |
| CENTER | 0.13% | 1.801 | 0.13% | 3,954.115 | 0.08% | 1.082 | 0.08% | 2,330.498 |
| COLORADO SPRINGS | 4.61% | 64.864 | 4.55% | 141,272.844 | 1.24% | 16.289 | 1.22% | 35,559 318 |
| FLEMING | 0.00% | 0.068 | 0.00% | 141.403 | 0.01% | 0.087 | 0.01% | 188 137 |
| FORT MORGAN | 0.65% | 9.081 | 0.61% | 19,015.973 | 0.65% | 8.584 | 0.64% | 18,495.260 |
| FREDERICK | 0.00% | 0.045 | 0.00% | 115.384 | 0.00% | 0.038 | 0.00% | 95.511 |
| HAXTUN | 0.04% | 0.546 | 0.04% | 1,103.302 | 0.04% | 0.575 | 0.04% | 1,217.513 |
| HOLYOKE | 0.14% | 2.023 | 0.14% | 4,214.092 | 0.12% | 1.598 | 0.12% | 3,441.244 |
| LAMAR | 0.19% | 2.663 | 0.18% | 5,555.122 | 0.17% | 2.192 | 0.16% | 4,715 263 |
| NO. COL. WCD | 0.00% | 0.000 | 0.00% | 0.000 | 0.27% | 3.573 | 0.31% | 9,078.000 |
| PLATTE RIVER | 10.37% | 145.955 | 12.31% | 382,403.019 | 8.66% | 113.902 | 9.41% | 273,363.902 |
| PUEBLO ARMY DEPOT | 0.20% | 2.856 | 0.20% | 6,253.067 | 0.20% | 2.641 | 0.20% | 5,820.433 |
| TRI-STATE (CO-WY) | 16.06% | 226.027 | 15.22% | 472,836.547 | 20.76% | 272.938 | 20.24% | 587,818.883 |
| WILLWOOD LT & PWR | 0.00% | 0.039 | 0.00% | 86.267 | 0.00% | 0.050 | 0.00% | 108.933 |
| WRAY | 0.08% | 1.059 | 0.07% | 2,318.709 | 0.04% | 0.501 | 0.04% | 1,104 557 |
| YUMA | 0.10% | 1.411 | 0.10% | 2,950.599 | 0.09% | 1.223 | 0.09% | 2,634.474 |
| TORRINGTON | 0.09% | 1.302 | 0.09% | 2,673.435 | 0.15% | 1.922 | 0.14% | 4,127.592 |
| WMPA | 0.48% | 6.731 | 0.47% | 14,727.997 | 0.38% | 5.036 | 0.37% | 10,775.528 |
| **TOTAL LOVELAND AREA OFFICE** | 33.15% | 466.471 | 34.12% | 1,059,621.875 | 32.87% | 432.231 | 33.08% | 960,875.046 |

SUBJECT TO REVISION

| CUSTOMER | Winter Season % | Cap | % | Eng | Summer Season % | Cap | % | Eng |
|---|---|---|---|---|---|---|---|---|
| AK-CHIN | 0.14% | 1.920 | 0.14% | 4,273.433 | 0.32% | 4.244 | 0.32% | 9,373.563 |
| APPA | 0.96% | 13.568 | 0.97% | 30,197.295 | 2.07% | 27.275 | 2.07% | 60,248.025 |
| CHANDLER HEIGHTS | 0.02% | 0.302 | 0.02% | 671.748 | 0.03% | 0.400 | 0.03% | 881.769 |
| COLORADO RIVER IRR./POWER | 0.06% | 0.881 | 0.06% | 1,933.823 | 0.03% | 0.442 | 0.03% | 1,011.397 |
| ELECTRICAL DISTRICT #3 | 0.20% | 2.880 | 0.21% | 6,409.748 | 0.66% | 8.631 | 0.66% | 19,063.962 |
| ELECTRICAL DISTRICT #4 | 0.26% | 3.680 | 0.26% | 8,189.262 | 0.37% | 4.897 | 0.37% | 10,815.570 |
| ELECTRICAL DISTRICT #5-M | 0.02% | 0.233 | 0.02% | 518.692 | 0.10% | 1.274 | 0.10% | 2,813.842 |
| ELECTRICAL DISTRICT #5-P | 0.19% | 2.633 | 0.19% | 5,859.936 | 0.22% | 2.948 | 0.22% | 6,510.552 |
| ELECTRICAL DISTRICT #6 | 0.00% | 0.000 | 0.00% | 0.000 | 0.47% | 6.245 | 0.47% | 13,794.786 |
| ELECTRICAL DISTRICT #7 | 0.05% | 0.729 | 0.05% | 1,623.416 | 0.37% | 4.807 | 0.37% | 10,618.756 |
| MARICOPA COUNTY MWCD NO.1 | 0.17% | 2.373 | 0.17% | 5,280.927 | 0.44% | 5.748 | 0.44% | 12,697.156 |
| OCOTILLO WCD | 0.02% | 0.272 | 0.02% | 606.459 | 0.09% | 1.162 | 0.09% | 2,565.706 |
| QUEEN CREEK IRR. DIST. | 0.00% | 0.000 | 0.00% | 0.000 | 0.14% | 1.887 | 0.14% | 4,167.452 |
| ROOSEVELT IRR. DIST. | 0.13% | 1.761 | 0.13% | 3,918.404 | 0.40% | 5.243 | 0.40% | 11,581.167 |
| ROOSEVELT WATER CONS. DIST. | 0.11% | 1.616 | 0.12% | 3,596.519 | 0.18% | 2.364 | 0.18% | 5,221.513 |
| SAFFORD | 0.04% | 0.560 | 0.04% | 1,246.991 | 0.09% | 1.227 | 0.09% | 2,710.445 |
| SALT RIVER PROJECT | 3.70% | 52.113 | 3.73% | 115,980.178 | 7.85% | 103.224 | 7.85% | 228,005.552 |
| SAN CARLOS IRR. PROJECT | 0.13% | 1.840 | 0.13% | 4,094.242 | 0.10% | 1.366 | 0.10% | 3,018.303 |
| SAN TAN IRR. DISTRICT | 0.00% | 0.000 | 0.00% | 0.000 | 0.07% | 0.882 | 0.07% | 1,948.991 |
| THATCHER | 0.03% | 0.363 | 0.03% | 806.788 | 0.04% | 0.556 | 0.04% | 1,228.656 |
| WELLTON-MOHAWK IRR. DIST. | 0.03% | 0.448 | 0.03% | 996.974 | 0.01% | 0.146 | 0.01% | 320.783 |
| WILLIAMS AFB | 0.06% | 0.912 | 0.06% | 1,993.462 | 0.17% | 2.265 | 0.17% | 5,002.065 |
| YUMA PROVING GROUNDS | 0.03% | 0.415 | 0.03% | 1,040.333 | 0.03% | 0.347 | 0.03% | 732.808 |
| COLORADO RIVER COMMISSION | 2.09% | 29.477 | 2.11% | 65,603.370 | 1.71% | 22.420 | 1.71% | 49,521.181 |
| **TOTAL PHOENIX AREA OFFICE** | 8.45% | 118.976 | 8.53% | 264,842.000 | 15.97% | 210.000 | 15.97% | 463,854.000 |

SUBJECT TO REVISION

## EXAMPLE: Variable Impacts to Hydropower Operations

Assuming the following conditions on a given summer day in an area served by Glen Canyon Powerplant:

Interim Low Fluctuating Flow Alternative
Monday, 7 a.m. water releases: 5,000 cfs
600,000 acre-feet release month (maximum allowable daily change of ±5,000 cfs)
All GCD units on-line
All interconnected utility generation and powerlines operational
GCD assigned to provide load control area regulation

Domestic electricity use will increase as people wake, prepare for school, work, and other daily activities. Business and industrial loads will increase as workers arrive and start up equipment, machinery, and air conditioning systems. As the day progresses and outside temperatures increase, air conditioners will draw more power as they work to maintain comfortable indoor temperatures. That requires increased generation from system powerplants, including GCD. The gates at GCD would open and increase water flow to the generators at a rate no faster than 2,500 cfs/hour as demand for electricity from Western's customers and others within the control area increased. If demand were to increase faster than GCD was allowed to operate to keep up, another source of power would be needed to make up the shortage. That source could be another SLCA/IP hydropowerplant or an interconnected thermal powerplant (**the resulting impact:** major added cost to the wholesale customer because thermal generation had to be purchased during onpeak periods).
If that source of additional power were to go out of service, or had to use all its available generation for its own loads, GCD, as the dam providing load control area regulation, would automatically increase generation to maintain an uninterrupted flow of power to all area loads (**the resulting impact**: minor to moderate additional costs to the customer for the additional energy provided to meet load). However, if GCD were close to its maximum allowable daily release limits, it would likely not be performing regulation control for the load control area (**the resulting impact**: major added costs for utilities that would have to contract with thermal powerplants for onpeak regulation control, and some increased risk of outages, leading to an emergency, if the thermal plant could not subsequently keep up with rapidly changing loads).

The affected utility would then likely request **emergency assistance** from the IPP. GCD often serves as the resource used to provide that assistance, and would do so in this case, providing the generation capability existed and the transmission system could accomodate it (**the resulting impact:** minor to moderate added costs to the customer, depending on the amount and duration of the assistance required). However, if GCD had already achieved its maximum allowable release for the day (10,000 cfs, based on a maximum allowable daily change of 2,500 cfs, up or down), then another powerplant (most likely a thermal powerplant) would have to provide the emergency assistance (**the resulting impact**: major additional cost to the utility for onpeak energy).

If the emergency were to extend beyond 72 hours, the utility would request **outage**

**assistance**, most likely from Western and specifically from GCD. As GCD would be operating under a restricted operational scheme (i.e., interim low flutcuating flows), and had already fluctuated to the allowable daily limit, GCD could not be used to provide either emergency assistance (beyond a certain minimum), or scheduled outage assistance (**the resulting impact:** if another resource was readily available within IPP, the event could be considered minor. If another resource was not readily available, there would be a potential for the condition to develop into an emergency while another source was being acquired (**the resulting impact:** some outages could be experienced and GCD may be forced to respond to an emergency situation).

NOTE: Emergencies are covered under all circumstances.

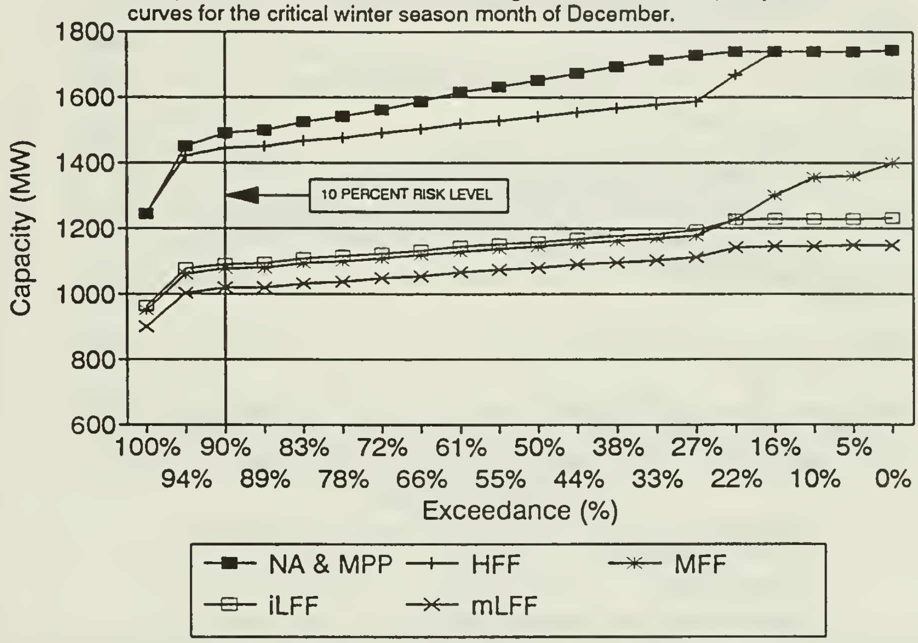
## Equivalent Forced Outage—Salt River Project

Equivalent forced outage rates for the Salt River Project would be affected by changes in dam operations. For a detailed analysis of these changes, under both the hydrology and CROD marketing approaches, see the Power Resources Committee Report (1993).

# FIGURE E-1

## Operable CRSP + Fontenelle Capacity

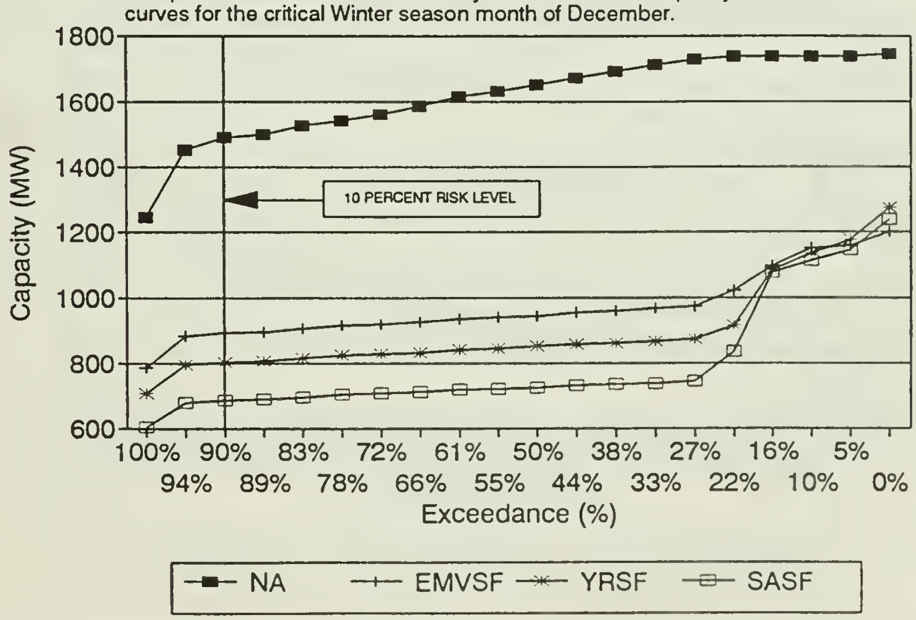
Comparison of No-action and fluctuating flow alternatives capacity exceedance curves for the critical winter season month of December.




# FIGURE E-2

## Operable CRSP + Fontenelle Capacity

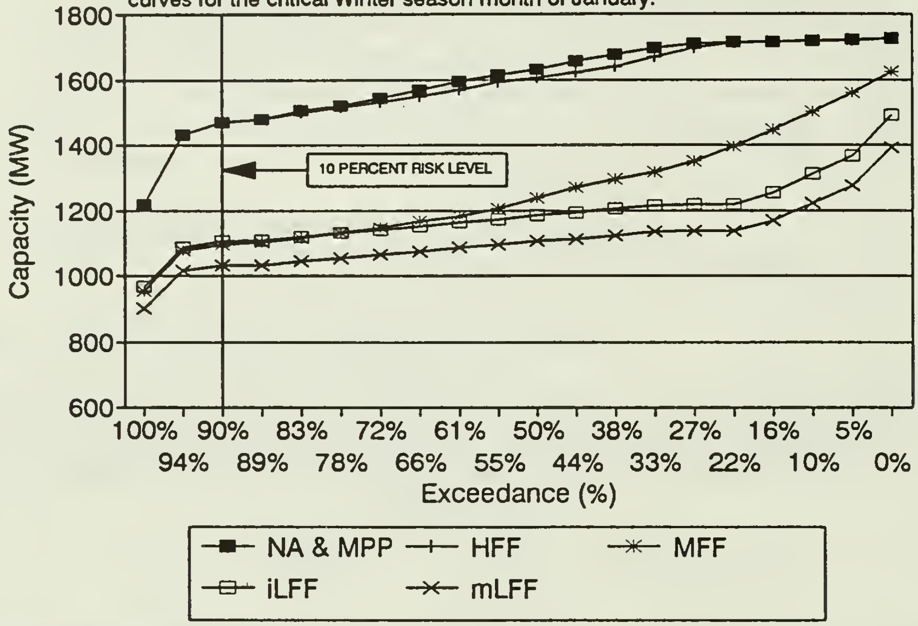
Comparison of No-Action and steady flow alternatives capacity exceedance curves for the critical Winter season month of December.



# FIGURE E-3

## Operable CRSP + Fontenelle Capacity

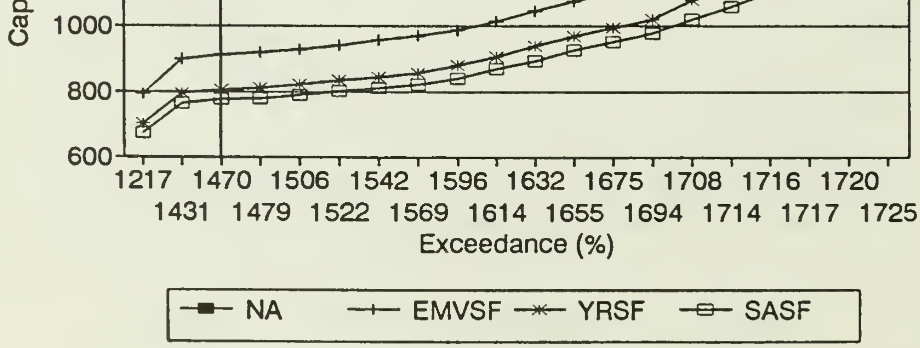
Comparison of No-action and fluctuating flow alternatives capacity exceedance curves for the critical Winter season month of January.




# FIGURE E-4

## Operable CRSP + Fontenelle Capacity

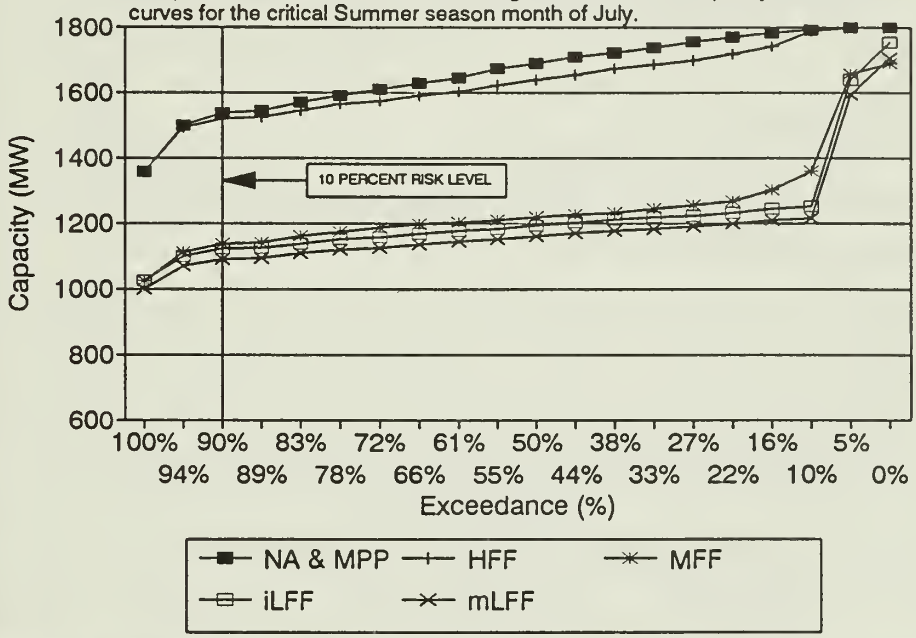
Comparison of No-action and steady flow alternatives capacity exceedance curves for the critical Winter season month of January.



# FIGURE E-5

## Operable CRSP + Fontenelle Capacity

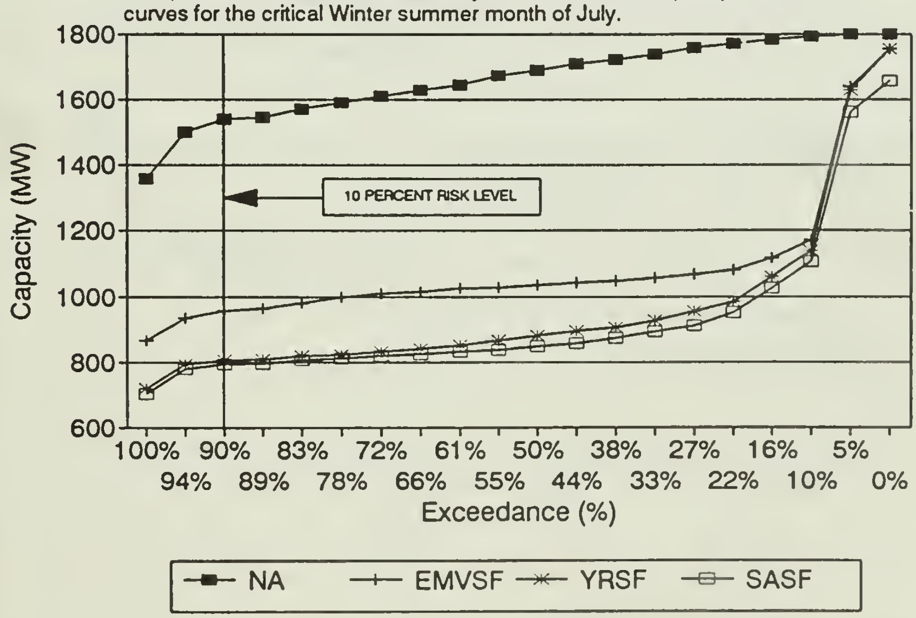
Comparison of No-action and fluctuating flow alternatives capacity exceedance curves for the critical Summer season month of July.




# FIGURE E-6

## Operable CRSP + Fontenelle Capacity

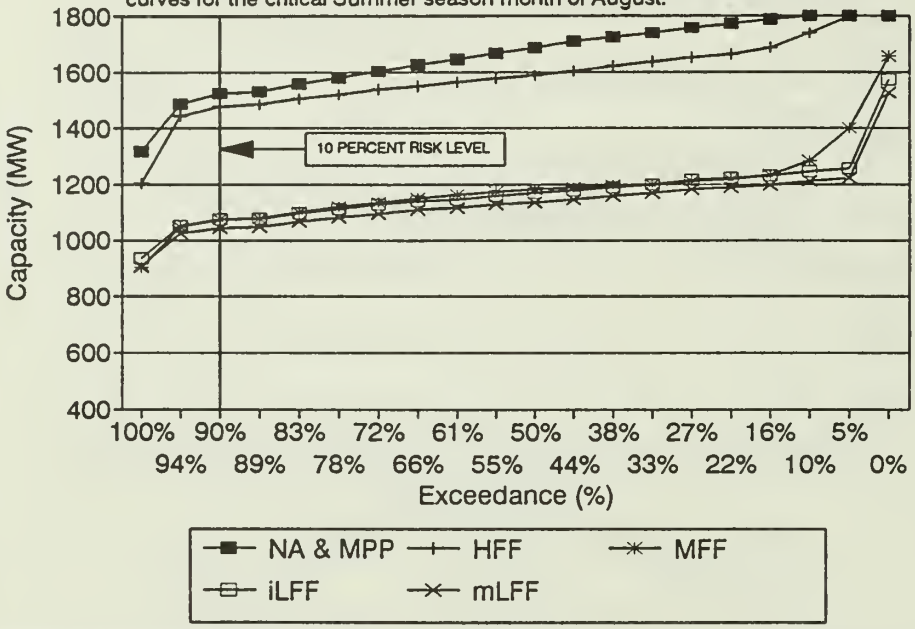
Comparison of No-action and steady flow alternatives capacity exceedance curves for the critical Winter summer month of July.



# FIGURE E-7

## Operable CRSP + Fontenelle Capacity

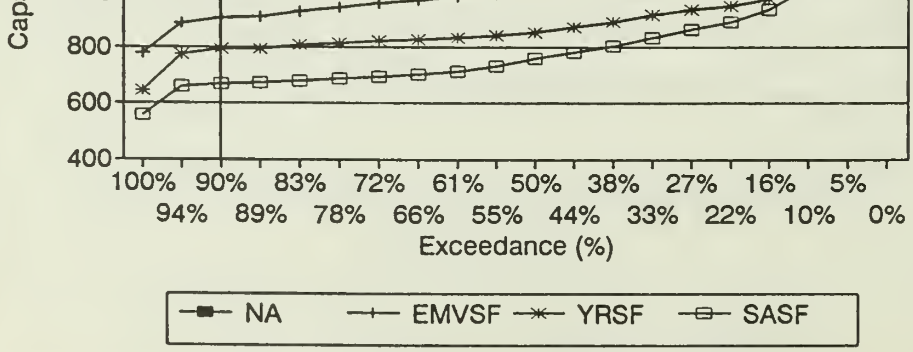
Comparison of No-action and fluctuating flow alternatives capacity exceedance curves for the critical Summer season month of August.




# FIGURE E-8

## Operable CRSP + Fontenelle Capacity

Comparison of No-Action and steady flow alternatives capacity exceedance curves for the critical Summer season month of August.



# Table E-2.--Retail rate impacts on representative small customers (mills per kWh)

| STATE | ALTERNATIVE | | NO ACTION | MAXIMUM POWERPLANT CAPACITY | | HIGH FLUCTUATING FLOWS | | MODERATE FLUCTUATING FLOWS | | INTERIM LOW FLUCTUATING FLOWS | | MODIFIED LOW FLUCTUATING FLOWS | | EXISTING MONTLY VOLUME STEADY FLOWS | | SEASONALLY ADJUSTED STEADY FLOWS | | YEAR ROUND STEADY FLOWS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CUSTOMER TYPE | DISTRIBUTION LEVEL | RETAIL RATE | RETAIL RATE | PERCENT CHANGE | RETAIL RATE | PERCENT CHANGE | RETAIL RATE | PERCENT CHANGE | RETAIL RATE | PERCENT CHANGE | RETAIL RATE | PERCENT CHANGE | RETAIL RATE | PERCENT CHANGE | RETAIL RATE | PERCENT CHANGE | RETAIL RATE | PERCENT CHANGE |
| ARIZONA | REC | L | 23.86 | 23.86 | 0 | 23.91 | 18.76 | 24.35 | 2.94 | 24.35 | 2.05 | 24.40 | 2.26 | 24.56 | 2.93 | 24.82 | 4.02 | 24.68 | 3.80 |
| | | M | 34.99 | 34.99 | 0 | 35.02 | 0.50 | 36.02 | 2.94 | 34.61 | 2.92 | 36.18 | 3.40 | 36.53 | 4.40 | 77.70 | 6.32 | 36.84 | 4.77 |
| | | H | 30.77 | 30.77 | 0 | 57.82 | 1.33 | 34.64 | 12.58 | 34.61 | 12.48 | 35.13 | 14.17 | 35.13 | 17.58 | 38.24 | 24.28 | 37.14 | 20.70 |
| | MUNI | L | 85.70 | 85.70 | 0 | 85.77 | 0.08 | 86.47 | 0.72 | 86.46 | 0.89 | 86.56 | 1.00 | 86.77 | 1.25 | 87.18 | 8.98 | 86.97 | 1.48 |
| | | M | 80.03 | 80.13 | 0 | 80.18 | 5.14 | 81.68 | 2.06 | 81.67 | 2.05 | 91.36 | 0.59 | 82.37 | 2.92 | 83.26 | 4.04 | 82.79 | 3.45 |
| | | H | 72.53 | 72.53 | 0 | 73.34 | 1.12 | 81.72 | 12.67 | 81.66 | 12.59 | 82.67 | 13.98 | 85.68 | 18.13 | 79.37 | 24.80 | 88.03 | 21.37 |
| | OTHER | L | 70.42 | 70.19 | 0 | 70.25 | 0.50 | 79.37 | 2.94 | 79.37 | 2.21 | 70.98 | 1.04 | 71.10 | 1.30 | 71.46 | 11.23 | 71.27 | 1.54 |
| | | H | 47.34 | 47.34 | 0 | 47.51 | 0.45 | 58.10 | 3.72 | 49.09 | 3.70 | 49.32 | 7.18 | 58.10 | 5.24 | 99.75 | 7.22 | 50.26 | 6.17 |
| | | H | 58.05 | 58.05 | 0 | 58.18 | 0.22 | 59.41 | 2.34 | 59.40 | 2.33 | 86.56 | 2.60 | 59.99 | 3.34 | 60.75 | 4.65 | 60.36 | 3.98 |
| COLORADO | MUNI | L | 78.75 | 78.75 | 0 | 78.94 | 0.24 | 82.53 | 2.34 | 80.58 | 2.32 | 99.75 | 0.59 | 81.41 | 3.38 | 82.52 | 4.79 | 81.94 | 3.05 |
| | | M | 88.13 | 88.13 | 0 | 88.32 | 0.22 | 90.90 | 2.22 | 90.08 | 2.21 | 90.31 | 7.18 | 60.85 | 3.20 | 82.53 | 4.79 | 81.94 | 3.80 |
| | | H | 52.09 | 52.09 | 0 | 52.09 | 0.50 | 58.10 | 5.32 | 58.10 | 5.28 | 35.13 | 0.59 | 69.20 | 7.89 | 34.64 | 11.23 | 57.04 | 9.50 |
| NEW MEXICO | REC | L | 52.09 | 67.98 | 0 | 68.06 | 0.24 | 68.85 | 2.94 | 68.85 | 12.48 | 68.85 | 3.40 | 68.85 | 4.40 | 80.40 | 1.79 | 69.01 | 1.52 |
| | MUNI | L | 66.97 | 66.97 | 0 | 67.01 | 0.30 | 67.45 | 0.72 | 67.45 | 0.72 | 67.50 | 0.79 | 67.67 | 1.05 | 67.97 | 1.49 | 67.81 | 1.25 |
| | | M | 88.13 | 88.13 | 0 | 78.36 | 0.27 | 80.34 | 2.80 | 80.32 | 2.2[illegible] | 80.58 | 7.18 | 81.28 | 4.01 | 82.53 | 5.60 | 81.88 | 4.77 |
| | | H | 34.99 | 83.99 | 0 | 84.54 | 0.65 | 91.36 | 8.85 | 91.36 | 8.77 | 92.33 | 9.93 | 95.13 | 13.26 | 99.75 | 18.76 | 97.36 | 15.92 |
| | OTHER | L | 52.09 | 57.79 | 0 | 57.82 | 2.05 | 35.13 | 0.85 | 58.10 | 0.54 | 35.13 | 0.59 | 58.10 | 0.78 | 58.42 | 1.09 | 58.32 | 4.77 |
| NEVADA | REC | H | 65.82 | 65.82 | 0 | 90.18 | 0.50 | 69.23 | 5.32 | 69.20 | 5.14 | 69.62 | 5.77 | 90.08 | 7.89 | 72.51 | 10.16 | 71.54 | 3.80 |
| UTAH | REC | L | 67.52 | 67.52 | 0 | 57.82 | 0.52 | 69.17 | 2.44 | 58.10 | 12.48 | 69.33 | 2.68 | 69.89 | 3.51 | 72.51 | 4.87 | 70.33 | 4.16 |
| | | H | 74.65 | 74.65 | 0 | 74.94 | 0.89 | 78.06 | 4.57 | 78.04 | 4.54 | 78.41 | 5.04 | 79.54 | 6.55 | 86.56 | 8.98 | 80.42 | 3.98 |
| | MUNI | L | 70.42 | 4.43 | 0 | 70.47 | 0.07 | 70.93 | 0.72 | 79.37 | 0.72 | 70.98 | 9.93 | 71.10 | 1.05 | 81.66 | 1.48 | 71.30 | 1.25 |
| | | M | 52.09 | 76.00 | 0 | 57.82 | 0.50 | 77.71 | 2.25 | 77.70 | 0.24 | 77.89 | 0.59 | 79.37 | 3.22 | 79.37 | 4.43 | 78.89 | 3.80 |
| | | H | 68.06 | 64.09 | 0 | 64.45 | 0.56 | 68.24 | 6.52 | 68.24 | 6.48 | 80.40 | 7.18 | 79.37 | 7.89 | 72.27 | 18.76 | 71.15 | 11.02 |
| WYOMING | REC | H | 72.78 | 1.75 | 0 | 73.14 | 0.49 | 76.62 | 5.27 | 76.59 | 5.23 | 77.03 | 3.40 | 78.27 | 7.54 | 80.40 | 10.47 | 79.30 | 3.80 |
| | MUNI | L | 35.71 | 35.71 | 0 | 35.78 | 0.20 | 36.83 | 3.16 | 36.83 | 3.14 | 36.99 | 3.58 | 37.34 | 4.56 | 38.01 | 8.98 | 37.66 | 5.46 |
| | | M | 57.17 | 57.17 | 0 | 57.30 | 0.23 | 58.39 | 2.13 | 58.39 | 2.12 | 58.55 | 2.41 | 58.39 | 2.96 | 59.73 | 4.48 | 59.16 | 3.48 |

L = Lower Quartile Value Observed  M = Median Value Observed  H = Upper Quartile Value Observed
REC = Rural Electric Cooperative Utility  MUNI = Municipal Utility  OTHER = Irrigation Districts
Missing customer type and/or distribution levles indicate non-applicability for that state and/or customer type.

SUBJECT TO REVISION

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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources, protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. Administration.

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*The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.*