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A PARAMETRIC STUDY OF THE VALUE OF HYDROLOGICAL INFORMATION FOR IRRIGATION AND HYDROPOWER MANAGEMENT OF THE FEATHER RIVER

ECON INCORPORATED

Report No. 75-127-5
NINE HUNDRED STATE ROAD
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FINAL

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A PARAMETRIC STUDY OF THE VALUE OF HYDROLOGICAL INFORMATION FOR IRRIGATION AND HYDROPOWER MANAGEMENT OF THE FEATHER RIVER

Prepared for

The National Aeronautics and Space Administration

Office of Applications

Washington, D. C.

Contract No. NASW-2558

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NOTE OF TRANSMITTAL

This report has been written for the National Aeronautics and Space Administration, Office of Applications under Contract NASW-2558.

The conclusions presented in this report are based on a case study of water management operations at the Oroville Damsite in California, and the associated hydrological, meterological, forecasting and economic conditions in the Feather River Basin that affect such operations. Generalizations of the results obtained from this case study to other river basins or to the United States as a whole should be made with considerable caution, since significant variations exist among river basins in hydrological and other conditions that affect water management operations. In particular, a statistical analysis is required for other river basins along the lines suggested in the report with respect to the relationship between errors in snow cover measurement and the resultant errors that occur in forecasted water supply.

ECON acknowledges the contribution of the Principal Investigator, Elliot Wetzler, the author of this report, and the contributions of Francis Sand, who wrote Section 4.4 and Chapter 5 and Peter Stevenson and Martin Putnam, who wrote respectively, Section 4.1 and Appendix H.

The author wishes to thank A. J. Brown and his staff, W. Cook, R. Hamilton, L. Lerner, W. Matsen and his staff, J. Peters and her staff and others at the State of California Department of Water Resources who provided cooperation and assistance to the author.

Submitted by: Francis Sand
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Approved by: B. Miller
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Project Director

ABSTRACT

This report presents a case study analysis of the relationships between improvements in the accuracy, frequency and timeliness of information used in making hydrological forecasts and economic benefits in the areas of hydropower and irrigation. The area chosen for the case study is the Oroville Dam and Reservoir. Any information which can be used to improve the quality of the basin runoff forecast can lead to economic benefits by indirectly affecting the supply of water for hydropower and irrigation. By allowing the timely and accurate mapping of the aerial extent of snow in the basin, earth resources survey* systems such as LANDSAT can contribute to improvements in the corresponding accuracy and timeliness of forecasts.

This study treats the subject of benefits resulting from improved runoff forecasts in a generalized way without specifying the source of the improvements. As an aid to the reader interested in satellite snow mapping applications, the relationship between the quality of measurements of snowcover and the accuracy of the spring runoff forecast (April 1) is analyzed. For the most part, the study is constrained by the requirement that flood control regulations (as formulated by the Army Corps of Engineers) and power generation plans --

*"ERS," acronym to be used subsequently in text.

existing "policy" of reservoir management -- be followed faithfully. A special section of the study, however, is devoted to the consideration of benefits under different policies, e.g., less flood control reservation space.

The estimation of benefits from improved seasonal runoff forecasting has required: (i) a review of the runoff forecast models for Oroville in use at the California Department of Water Resources and (ii) a statistical analysis of the forecast errors in the critical April 1 seasonal runoff forecast. The methodology for making the (April through July) seasonal runoff forecast* was reviewed in detail, and the relationship between the forecast models and the measurement of snowcover discussed. The errors in the April 1 forecast were calculated for the years 1942 through 1967, and a regression analysis performed to determine the extent to which improved snowcover measurements could contribute to improved seasonal runoff forecasting. It was found that 92.5% of the April forecast error variance could be "explained" by the April-July precipitation; therefore only 7.5% of the error variance remained to be affected by the improved snowcover measurements. On the other hand, analysis of the same data revealed a significant negative bias in the April forecasts, largely due to the underforecasts in unusually wet years. Correction of the bias could possibly lead to a significant advantage for the reservoir management in those years. However,

*Forecasts are made on the first of each month from February through June.

it is not yet clear whether improved snowcover measurements would contribute to this bias correction and, if so, to what tent they would reduce the bias.

We caution against drawing final or general conclusions regarding the application of ERS derived snow mapping to improved reservoir management, in view of the complexity of the latter subject and the uncertainties surrounding the relative importance of various inputs to the decision process. Moreover, geographical, climatological and technological factors may combine in such a manner that the value of improved snow mapping is more important in the prediction of runoff in some river basins than in others.

The relationship between increases in the accuracy of forecasts, length of the forecast period and economic benefits at Oroville in the areas of hydropower and irrigation are shown in Figures 1 and 2. These results are obtained under the existing policies of reservoir management. Figure 3 shows the relationship between maximum economic benefits and a policy variable affecting the amount of flood control reservation space.

The total potential economic gains which can be obtained from policy variation amount to about $9,760,000 annually (average marginal value of additional annual hydropower in 1975 dollars at 1975 prices). By adopting a more conservative policy, but nevertheless utilizing improved forecasts of the expected inflows to Oroville, some fraction of this additional

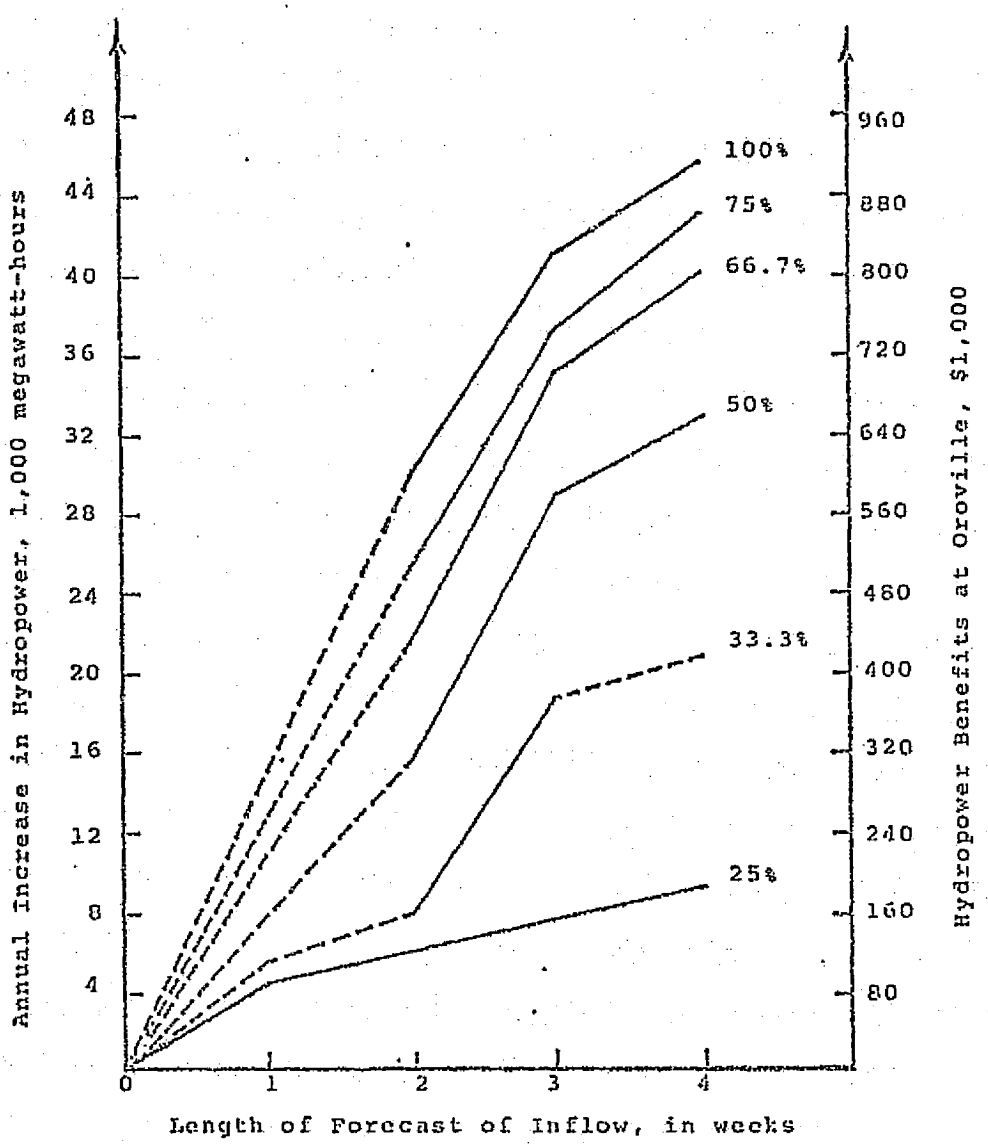

Figure 1. Hydropower Benefits at Oroville from Increased Forecast Accuracy and Length of the Forecast Period

Note: Percent values are "increases in forecast accuracy." They can be defined as:

$$100 \times \frac{\text{Std. Dev. of Current Forecast Error} - \text{Std. Dev. of Improved Forecast Error}}{\text{Std. Dev. of Current Forecast Error}}$$

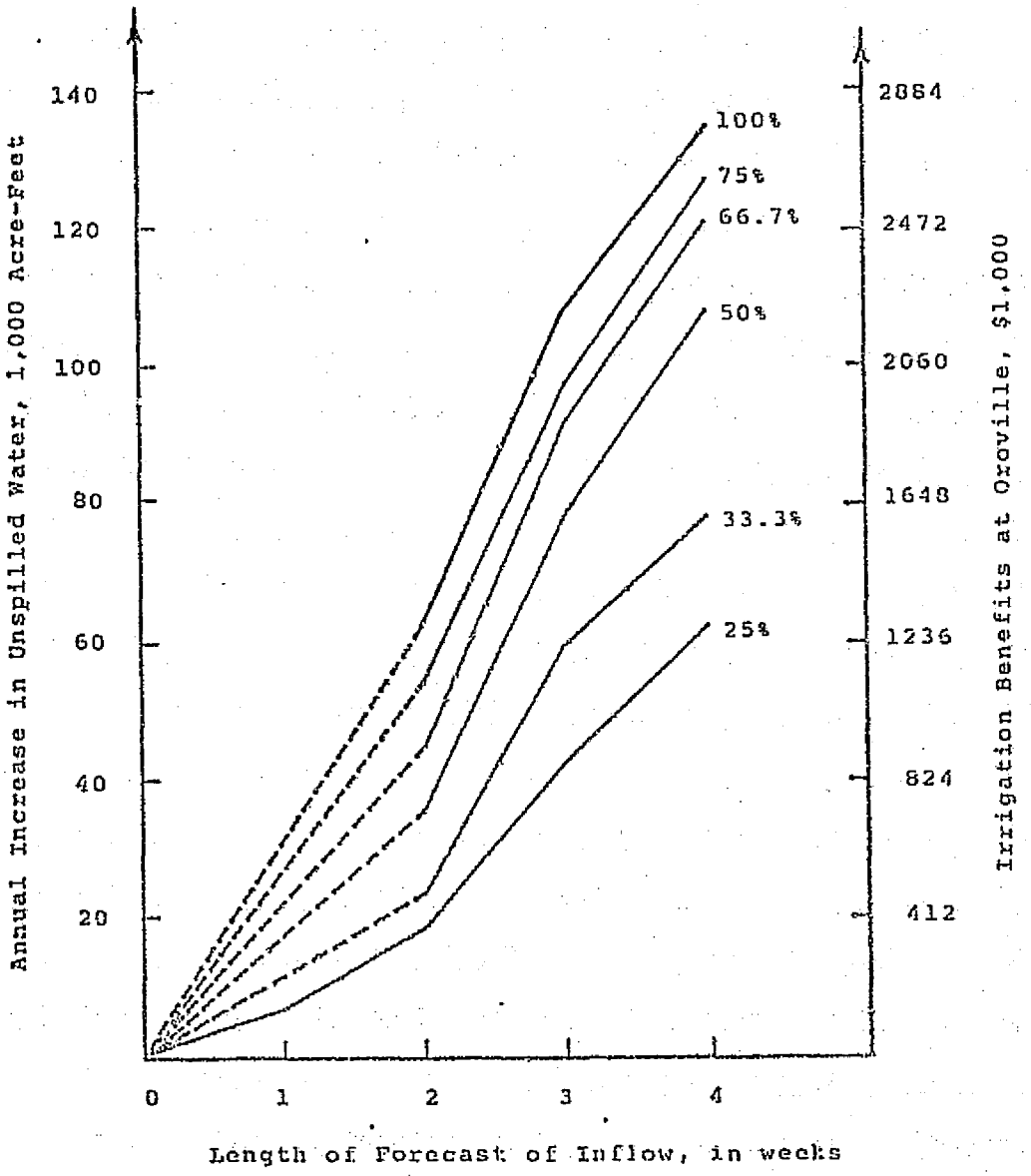

Figure 2 Irrigation Benefits at Oroville from Increased Forecast Accuracy and Length of the Forecast Period

Note: Percent values are "increases in forecast accuracy." They are defined as:

$$100 \times \frac{\text{Std. Dev. of Current Forecast Error} - \text{Std. Dev. of Improved Forecast Error}}{\text{Std. Dev. of Current Forecast Error}}$$

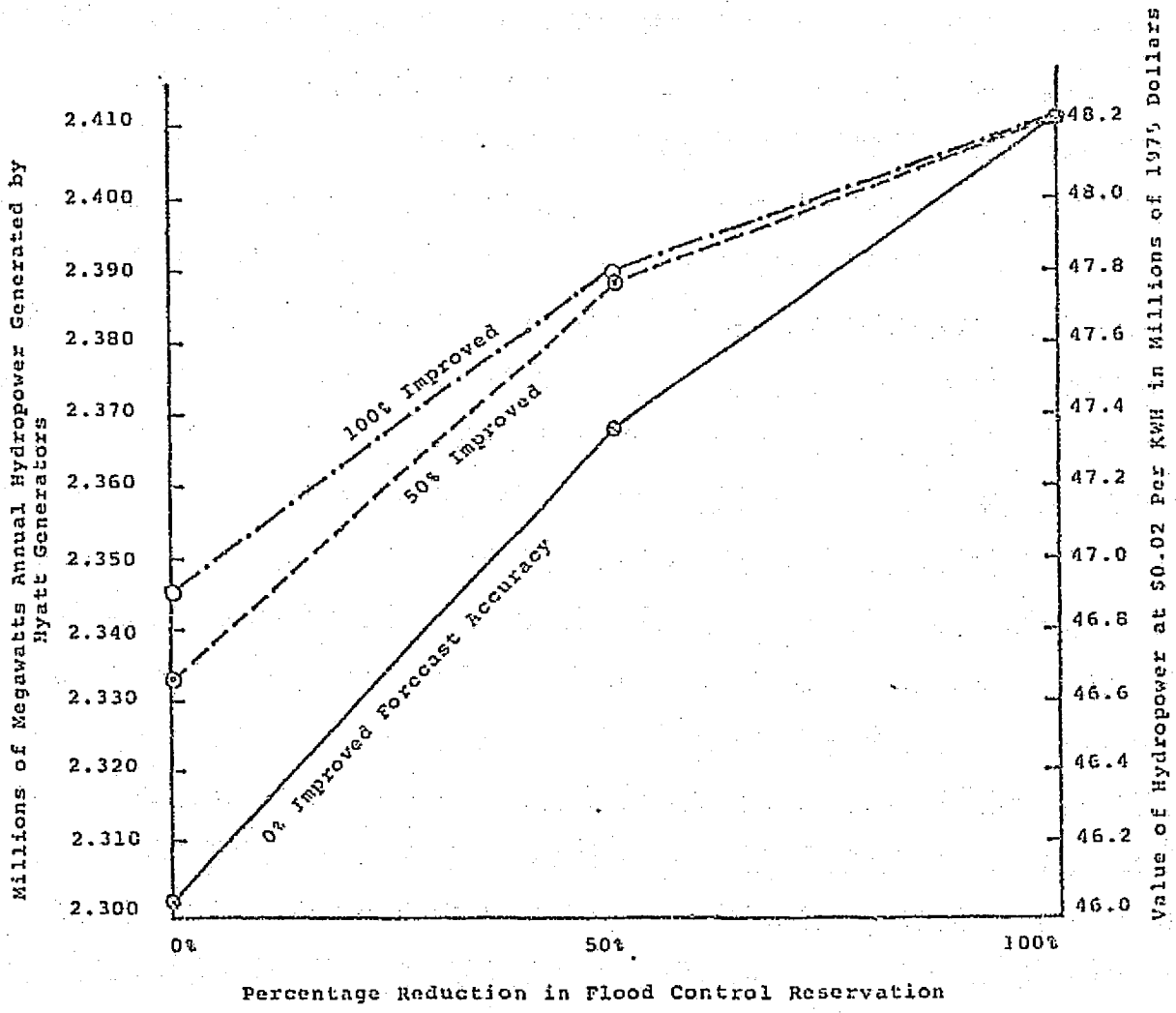

Figure 3. The Economic Effects (Potential) of Policy Changes (Hydropower Only) in Water Management at Oroville

Note 1: Percent values are "increases in forecast accuracy." They can be defined as:

$$100 \times \frac{\text{Std. Dev. of Current Forecast Error} - \text{Std. Dev. of Improved Forecast Error}}{\text{Std. Dev. of Current Forecast Error}}$$

Note 2: Four week forecast range was used for improvements.

potential gain may be generated.* In view of the fact that the above estimate does not include off-peak power generation and it does not include additional benefits in irrigation and other areas of application, it may be regarded as a low estimate of the true maximum potential benefits. A full-scale investigation of the optimal policy with regard to maximum economic output from Oroville, subject to reasonable constraints, thus appears to be warranted.

*The estimation of the value of this fraction has to be the subject of another study, because of the complexity, both technical and legal, of changing reservoir management policies.

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1. INTRODUCTION

1.1 The General Water Impoundment Management Problem

Water impoundment management serves a variety of purposes. It can be used as a means of preventing floods or minimizing flood damage, and also to maximize the amount of power generated. It can be used to supply water for a variety of uses (agricultural, industrial, residential) at the most appropriate times and amounts. These various functions of water management may at some seasons of the year be complementary and at other times be competitive with each other. An example of such a relationship is hydropower generation and downstream water supply. If, at a certain time of the year, a high demand for hydropower coincides with a high demand for downstream water, then these two users are complementary since water first used for hydropower can then be used for downstream water supply. However, if the demand for hydropower is high now, and will be low later in the season, and the demand for downstream water is low now, but will be high later in the season, then the two uses of water are competitive. More economically useful hydropower means less economically useful downstream water while, conversely, more economically useful downstream water means less economically useful hydropower. One function that is competitive with hydropower generation is flood control. Maximizing the hydropower generation potential of each acre-foot of water at Oroville requires that the average height of water above the turbines be at the maximum feasible level. However, in order to prevent floods, at certain times of the year it is required that the water level in the Oroville Reservoir be kept well below the maximum feasible level. The more stringent the flood control criteria, the less hydropower can be generated. Clearly, this presents a critical

management problem if flooding would cause serious economic damage while, at the same time, the demand for hydropower is extremely high.

In order to determine, in an economically proper way, how much water should be allocated to different uses, it is necessary to know in detail the demand for and the supply of water. The total supply of water depends on the amount of water in the reservoir, the water table, evaporation and evapotranspiration conditions, the amount of snow cover and the amount of future rainfall and snowfall.

Therefore, to estimate water supply requires estimates of each of the above variables. Since the amount of water in a reservoir will be known with a high degree of accuracy, we can omit that variable from the present discussion. The estimation of water table, evaporation, and evapotranspiration conditions are handled in present-day short-term forecasting models in a very approximate way. For long-term seasonal forecasting models, these conditions are generally not considered to be important. The water content of snow cover can be estimated by ground truth, aircraft, or satellite. Predictions of future rainfall and snowfall depend on weather forecasting models. Potentially, better information on some of these variables could also be obtained by satellite.

With better information on these variables, better forecasts can be made of water supply. These improved forecasts, in turn, can be used to better manage reservoir operations. The relationship between better information which may be in the form of more accurate information, more timely information, or more frequent information, and better forecasts is discussed in Sections 2.1.1 to 2.1.4. The behavior of the actual seasonal forecast error is discussed in Section 2.1.5. The discussion in Sections 2.1.1 and 2.1.5 indicates how much error now exists in the seasonal forecast and thereby sets the upper bound on potential seasonal forecast improvement while

Section 2.2 indicates how much short-term forecast error exists, based on historical data of daily streamflow.

As stated above, management of a reservoir is carried out within the constraints of flood control criteria. Appendix A presents a theoretical discussion of proper flood control criteria based on the accuracy, frequency and timeliness of forecasts. These forecasts, in turn, are related to the accuracy, frequency, and timeliness of information (see Sections 2.1.1 to 2.1.4). The actual flood control criteria under which the managers of the Oroville Dam have to operate are given in Appendix B.

Section 2.4 presents an important discussion of the sources of the seasonal forecast errors. This section answers the question of how much of the forecast error is due to missmeasurement of snow cover and how much of it is due to other factors.

Given better forecasts as a result of better information, how does this process translate into economic benefits? This question is explored in Chapters 3 and 4 of this paper. Section 3.1 discusses a general economic model of hydropower benefits as a consequence of better forecasts. Section 3.2 presents a discussion of irrigation benefits as a consequence of better forecasts. Since Section 3.1 omits some of the critical constraints that affect economic benefits, a simulation model that includes the critical constraints is analyzed. Section 4.1 describes the original simulation model, Section 4.2 the modifications incorporated to simulate the effects of improved forecasts of water supply, and Section 4.3 the results obtained from the simulation of different degrees of improvement in water supply forecasts.

A brief description of operations at the Oroville Damsite and the characteristics of the Feather River Basin is given in the next section. A more extensive description of

the characteristics of the Feather River Basin is presented in Appendix E.

1.2 The Feather River Project

The Feather River Project is the initial unit of the California Water Plan. The project was approved by the California State Legislature in 1951 and the first appropriation occurred in 1957. The total Feather River Project cost is about $370 million divided between the Upper Feather Division and the Oroville Division. The Upper Feather Division consists of Frenchman Dam and Lake, Antelope Dam and Lake, Grizzly Valley Dam and Lake Davis, Abbey Bridge Dam and Reservoir, and Dixie Refuge Dam and Reservoir plus the Grizzly Valley Pipeline. The Oroville Division consists of the Oroville Dam and Lake Oroville, the Edward Hyatt Powerplant, the Thermalito Facilities, and three subsidiary dams. The total drainage basin area of the Feather River Project is 3611 square miles and had produced an average annual unimpaired runoff at the Oroville Damsite for 65 years of record (1902-1967) of 4.2 million acre-feet. Figure 1.1 shows the Feather River drainage area.

A detailed description of the Feather River Basin is given in Appendix E. This description covers (a) the location, area, elevation, and vegetation of the different components of the Feather River Basin, (b) the climate of the Basin, with specific references to temperature, precipitation, and snowfall, (c) runoff characteristics of the Basin, (d) flood characteristics of the Basin, and (e) the downstream areas subject to flooding.

The analysis of the benefits to be gained through improved water management in the Feather River Project as a result of remote-sensed data requires a description of water management decision parameters as they apply to current procedures employed at the Oroville-Thermalito facilities. These

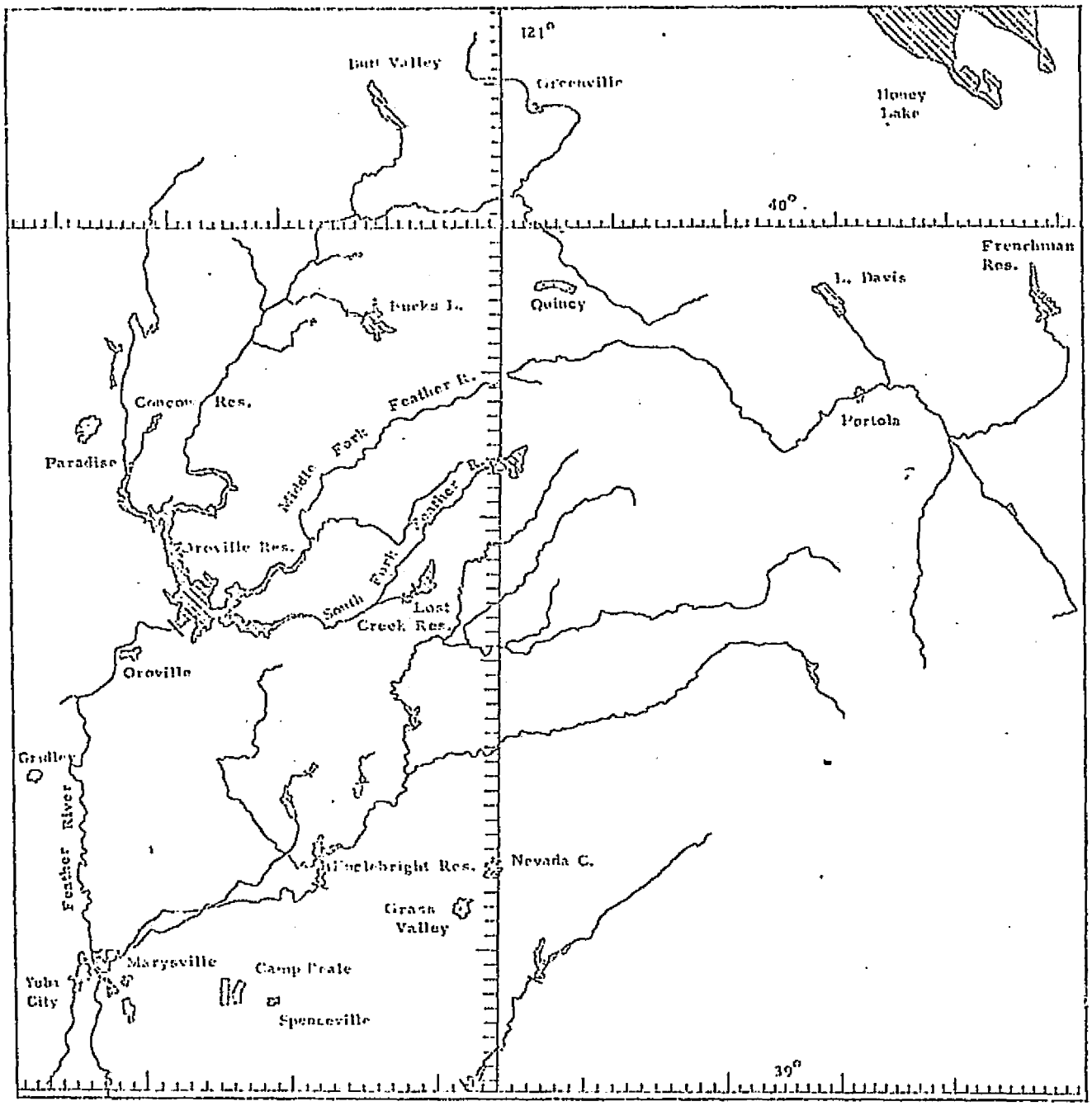

Figure 1.1 The Feather River Drainage Area

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facilities provide the main control of the flow of water from the Feather River drainage basin into downstream channels which comprise a portion of the California Water Project.

1.3 Current Operation of the California State Water Project

In an effort to prevent natural disasters (i.e., floods, droughts, etc.), historical data have been collected by water management officials with regard to uncontrolled flow rates in many water carrying channels. These data have been related to minimum and maximum permissible rates in each channel so that natural disasters can be avoided. Once this information is made available, efforts to control flow rates can be initiated and operational procedures outlined. Currently, control of flow rates at individual facilities is based on three basic parameters, (1) expected near-term inflow rates into reservoirs, (2) reservoir storage capacity, and (3) downstream channel capacity. Reservoir storage and downstream channel capacity are defined for each facility and do not need further elaboration here. These parameters are discussed in Appendix B. However, inflow rates are stochastic and will therefore be delineated further.

Expected near-term inflow rates are typically dependent on three basic variables: the state of the terrain (ground wetness, ground cover, soil type, shape, etc.), and actual near-term precipitation and snow cover. Currently, ground wetness is used to approximate the first variable and precipitation is determined from precipitation stations and weather forecasts. Snow cover is determined from snow survey stations. Ground wetness is simplified at present by assuming that it is functionally dependent only on precipitation. Using this type of data, five day hydrograph projections of inflow rates are made for the Feather River. Since short-term inflow rates can be relatively large, large safety factors are employed at Oroville in order to prevent natural disasters. Control of water

resources by using large safety factors does provide reasonably high levels of protection against floods, but it limits the ability to manage water resources in a dynamic sense.

1.4 Current Operation of the Oroville-Thermalito Facilities

The Oroville-Thermalito facilities function as a multi-purpose operation. Two major functions are flood control and power generation. It should be noted, however, that water supply and water quality control will play an increasing role as time passes and will provide critical input requirements and constraints to the California Water Project by the late 1980's.

Flood control is achieved by investigation of projected reservoir inflow rates and reservoir storage capacity, and reservoir outflow rates, which are determined from an antecedent precipitation index model (API model) described in Section 2.3.2. Within a year, this API model will be replaced by a "Generalized Streamflow Simulation System" model developed by the Joint Federal-State River Forecast Center.

Along with a flood control requirement, power is generated at the Edward Hyatt and Thermalito facilities. Edward Hyatt, with six generators (three reversible for pumpback), has a generation capacity of 678,750 kilowatts, and Thermalito, with four generators (three reversible for pumpback), has a generation capacity of 119,600 kilowatts. Although both facilities are designed for pumpback operations, this aspect of the project has only been used for test purposes to date. Eventually, power generation and pumpback capabilities will add degrees of freedom to the entire system that will impact on the decision policies of the managers.

2. STATISTICAL ANALYSIS OF HYDROLOGICAL INFORMATION AND FORECASTS

2.1 Translation of Better Information Into Better Forecasts

In this section, we will develop the effect of improvements in the accuracy, timeliness, and frequency of information on the distribution of forecast errors. For expositional purposes, we will examine first the question of the effect of improvements in the accuracy of information (i.e., improvements in the accuracy of data in the forecasting model). Later in this section, we will discuss the effect of more frequent data collection and dissemination of information on the distribution of forecast errors. The last part of this section will discuss the effect of the timeliness of the data collection and forecasting process.

2.1.1 Forecast Range Diagram

A general description of the degree of "accuracy" of a forecast is given by a cumulative probability density function of the forecast errors at each forecast date. For example, a representation of the cumulative distribution of forecast errors of the April to July seasonal runoff for the Feather River on February 1 is given by the flatter dashed line on Figure 2.1. On March 1, these errors are given by the flatter solid line; on April 1 by the steeper dashed line and on June 1 by the steeper solid line.

Points B1, B2, B3 and B4 schematically represent the "90 percent probability levels" for the February 1, March 1, April 1, and May 1 forecast dates, respectively. That is to say, at Point B, a 90 percent probability exists that the forecast error will be less than the level given by Point B. Likewise, points C1, C2, C3, and C4 show the 75 percent probability levels for, respectively, the February 1, March 1, April 1, and

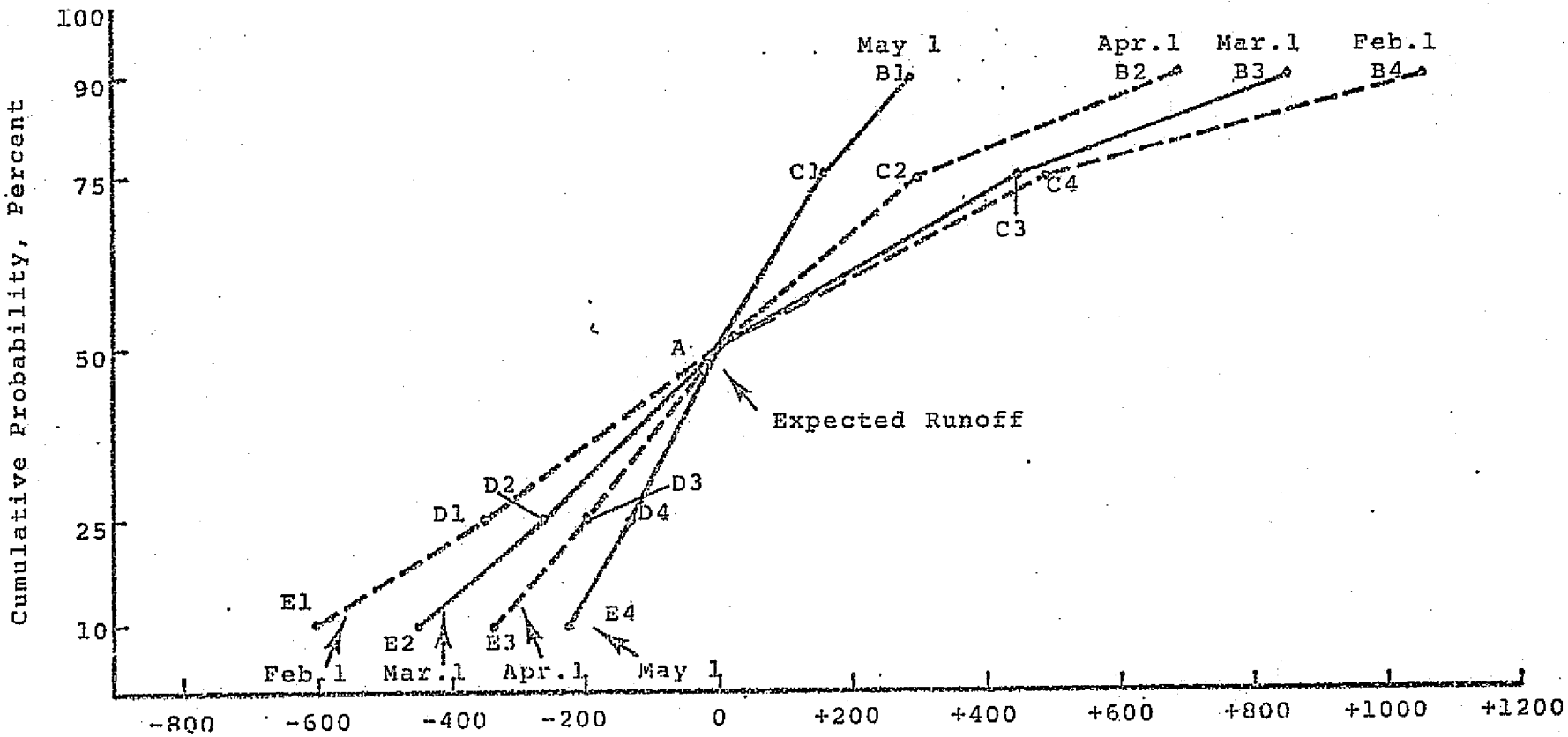

Figure 2.1 Cumulative Probability Distribution of Forecast Errors for a Forecast of the Mean Expected April through July Seasonal Runoff

May 1 forecast dates. At any point C, a 75 percent probability exists that the "positive" forecast error will be greater than the level given by Point C. Points D and E represent, respectively, the 25 percent and the 10 percent probability levels. The type of information given by Points B, C, D, and E can be translated into a "forecast range diagram."

Since a forecast range diagram takes selected points from a set of general probability distributions of the forecast error, it, of course, contains less total information than the original distributions. However, for some purposes, such as ease of exposition, it is often more convenient to use a forecast range diagram. In fact, because it contains less information, some phenomena (such as the effect of accuracy, frequency and timeliness of information on forecast accuracy) that can be explained easily with a forecast range diagram can be explained only with considerable difficulty (and possible confusion) using a set of general error distributions. For other reasons, such as for a decision-maker who is concerned with some critical (to the decision-making process) probability level, it is probably more useful to use a forecast range diagram than a set of more general error distributions such as those shown in Figure 2.1. Also, in some cases it may almost be a necessity to use a forecast range diagram. There can be situations where the scantiness of the underlying data does not permit a reasonably accurate representation of the general error distribution, but does permit the determination of the location of a limited number of selected probability levels.* Another point to be made for the usefulness (in a practical and pragmatic sense) of the forecast range diagram is that water resource decision-makers (at least in California) are familiar with this

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*This is the case for Figure 2.1 where we have arbitrarily drawn straight lines between known point values.

diagram, but are less familiar with, and typically do not have available, the set of more general forecast error distributions shown in Figure 2.1.

The forecast range diagram constructed by the Water Resources Department of the State of California for the Feather River at Oroville is illustrated in Figure 2.2. The points A, B1, B2, etc., in Figure 2.2 correspond to the identically labelled points in Figure 2.1.* The forecasting model underlying this forecast range diagram is derived from a process of comparing actual runoff with forecast runoff over a 25-year period.** It shows over the forecasting period, the specific probability values of having an amount of unimpaired water runoff above (or below) the mean forecast unimpaired water runoff. For example, on February 1, these is a 10 percent probability that the actual water runoff during the April to July period will be greater than 1,060,000 acre-feet above the mean forecast runoff. On May 1, however, there is a 10 percent probability that the actual water runoff will be 290,000 acre-feet above the mean forecast runoff, a considerable drop from the February 1 level. This funnel effect should occur, since forecasts can be updated by actual event information replacing some of the previously projected information.

We have been examining the forecast range diagram, which shows probability bands for a seasonal forecast. However, in principle the same type of diagram can be applied to any forecasted period, whether it be a century, a season, a month, a week, or a minute. A forecast range diagram of daily flows for the Feather River over a one-month period is described in

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*For expositional purposes, we have added points A, B1, B2, etc.

**In Section 2.1.3, we present some evidence which suggests that the forecast range diagram used by the State of California for the Feather River may be inaccurate.

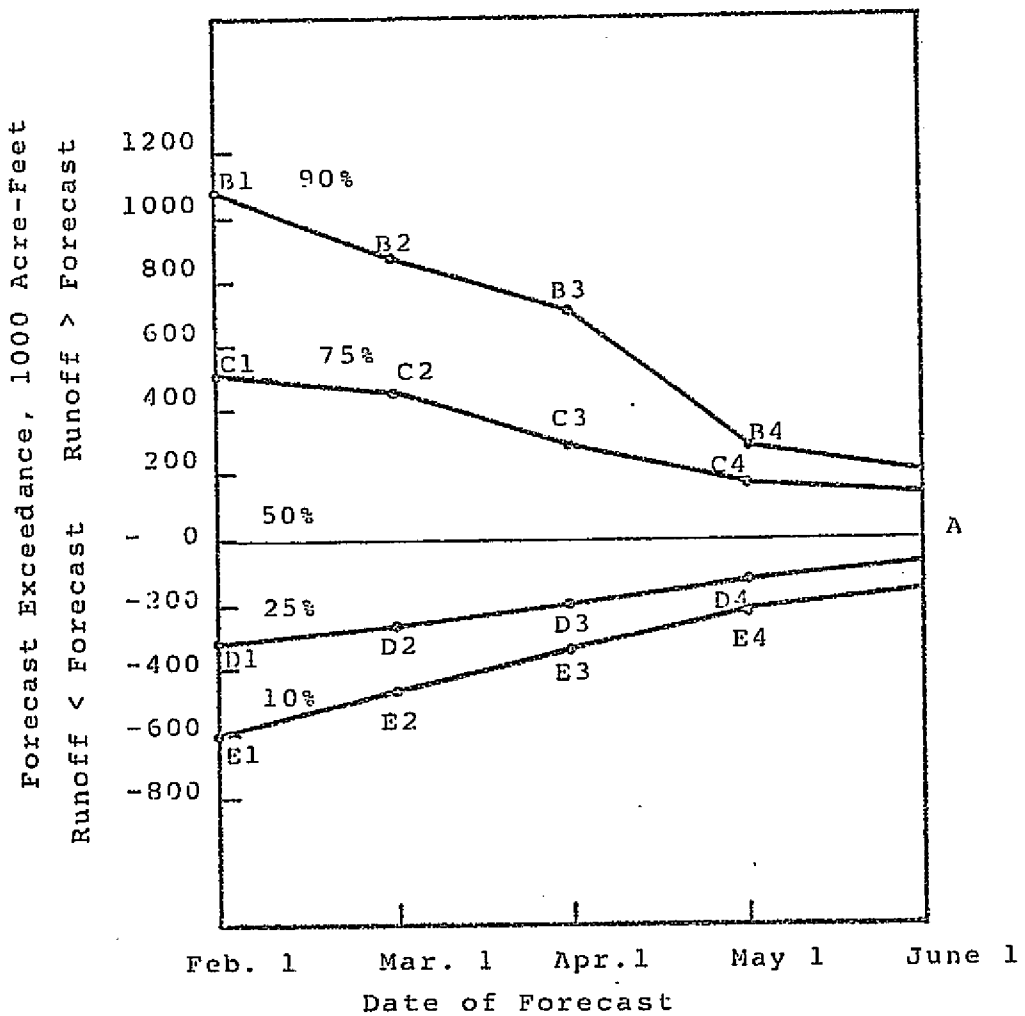

Figure 2.2 Forecast Range Diagram

Source: State of California, Department of Water Resources, Oroville, April-July Unimpaired Runoff, Sheet 3

Section 2.2. This means that the principles that we will derive from the forecast range diagram governing the relationship between the accuracy, frequency, timeliness of information and the accuracy of forecasts will apply to forecasts of any time period. (General principles derived from the forecast range diagram can be related to corresponding general principles applicable to the error distributions, but with a considerable loss in the clarity of the exposition.)

2.1.2 Accuracy of Information

In general, the determination of the spread of the forecast range diagram probability bands is given by the "accuracy" of the data used in the forecasting model and the "accuracy" of the forecasting model itself. The "accuracy" of the data inputs, however (reasonably) measured, are some function of the mean and frequency distribution of the errors in the data while the "accuracy" of the model, however (reasonably) measured, is some function of its error characteristics. Errors in the inferences derived from the sample data could be due to either (or both) an inaccuracy of measurement of the actual sample inputs used in the forecasting model (i.e., a measurement error) or to an extrapolation of the sample results to the whole (i.e., sampling error). Errors embedded in the forecasting model can be due to: (a) model misspecifications such as the omission of some important variables or to an imperfect relationship between some or all of the variables, or to (b) inaccurate estimates of coefficients on some or all of the variables. In practical terms, there always will be some inaccuracy in the data and some inaccuracy in the model used.

In Section 2.4, Analysis of the Sources of Error in the April-July Forecast, we will examine the "accuracy" of the April-July forecast model of the Feather River, or more specifically, the mean percentage error in the April-July

forecast of unimpaired runoff for the Feather River at Oroville due to model errors and due to errors in each of the forecast input variables.

As illustrated by Figure 2.3, improvements in accuracy of information cause the probability bands to narrow. The precise way in which such narrowing takes place depends on specific information on the nature of the distribution of data errors and the distribution of model errors. In general, information on the data distribution errors and model distribution errors can at best only be inferred (or assumed). However, the amount in which each source of error contributes to the overall error can be derived from an analysis of covariance. This information indicates which sources of error it pays to reduce in terms of more accurate forecasts and which sources of error can be safely ignored. Such an analysis was performed for the Feather River and is described in Section 2.4.

In Section 2.4, we develop the methodology for determining the relationship between improvements in the measurement accuracy of snow cover and precipitation and the accuracy of the forecast. Then, we examine specifically these relationships for the Feather River. In the case of the Feather River, improvements in either the measurement accuracy of snow cover or in the accuracy of measurement of precipitation that has already occurred will not improve the accuracy of the seasonal forecast significantly. If the relationship between forecast error and accuracy of forecasted precipitation developed in Section 2.4 for the Feather River holds for all levels of forecast error, then each 1.0 percent increase in the accuracy of predicted precipitation means an increase in forecast accuracy of 0.925 percent.

2.1.3 Frequency of Information

Frequency of forecast is a function of the frequency of data collection and the frequency of input of these data into

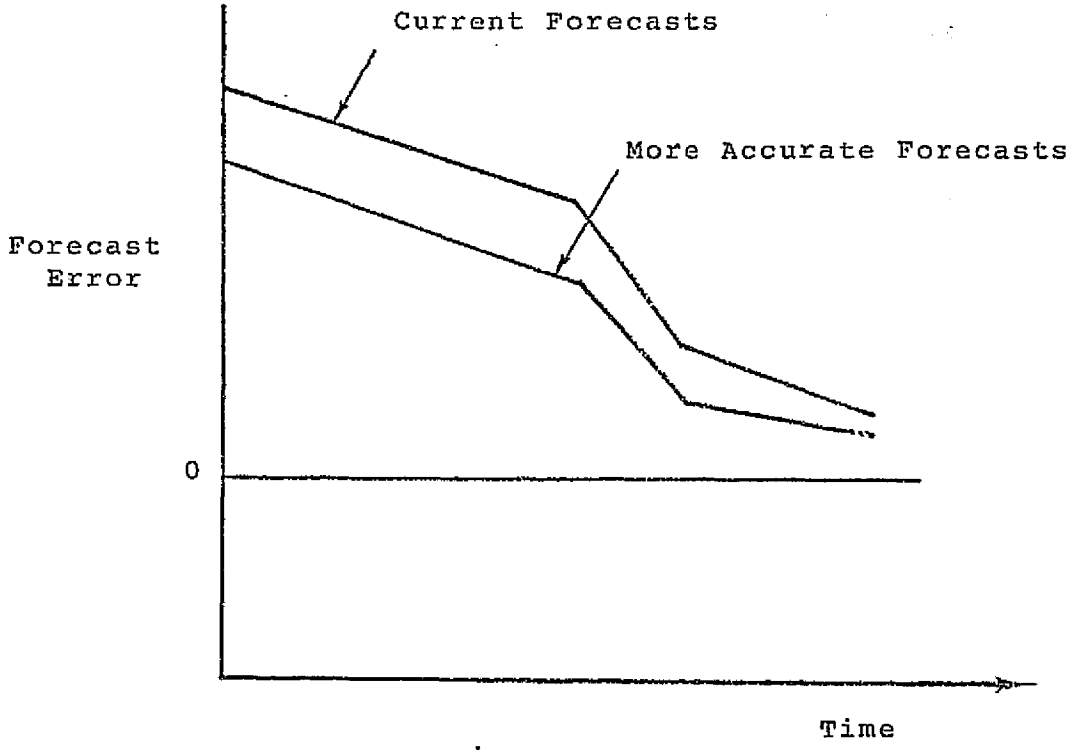

Figure 2.3 Effect of More Accurate Information on Forecast Accuracy

forecasting models. The update of data collection could be much more frequent than the frequency of inputting these data into forecasting models. This difference in frequency could occur if other purposes besides forecasting were served by data collection. The reverse, however, of more frequent forecasts than data collection cannot be true for statistically meaningful forecasts. Thus, frequency of data collection puts an upper bound on the frequency of forecasts.

On the forecast range diagram, straight lines sequentially connect expected forecast errors made on successive dates. In actual fact, when a forecast is made, the expected forecast error is a constant until a new forecast is given. Thus, the true picture of forecast information is given by the solid line step function shown in Figure 2.4. The solid line represents forecasts made at relatively infrequent intervals. If the frequency of forecasts were to double, then the expected forecast error would be given by the dashed line in the same figure. As the frequency further increased, the number of steps would correspondingly increase. In the limit, as the frequency of forecasts approached infinity, the forecast error would approach the solid irregular line marked "instantaneous" in Figure 2.4.

2.1.4 Timeliness of Information

The timeliness of information refers to the difference in time between the collection of data and the translation of this data into useful information such as a forecast. In Figure 2.5, less timely data is given by the outside probability band. If the difference in the time between data collection and forecasts were to be reduced, the outside probability band would be shifted to the left in a way that was exactly parallel to the original probability band. The distance between the original probability band and the new probability band is exactly given by the increase in timeliness. For example, if

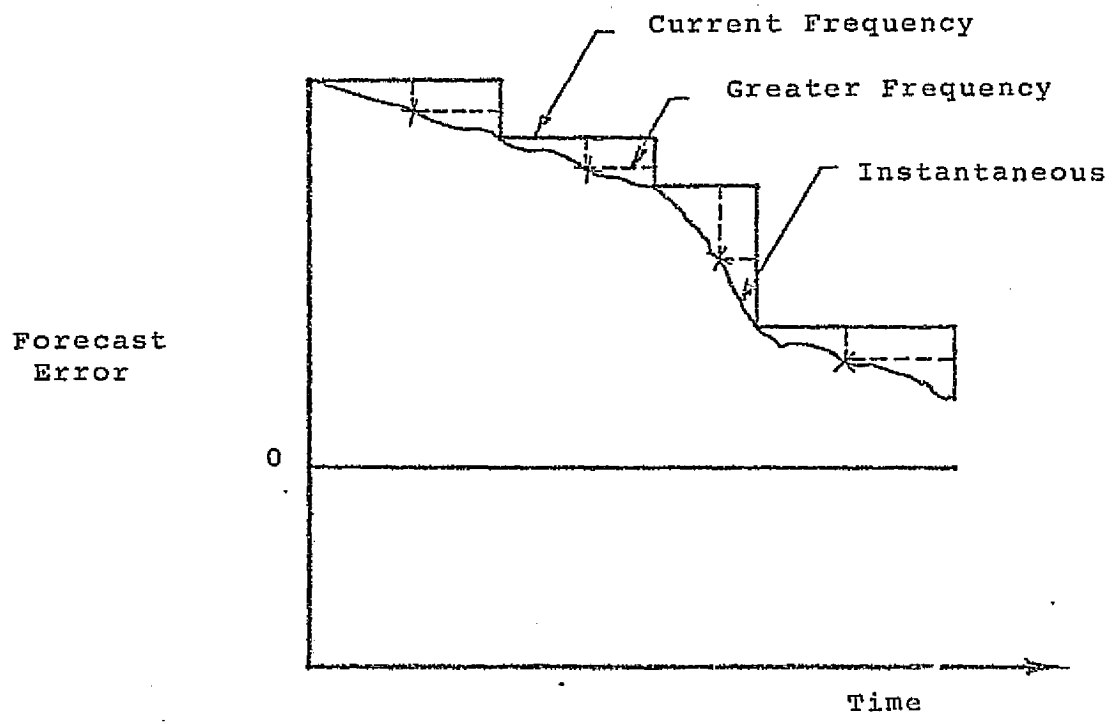

Figure 2.4 Effect on Forecast of Greater Frequency of Data Collection and Analysis

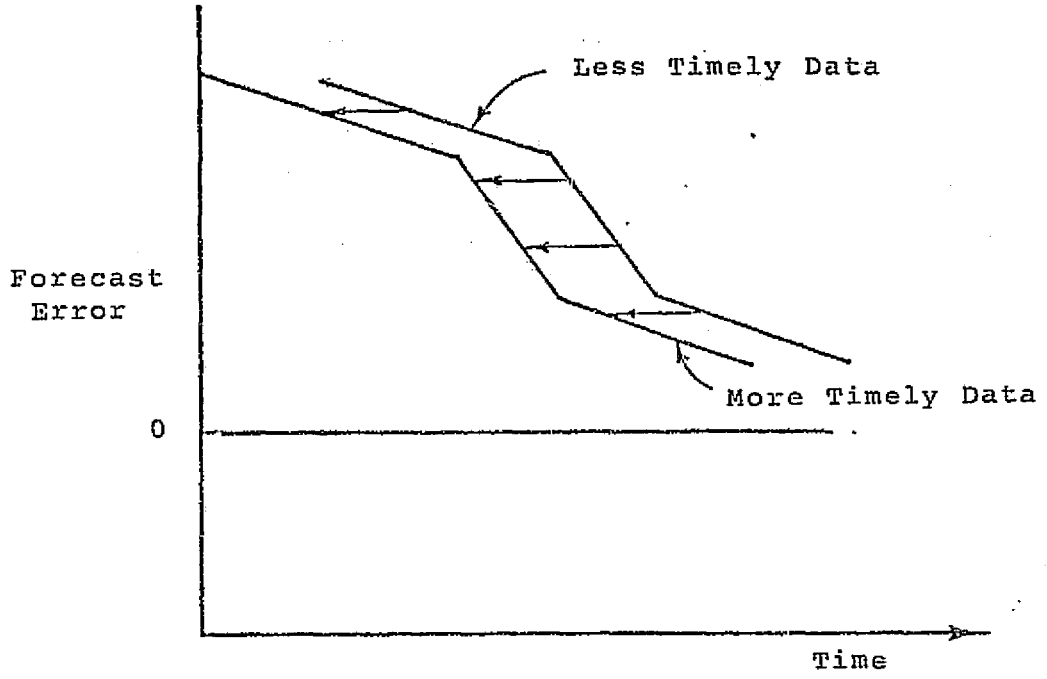

Figure 2.5 Effect on Forecast of More Timely Data

the gap between data collection and forecasts were reduced by one week, the probability band would be shifted to the left by one week.

2.1.5 Analysis of the Actual Behavior Over the Season in the Forecast Error

To determine the accuracy of the forecast range diagram used by the Water Resources Department of the State of California (Figure 2.2) and to determine the actual behavior of the forecast error from February to May over the last several years, we have calculated the seasonal forecast error for the forecast dates February 1, March 1, April 1, and May 1 for the years 1969 to 1974 and the average positive and average negative forecast error. Table 2.1 presents the forecasts made on the above dates and the estimated actual seasonal runoff.

Table 2.1 April-July Feather River Runoff Forecasts and Actual Runoff (in thousands of acre-feet)

Year	Forecast Made on:				Actual
	February 1	March 1	April 1	May 1	
1974	2070	2040	2800	2870	2688
1973	1940	2330	2400	2150	1913
1972	1520	1550	1000	1180	1198
1971	2600	2200	2400	2400	2701
1970	1950	1800	1580	1350	1114
1969	3000	4100	3800	3800	3304

The differences between the forecast runoff and the actual runoff are the forecast errors; these errors are plotted in Figure 2.6 and connected by dashed lines. For each forecast date, the average of all the positive errors is computed as is the average of all the negative errors. These positive and negative errors are shown by the heavy solid lines.

The last point does not imply that such a predictive relationship between the past and future meterological conditions of snow cover and precipitation will be simple. For example, as predictors of future conditions, the time pattern of prior accumulated amounts of precipitation and snow cover may be as important as the level of such accumulations. Furthermore, prior levels of snow cover may have greater predictive value in forecasting future precipitation than in forecasting future accumulations of snow cover. In addition, inverse relationships may exist. For example, a large precipitation

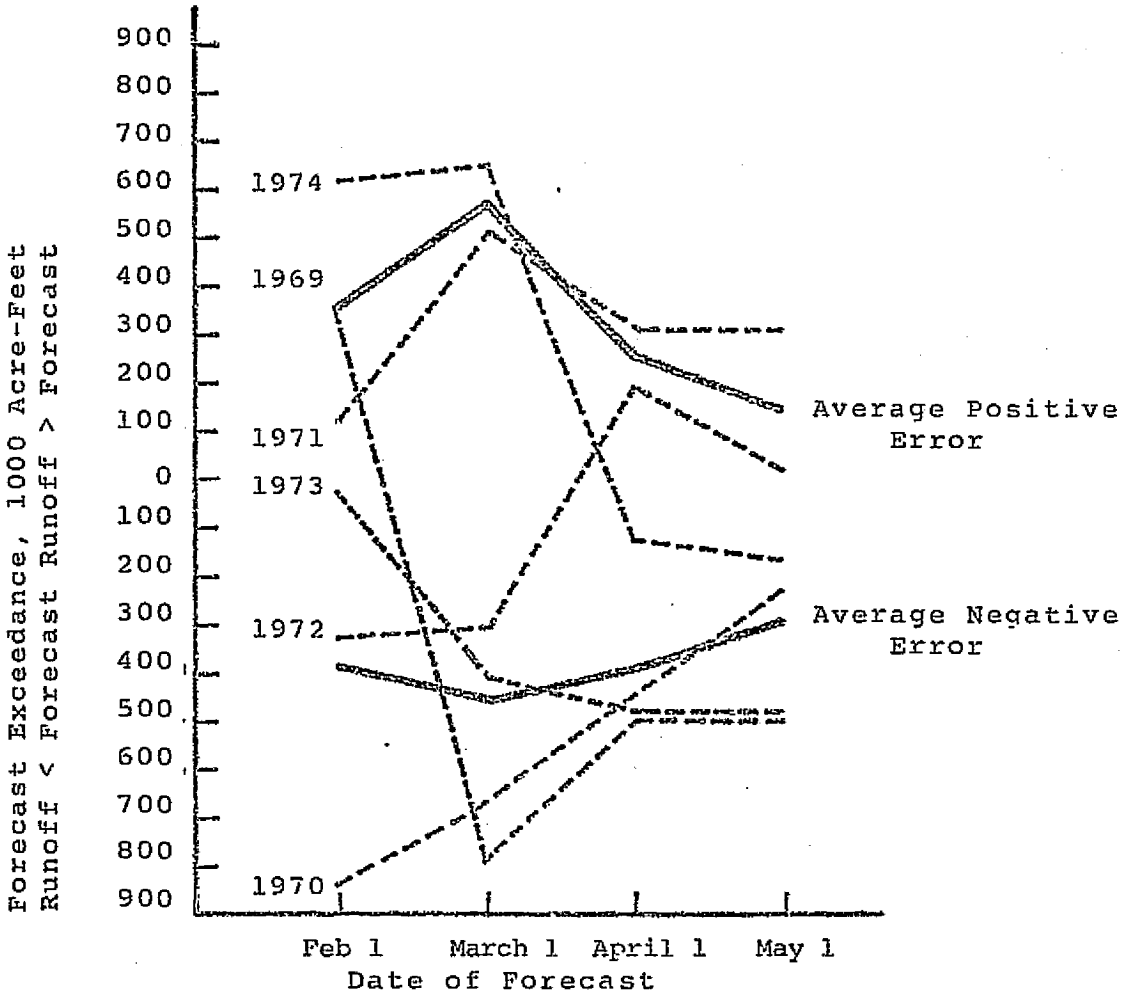

Figure 2.6 Forecast Error in Acre-feet for April to July Unimpaired Runoff Into Oroville Reservoir

early in the season may presage a small precipitation later in the season.

An examination of the correlations between the October through March and the April through July snow cover and precipitation indices (from the forecasting equation discussed in Section 2.3.1) shows that no statistically significant relationship exists between the October through March and the April through July precipitation indices. The correlation between the October through March snow cover variable and the April through July precipitation index, though much higher, is also not statistically significant at the 5 percent level. The correlation coefficients (r's) between these variables are:*

r = 0.1284 between October-March and April-July precipitation

r = 0.2320 between October-March snow cover and April-July precipitation.

A stronger relationship probably could be obtained by breaking out the October-March and the April-July periods into monthly units and doing a statistical analysis on the monthly snow cover and precipitation values.**

2.2 Forecast Range Diagram of Daily Feather River Streamflow

To understand the nature of the stochastic process involved in the Feather River streamflow, and in order to be able to derive short-time-frame forecast range diagrams analo-

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*The correlation coefficient (r) is a statistical measure of the degree of linear association between two variables. A value for r close to zero indicates little statistical association, while a value close to one indicates very high statistical association.

**While beyond the scope of this study, sufficient data in terms of sample points needed to construct reliable precipitation and snow indices exist for making such an analysis for the period 1952 to the present.

gous to the Feather River seasonal forecast range diagram (Figure 2.7), a "Box-Jenkins"* type of statistical analysis was performed. In a Box-Jenkins analysis, a time series is broken out into two components, an underlying deterministic segment representing the central tendency of the time series distribution and a stochastic segment representing the distribution of deviations from the central tendency. For example, given the jagged time series line shown in Figure 2.7, the Box-Jenkins analysis will break up this line into two components: a smooth line showing the deterministic or central tendency effects, and a stochastic component which is derived by taking the difference between the deterministic component and the actual time series line.

In hydrology, where streamflow has a strong seasonal tendency, application of a Box-Jenkins approach is extremely promising. A mathematical treatment of this analysis as it applies to the Feather River is given in Appendices C and D.

A graph of the 30-day mean and standard deviation Box-Jenkins results for the natural logarithm of daily streamflow is given in Figure 2.8. The results shown in Figure 2.8 can be transformed into the estimated actual streamflow "errors" by taking the antilogs of the computed results shown in this figure. Because the "errors" around the natural logarithm of streamflow have been treated as normally distributed, the "errors" will be log-normally distributed around the actual streamflow. Thus, the positive standard deviation above the mean will be significantly larger than the negative standard deviation below the mean.

Imagine now that a forecast was desired of the daily streamflow 30 days from the present. In effect, we would be

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*Box, George E.P., and Jenkins, Gwilym., Times Series Analysis Forecasting and Control, Hold-Day, San Francisco, 1970.

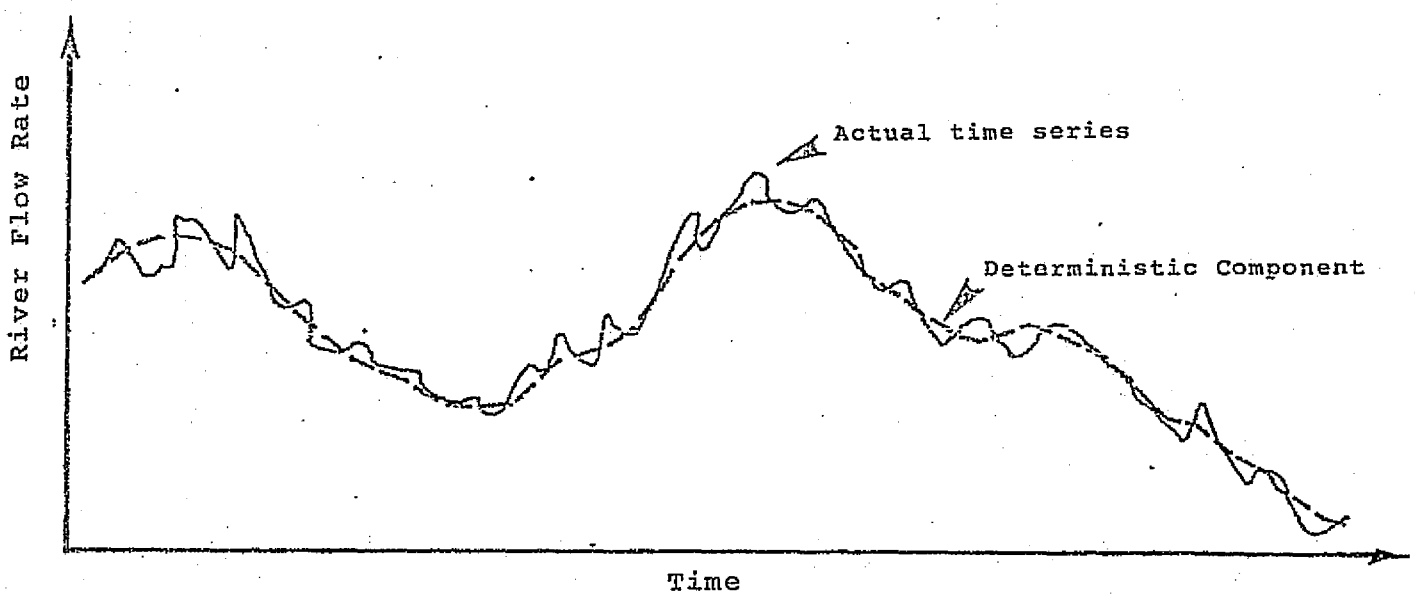

Figure 2.7 Hypothetical Time Series and Its Deterministic Component

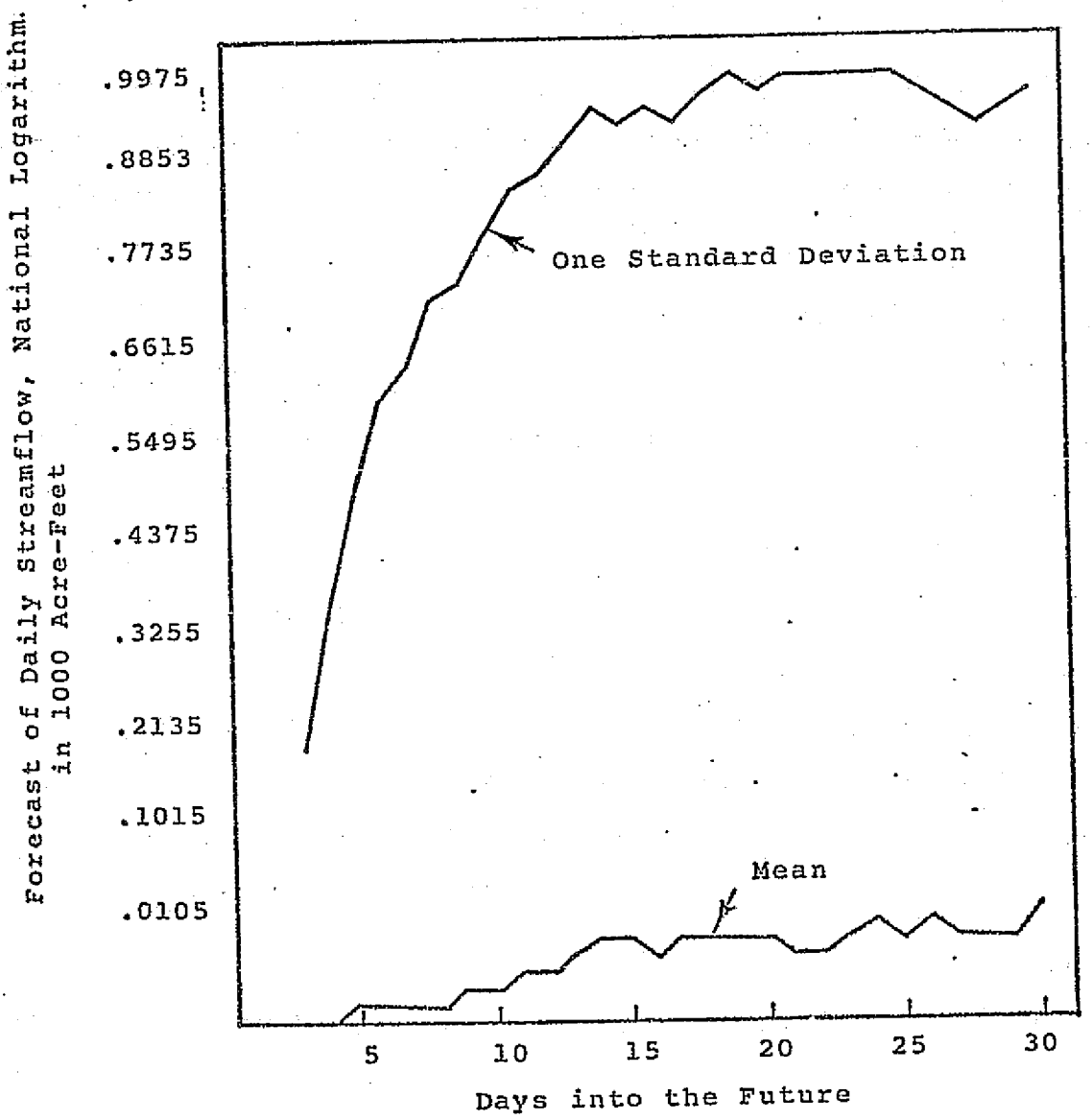

Figure 2.8 Mean and Standard Deviation of Stochastic Components of Daily Streamflow

"looking" from the t + 30 date in Figure 2.8 back to the t date in this figure. A presentation of this "looking backwards" in more familiar terms would mean taking the mirror image of the standard deviation line in Figure 2.8 and then converting this single line into .9, .75, .25, and .1 probability levels of the streamflow. This has been done in Figure 2.9. What we find is the familiar forecast range diagram applied to daily streamflow. The importance of this result is that it ties in directly with the discussion in Section 2.1 on the use of the forecast range diagram to translate better information (either more accurate, more timely, or more frequent) into better forecasts. This translation can now be done for daily streamflow data. The results presented in Figure 2.9 indicate that past daily streamflows provide some forecasting information on future daily streamflows. At the 90 percent probability level, information of value on daily streamflow can be obtained two weeks in advance. The percentage error at this probability level rapidly diminishes as one approaches the actual forecast date. Since current short-term forecasting models of the "API type" that are currently in use in California do not incorporate past streamflow behavior using a statistical model, these results suggest that these short-term forecasting models can be improved by incorporating recent past streamflow behavior as well as the seasonal pattern of streamflow. From an economic standpoint, the main improvement in forecasts that past event streamflow information would make possible is the ability to make a longer period forecast, say two weeks, rather than the current five-day forecast.

2.3 Types of Forecast Currently Performed

2.3.1 April-July Seasonal Forecast

On February 1, March 1, April 1, and May 1, forecasts of the April through July unimpaired runoff for major California

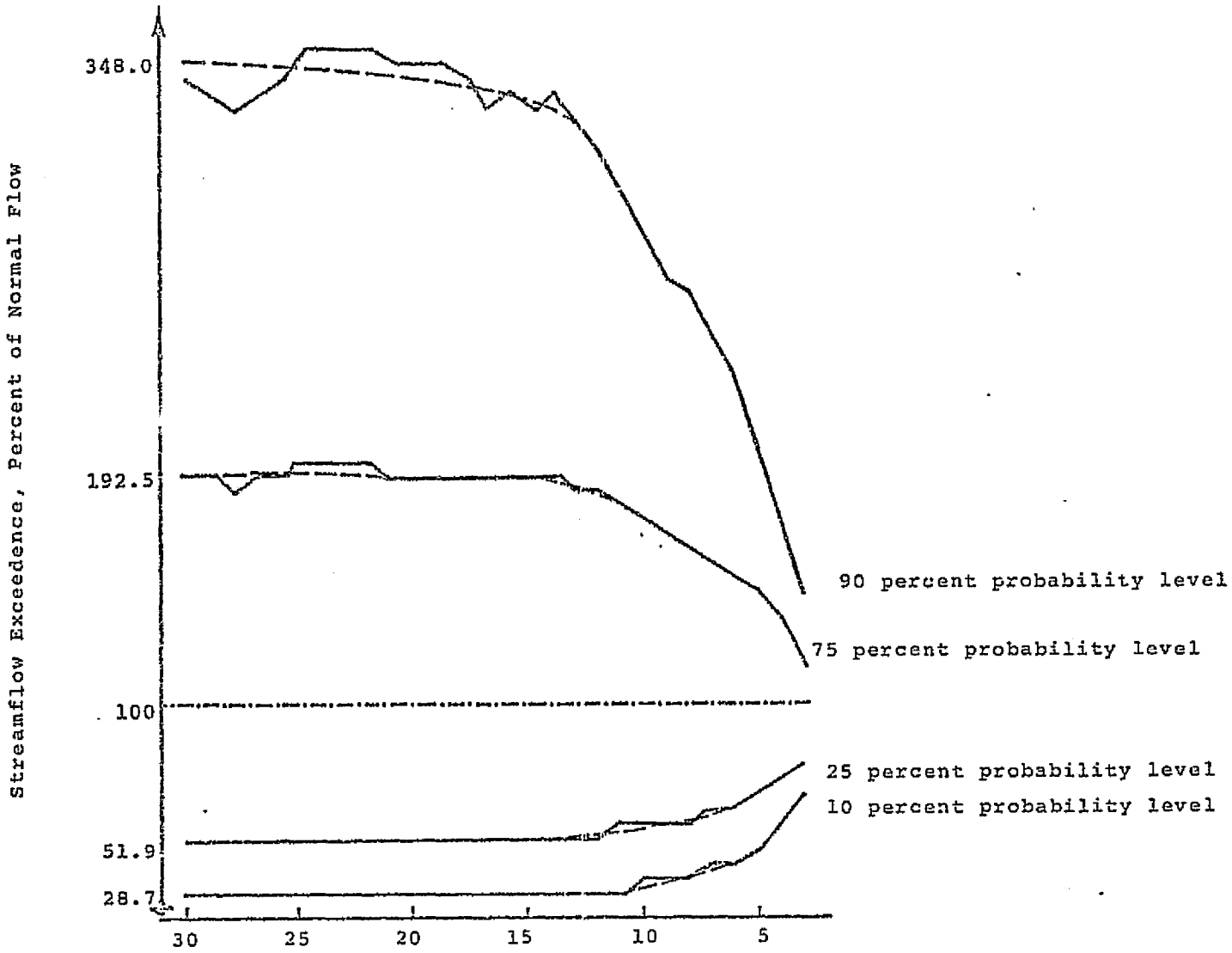

Figure 2.9 Forecast Range Diagram for Daily Streamflow

rivers and streams are published in Bulletin No. 120.* Weekly updates are made of these April and July runoff forecasts; they are sent out on a limited distribution basis to major users of these forecasts.** The April through July unimpaired runoff forecast for the Feather River at Oroville is based on an equation developed by the Snow Surveys and Water Supply Forecasting Section.*** This equation and equations similar to it for other California rivers were developed by this section using the statistical technique of multiple regression analysis. The Feather River at Oroville forecast equation is:****

$$\hat{W} = -297.7 + 4.9303S^2 + 8.4855P_1 + 4.3578P_2 \qquad (2.1)$$

$$\begin{array}{lll} (0.2986) & (1.1110) & (0.2799) \\ 16.510 & 7.638 & 15.572 \end{array}$$

$R^2 = .98$

$\tau = 130.9$

$DW = 2.04$

Note: Numbers in parentheses are the standard errors of the regression coefficients.

Numbers directly under the standard errors of the regression coefficient are the t-values***** associated with the regression coefficient.

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*"Water Conditions in California", Bulletin No. 120 - (year), Reports 1-4 (February 1 - May 1), State of California, Department of Water Resources, Sacramento, California.

**Weekly forecasts consist of a median forecast and a forecast at the 80 percent and 20 percent probability levels.

***State of California Department of Water Resources, Division of Resources Development, Flood Forecasting and Operations Branch, Snow Surveys and Water Supply Forecasting Section.

****The coefficient in this equation is slightly different from the one obtained by the Snow Surveys and Water Supply Forecasting Section.

*****The t-value is the ratio of the regression coefficient to the standard error. The higher the t-value, the less likely the "true" value of the regression coefficient is, in fact, zero.

where:

$\hat{W}$ = forecast of April through July unimpaired runoff at Oroville (in thousands of acre-feet)

S = .1 X average measured index of water content of snow (in inches)

P_1 = average measured index of water content of precipitation (in inches) for the October through March period

P_2 = average index of water content of precipitation (in inches) for the April through July period

R_2 = coefficient of determination*

T = standard error of estimate

DW = Durbin-Watson statistic**

This regression was computed from April 1 data for the years 1942 through 1967 on the water content of snow cover and the actual precipitation that occurred from October through March and from April through June. The values of the R^2 (.98), the standard error of estimate (130,900 acre-feet), the t-values on the regression coefficients (16.5, 7.6, and 15.5) and the Durbin-Watson statistic (2.04) indicate an excellent fit.

The procedure for making the April-July forecast on February 1, March 1, April 1, May 1, and June 1 is shown by the following equations:

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*The coefficient of determination indicates how much of the variation in the dependent variable is explained by variations in the independent variables. An R^2 of .98 means that 98 percent of the variation in the dependent variable is explained by the variation in the independent variables.

**A Durbin-Watson statistic measures the degree of "serial" correlation. A value close to 2 indicates that the problem of serial correlation is not present.

February 1:

$$W(F) = a_1 + a_2[S(F) + 30]^2 + a_3[P_1(F) + 32] + a_4[145] \quad (2.2)$$

March 1:

$$W(M) = a_1 + a_2[S(M) + 10]^2 + a_3[P_1(M) + 15] + a_4[145] \quad (2.3)$$

April 1:

$$W(A) = a_1 + a_2[S(A)]^2 + a_3[P_1(A)] + a_4[145] \quad (2.4)$$

May 1

$$W(My) = a_1 + a_2[S(A)]^2 + a_3[P_L(A)] + a_4[P_2(My) + 73] \quad (2.5)$$

June 1

$$W(J) = a_1 + a_2[S(A)]^2 + a_3[P_1(A)] + a_4[P_2(J) + 12] \quad (2.6)$$

where, from the forecast equation:

$a_1 = 297.7$

$a_2 = 4.9303$

$a_3 = 8.4855$

$a_4 = 4.3578.$

The variables are:

$W(i)$ = April-July Feather River unimpaired water runoff forecast, where i = F,M,A,My,J, and F = February, M = March, A = April, My = May, and J = June

$S(i)$ = snow index up to the end of the i-1 month

$P_1(i)$ = October – March (cumulative) precipitation index up to the end of the i-1 month

$P_2(i)$ = April – June (cumulative) precipitation index up to the end of the i-1 month

The constants 30 and 10 are, respectively, the historical average increase in the snow index in February and March.
The constants 32 and 15 are, respectively, the historical average increase in the October — March precipitation index in February and March.
The constants 73 and 12 are, respectively, the historical average increase in the April — June precipitation index in May and June.

To illustrate the use of these equations for a particular date (February 1), the snow index for the February 1 forecast is composed of an index of the water content of snow on January 31 plus the average historical increase in the snow index in February and March (30), the October - March (cumulative) precipitation from October 1 to January 31 plus the historical average increase in the precipitation index in February and March (32), and the average historical value for the April - June (cumulative) precipitation index (145).

Two problems exist with this approach. (1) Since the technique employed essentially is a curve fitting approach, the underlying physical and meteorological relationships cannot be directly related to the regression equation. If the typical physical and meteorological characteristics of the basin become modified over time, such shifts will not be picked up by the regression equation. (2) Furthermore, extreme meteorological conditions that lie outside the range of data values used to estimate the regression equation could produce forecasts that are far different from the actual results. This would occur if the underlying physical and meteorological conditions dictate an "extrapolation line" above or below certain critical values that is different from the "interpolation line" that exists for less extreme phenomena.

2.3.2 Five-Day Forecast of Hydrograph (at Six-hour Increments)*

The current procedure used in forecasting a five-day hydrograph will be replaced by a conceptually different and more sophisticated scheme in about a year's time. For the current scheme, the following data are required for the Feather River:

(a) the antecendent precipitation index

(b) base flow near Oroville

(c) snow depth at Gold Lake (6700')

(d) snow depth at other levels (from stations outside Feather River Basin)

(e) "other" data (either (1) "synthetic climate," (2) "snow departure", or (3) "week departure")

(f) projected basin storm precipitation data

(g) elevation at which freezing takes place

A description of the antecedent precipitation index, the synthetic climate, the week departure and the snow departure follows.**

Antecedent Precipitation Index (API)

"The API [Antecedent Precipitation Index] is a basin moisture index which associates the basin wetness with the amount of rain that has fallen on the basin, and the length of non-rain periods between storms."

The API increases directly as a percentage of the volume of rain over the basin in a 24-hour period, and decreases according to a decay function during non-rain periods. During prolonged dry periods the decay function reaches a constant reduction rate, called a minimum reduction, which is a function

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*This description is based primarily on an unpublished paper obtained from the Flood Forecasting Section, Rainfall-Runoff Forecast Scheme, dated 8/5/66.

**Rainfall-Runoff Forecast Scheme, pp. 10-11.

of the time of the year; i.e., the rate of drying is much greater in July than in January.

Synthetic Climate (SC)

"The Synthetic Climate attempts to associate the basin plant cycle to a long term average temperature, which has been adjusted for the seasonal radiation changes. The plant cycle, in turn, indexes that portion of the basin moisture which is lost to plants,(i.e., evapotranspiration, interception, etc.)".

Week Departure (WD)

"The depletion of basin moisture due to plant usage is indexed by the number of weeks that have passed from the present storm to the date of minimum plant moisture usage. The assumption is made that plant moisture usage increases uniformly with time from the date of minimum usage."

Snow Departure (SD)

"The basin moisture is sometimes well indexed by the departure of the present basin snowpack depth from the average or normal (15-year) snowpack depth. This leads to the use of a snow departure parameter."

The antecedent precipitation index and the "other" data are used to construct an "antecedent index." The following equation gives the general formula used to determine the antecedent index:

$$AI = \alpha + \beta\ (\text{"other" variable}) + \partial\ (\text{"other" variable})^3 + \delta\ (API) + \varepsilon\ (API)^3 \qquad (2.7)$$

where

AI = antecedent index

"other" variable = either (1) synthetic climate, (2) week departure, or (3) snow departure

API = antecedent precipitation index

$\alpha, \beta, \partial, \delta, \varepsilon$ = constants

The antecedent index is one of the basic inputs in the five-day hydrograph forecast. From the snow depth data, estimates of the equivalent water content are made. These water equivalents are used to estimate initial water equivalents at 1000 foot intervals. The other basic input is the projected basin storm precipitation at six hour intervals.

2.4 Analysis of the Sources of Error in the April-July Forecast

We have discussed in Section 2.1 of this paper the relationships that exist between better information and better forecasts. For that analysis we have used a forecast range diagram. We can choose one date on that diagram, say April 1, and determine how much of the average error in the forecast made on that date is due to each of the possible sources of forecast error. For the forecasting model used to predict the April through July Feather River runoff, there are four broad sources of forecasting error. These sources of error are:

1. Misestimation of the Water Content of Snow Cover (variable S^2 in the forecast equation)
2. Misestimation of Actual Precipitation (variable P_1 in the forecast equation)
3. Misforecast of Future Precipitation (variable P_2 in the forecast equation)
4. Other Sources of Error.

Theoretically, a further subdivision of the sources of error is possible. Two general statistical reasons exist for

a misestimation of the amount of precipitation or the water content of snow cover, errors caused by mismeasurement of actual samples of these variables (i.e., measurement errors) and errors caused by extrapolating from a sample to the population (i.e., sampling errors). For the third source of error listed, the misforecast of future precipitation, the reason for such a misforecast is obvious. Since the forecast of precipitation is simply the historical mean precipitation over the forecast period (see Section 2.3.1), the misforecast of future precipitation is given by the difference between the actual precipitation that will occur during the forecast period and the historical mean precipitation during the forecast period. Category 4, "other" sources of error, can be subdivided into the following types of error:

(a) misspecification of the forecast model (e.g., exclusion of one or more variables that should be included in the forecast model)

(b) misestimation of the actual unimpaired water runoff.

To set the forecast error picture in a quantitative perspective, the average absolute April-July forecast error over the 26-year period from 1942 to 1967 was 349,000 acre-feet. The average April - July runoff over the same period was 1,977,423 acre-feet. Thus, the average forecast error on April 1 was 17.7 percent.

To determine the contribution of each of the four major sources of forecast error listed above, we have performed what may be termed "an analysis of covariance." The actual procedure used is simple and straightforward. The data used for the analysis are presented in Appendix F. For the years 1942 to 1967, the error in the forecast was calculated by subtracting the actual runoff from the April 1 forecast of runoff, using the forecasting equation (2.4):

$$\hat{E} = \hat{F} - A$$

where $\hat{E}$ = estimated forecast error in April to July runoff

$\hat{F}$ = forecast of April to July runoff made on April 1 (2.8)

A = actual April to July runoff.

Using a regression analysis, the estimated forecast error $\hat{E}$ is related to the April 1 - July 31 precipitation (P_2). The results, in summary, are:

$$E = 638 - 4.3688P_2$$

$$(0.2540) \qquad R^2 = .925 \qquad (2.9)$$

$$t = -17.2031 \qquad \sigma = 133.45$$

$$DF = 24$$

Note: Number in parentheses is the standard error of the regression coefficient. The number directly under the standard error is the t-value of the regression coefficient.

In Equation 2.9, 92.5 percent of the April 1 forecast error variance is explained by P_2. In other words, 92.5 percent of the error variance in the April forecast is due to the current inability to predict precipitation for the April through July period. Based on the discussion in Section 2.1.5, it may be that better predictions of the April through July precipitation could be obtained by investigating the forecasting value of the level of pre-April precipitation and snow cover. The remaining 7.5 percent of the forecast error variance is due to such errors as the mismeasurement of the runoff, possible omission of certain variables such as evaporation, as well as the inaccuracy in the snow water content index. It corresponds closely to the

"procedural" or "scheme" error as those terms are used by the California Department of Water Resources.

Since these results are based on what appears to be a sufficiently large sample (26 years of data), they almost certainly are valid for the Feather River for years that are different from those used in the regression equations. However, it needs to be noted that these results do not necessarily hold for other rivers. Only a study, river by river, can determine the general validity of these results.

3. ANALYTIC MODELS OF HYDROPOWER AND IRRIGATION BENEFITS

3.1 Model of Theoretical Maximum Economic Benefits in Hydropower in the Absence of Power Generation Constraints*

If we assume a one-to-one correspondence between changes in the accuracy of information and changes in the accuracy of forecasts (holding frequency and timeliness of information constant), then the calculation of economic benefits in hydropower from changes in the accuracy of information in the absence of power generation constraints is a relatively straightforward task. Such a calculation involves the following steps:

1. Calculation of the height of water above sea level at the Oroville Dam in the flood control season for present-day suction and improved operations

2. Determination of the relationship between the water height and electric power generation at Oroville

3. Calculation of the volume of water passing through the Oroville generator during the flood control season using present-day accuracy of information and more accurate information and

4. Determination of the cost of producing power by hydroelectric means at Oroville and by alternative means. Mathematically, we could write:

$$E_o \approx f(\bar{H}_o, V_o) \text{ and } E_1 \approx f(\bar{H}_1, V_1) \tag{3.1}$$

$$B = (P_a - P_h)(E_1 - E_o) \tag{3.2}$$

*The analytic model is presented to show the potential benefits in the absence of flood control and hydropower constraints. This model only gives an upper bound to the benefit calculations, because a realistic hydropower model has to recognize existing constraints.

where

E_i = the electric power generated at Oroville*

$i = \begin{cases} 0 \text{ for current operations} \\ 1 \text{ for improved operations} \end{cases}$

$\overline{H}_i$ = the "adjusted average head" during the flood control season; the average head requires adjustment to take into account the non-linearities in the relationship between head and power generation

V_i = the volume of water through the generators during the flood control season

P_a = the incremental cost of alternative means of producing electric power

P_h = the incremental cost of producing hydroelectric power

B_1 = hydropower benefit in absolute dollar terms.

Since the power generated at Thermalito will be insensitive to improvements resulting from more accurate forecasts; Thermalito is not included in these calculations. This insensitivity results from the fact that variations in the head at Thermalito usually do not exceed five feet and any spilled water bypasses the Thermalito plant. Therefore, omitting Thermalito will hardly affect the absolute dollar benefit from improved forecasts, but will affect the percentage increase in benefit.

The average weekly water height during the December through February period (weeks 48 through 8), using the OROSIM computer simulation model to simulate current operations for the water years 1968/69 to 1972/73 was 835.35 feet (with a standard deviation of 9.68 feet). With perfect forecasts and no power generation constraints, the average elevation can be determined

*Based on a letter from Robert P. Hamilton, Chief Power Sales Section, Energy Division.

by the volume of water spilled under current operations, but presumably not spilled by improved operations, and by the relationship between reservoir volume and elevation. For the period 1968/69 to 1973/74, the actual average annual spill was 620,139 acre-feet.

Two limiting cases could be used for the calculation of potential benefits in an unconstrained situation. One extreme case is to assume that the improved information is used to maintain the same elevation as before, but to increase the flow of water through the generators (ignoring power generation constraints). The other extreme case is to assume that the same flow of water occurs through the generators, but to increase the average elevation during the December-February period (ignoring flood control criteria).

However, the theoretical maximum power generation is to increase the water elevation to the maximum feasible from a physical standpoint (ignoring flood control rules) and then maintain an outflow such that outflow equals inflow (ignoring flood control rules and power generation constraints). In the case of maximum feasible water elevation, the elevation would be 901 feet.

The relationship between power generation and water elevation above mean sea level at Oroville is illustrated by Figure 3.1. In equation form (ignoring minimum and maximum pool elevation) we have from the OROSIM program the following relationship between average elevation and the power component V:

$$V = -1.256883 + .003443417\bar{H} - 1.523806X10^{-6}\bar{H}^{2} \qquad (3.3)$$

where

V = power generated per unit of water in megawatt-hours per acre-foot

$\bar{H}$ = average head above sea level at Oroville

The following formula is used in OROSIM to calculate megawatt-hours generated at Oroville for each week:

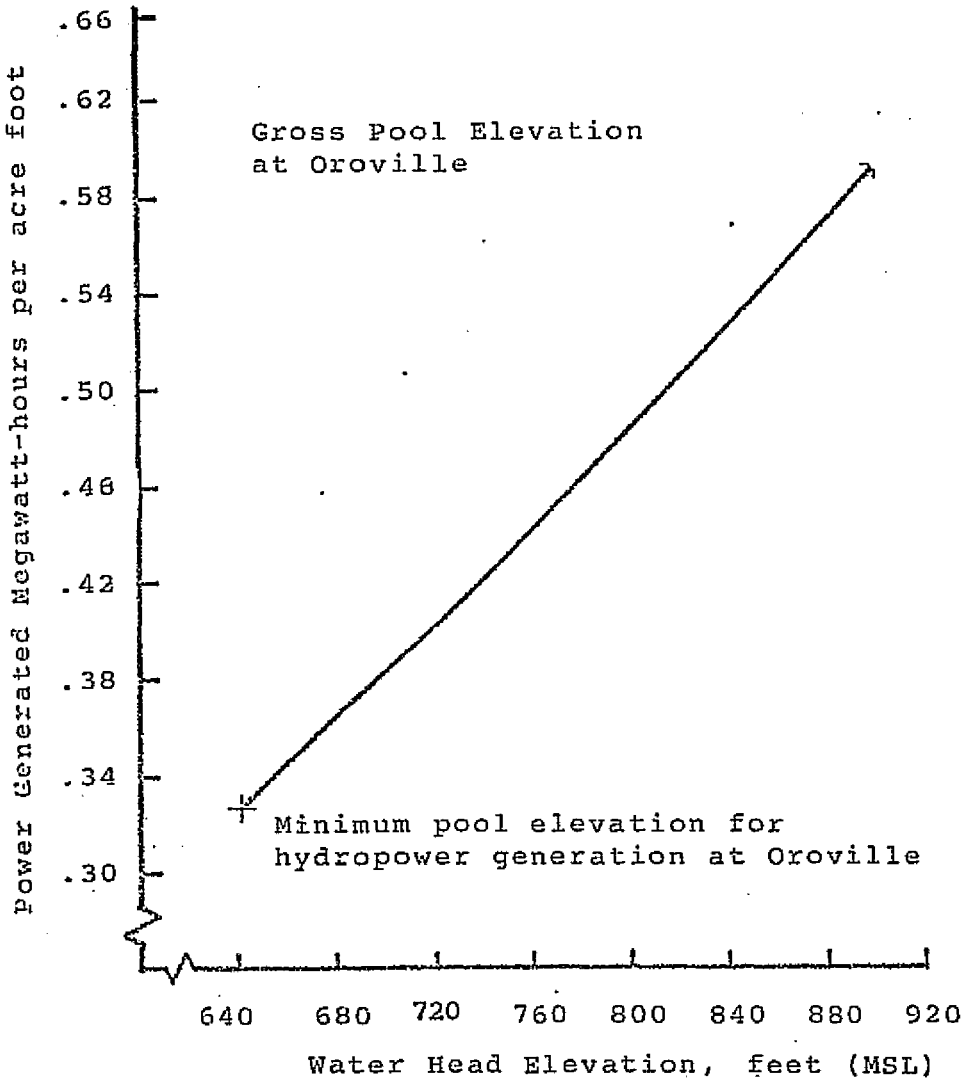

Figure 3.1 Hydroelectric Power Generation at Oroville (Hyatt Only) as a Function of Pool Elevation

$$E = QV \tag{3.4}$$

where

E = megawatt-hours per week

Q = weekly outflow in acre-feet

V = power component calculated from Equation 3.3.

From the historical data, the average weekly outflow through the generators during the December through February period for the water years 1968/69 to 1973/74 was 78,197 acre-feet. An average loss per week through spill of 47,703 acre-feet occurred during this period. At an average elevation of 835.35 feet, the average weekly power generated was 43,496 megawatt-hours.

In the unconstrained maximum feasible elevation case, the elevation is 901 feet with a no-spill weekly outflow of 125,900 acre-feet. The weekly power generated using Equations 3.3 and 3.4, therefore, is 76,623 megawatt-hours.

In the unconstrained present-day elevation case, the elevation is 835.35 feet with a no-spill weekly outflow of 125,900 acre-feet. The weekly power generated, therefore, is 70,031 megawatt-hours. The hydropower difference between the less and more conservative unconstrained cases is about 9 percent.

The Department of Water Resources of the State of California (DWR) in its calculations uses an average generation rate for the Hyatt and Thermalito power plants of 666 kilowatt-hours per acre-feet.* With an average annual maximum saving in spill of 620,139 acre-feet, the annual increase in power is 413,012,574 kilowatt-hours. Assuming, as before, that this additional energy is generated during the 13-week December through February period, the average increase in weekly power during this period is 31,770,197 kilowatt-hours.

In 1974, according to Pacific Gas and Electric Company (PG&E), the major power company in the northern California area, the average cost of operating a steam power plant using natural gas was 6.5 mills per kilowatt-hour. With oil, the same steam power plant in 1974 had a cost of 15.8 mills per kilowatt-

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*Based on a letter from Robert P. Hamilton, Chief, Power Sales Section, Energy Division.

hour.* For hydroelectric power generation, we estimate the cost at 1 mill per kilowatt-hour. About 65 percent of the fuel used by PG&E in these steam plants is natural gas and about 35 percent is oil. Thus, the average cost for a steam plant in northern California is 9.75 mills per kilowatt-hour. PG&E does not have any gas turbine plants, which are more expensive to operate and would be used only in peak load type situations.

However, the following points should be noted:

1. The cost of using natural gas is artificially low by a very substantial amount because of Federal government price ceilings on natural gas.

2. The world market price of oil at the end of 1974 is significantly higher than the average world market price of oil for the entire year of 1974.

3. The price of domestically produced "old" oil, as a consequence of Federal government price ceilings, is less than half the world market price of oil.

Therefore, we have estimated that the cost of operating steam plants at world market prices for oil and natural gas to be substantially higher than 8.75 mills per kilowatt-hour. The January 1975 operating cost for steam plants using oil at world market prices probably would have been at least 23 mills per kilowatt-hour. The January 1975 operating cost for steam plants using natural gas at decontrolled prices (and with domestic oil prices also decontrolled) probably would have been at least 20 mills per kilowatt-hour. Therefore, we believe that a value of at least 21 mills per kilowatt-hour

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*These figures were obtained from a conversation with the assistant of Mr. Kapnelian, Manager of Power Control at Pacific Gas and Electric. The comparable numbers for the Tennessee Valley Authority, based on the TVA's 1974 Financial Report, are 1.05 mills per hour for hydroelectric power and 5.708 mills per hour for steam generation. The cost of steam generation cited above apparently does not reflect the full impact of the 1974 rise in oil price.

Table 3.1 Average Weekly Power, December Through February, in kilowatt-hours

Situation	Average Weekly Power	Increase Over Present Constrained
Constrained Present-Day Elevation	43,496,000	----
Unconstrained Present-Day Elevation	70,031,000	26,535,000
Unconstrained Maximum Elevation	76,623,000	33,127,000
DWR Value	n.a.	31,770,197

represents the average cost of operating steam plants in northern California using world market price for oil and natural gas. Thus, the value we have used for $P_a - P_h$ in Equation 3.2 is 20.0 mills.*

From Table 3.1 and the above cost numbers, we calculate the average annual hydropower benefits of perfect forecasting at Oroville to be: $8,600,000 in the unconstrained maximum feasible elevation case and $6,900,000 in the unconstrained present-day elevation case.

Once we consider a realistic case that includes the various constraints that affect the system, much lower benefit values are obtained.

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*This 20.0 mills per kilowatt-hour value compares with a charge of 2.59 mills per kilowatt-hour for excess energy generated by the project under Part III, Article 17, of the Sales Contract. "The value of this energy to the purchasing electric utilities is now several times the above [2.59 mills per kwh] amount because of the recent sharp increase in the cost of oil, the major fuel for generation of electric energy in California." Quote from letter dated May 27, 1975 from Robert P. Hamilton, Chief, Power Sales Section, Energy Section, Department of Water Resources, State of California.

3.2 Irrigation Models

3.2.1 Soil Conservation Service Model

Several models have been developed to determine the economic benefits of better information with respect to irrigation activities.* Models in the Soil Conservation Service Handbook and the University of Michigan Report have basically the same underlying concepts, while the one in the Earth Satellite Report has elements similar to those in the SCS Handbook and the Michigan Report. The Soil Conservation Service Handbook gives a concise descriptive presentation of a model for estimating these benefits.** One of the assumptions of this model, as with models in the Michigan and Earth Satellite Reports, is that, in the absence of advance information on seasonal water supply, the farmer will plant approximately the same acreage and crops each year. However, with advance information on seasonal water supply, it is assumed that the farmer will adjust his acreage and crops to realize benefits from such information. The procedure used is as follows:

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*Snow-Surveys and Water Supply Forecasting, SCS National Engineering Handbook, Section 22, Soil Conservation Service, U.S. Department of Agriculture, Washington, D.C., April 1972.

Decision Making Under Uncertainty: Economic Evaluation of Steamflow Forecasts, Gunter Shramm, Principal Investigator, The University of Michigan, School of Natural Resources, Ann Arbor, Michigan (Final Report to the Office of Water Resources Research, U. S. Department of Interior), July 1974.

Earth Resources Survey Benefit Cost Study, Appendix 2, "Snow Mapping and Run-off Forecasting: Examination of ERTS-1 Capabilities and Potential Benefits from an Operational ERS System." Prepared by the Earth Satellite Corporation and the Booz-Allen Applied Research Corporation for the U.S. Department of Interior/Geological Survey, November 22, 1974.

**Snow-Surveys and Water Supply Forecasting, op. cit., pp. 9-28 to 9-33.

1. Determine the total irrigated area in the region.

2. Determine the acreage irrigated completely or partially by surface water sources. Find the amount of this acreage that is affected by water supply forecasts.

3. Determine (they suggest by sampling procedures) the types of irrigation enterprises and the total acreage of each type.

4. "Using representative sample areas of each type, determine the average size of farm, crops grown, farming procedures, fixed and variable costs, and gross and net returns to the farmers, assuming normal or average water supply. This establishes a base for comparing alternatives in those years in which the available water supply is considerably less or more than normal."

The Handbook illustrates points 3 and 4 of this procedure with an example based on an SCS study using 1960 data of the Boise, Idaho area. The results of that study for a 200-acre irrigated farm in southern Idaho with water rights to only 150 areas in a normal year are shown by Figures 3.2 and 3.3.

For our purposes, the ratio of benefits (as measured by net farm income) with accurate forecasts of seasonal water supply to the benefits without such forecasts is an important relationship to examine. From Figure 3.2 we obtain the following results:

Greater than normal water supply

$$r = \frac{-4.8 + .12\,X}{7.6} \qquad (X > 100) \tag{3.5}$$

Less than normal water supply

$$r \approx \frac{-4.8 + .12\,X}{-53.2 + 1.124\,X + .0052\,X^2} \qquad (75 < X < 100) \tag{3.6}$$

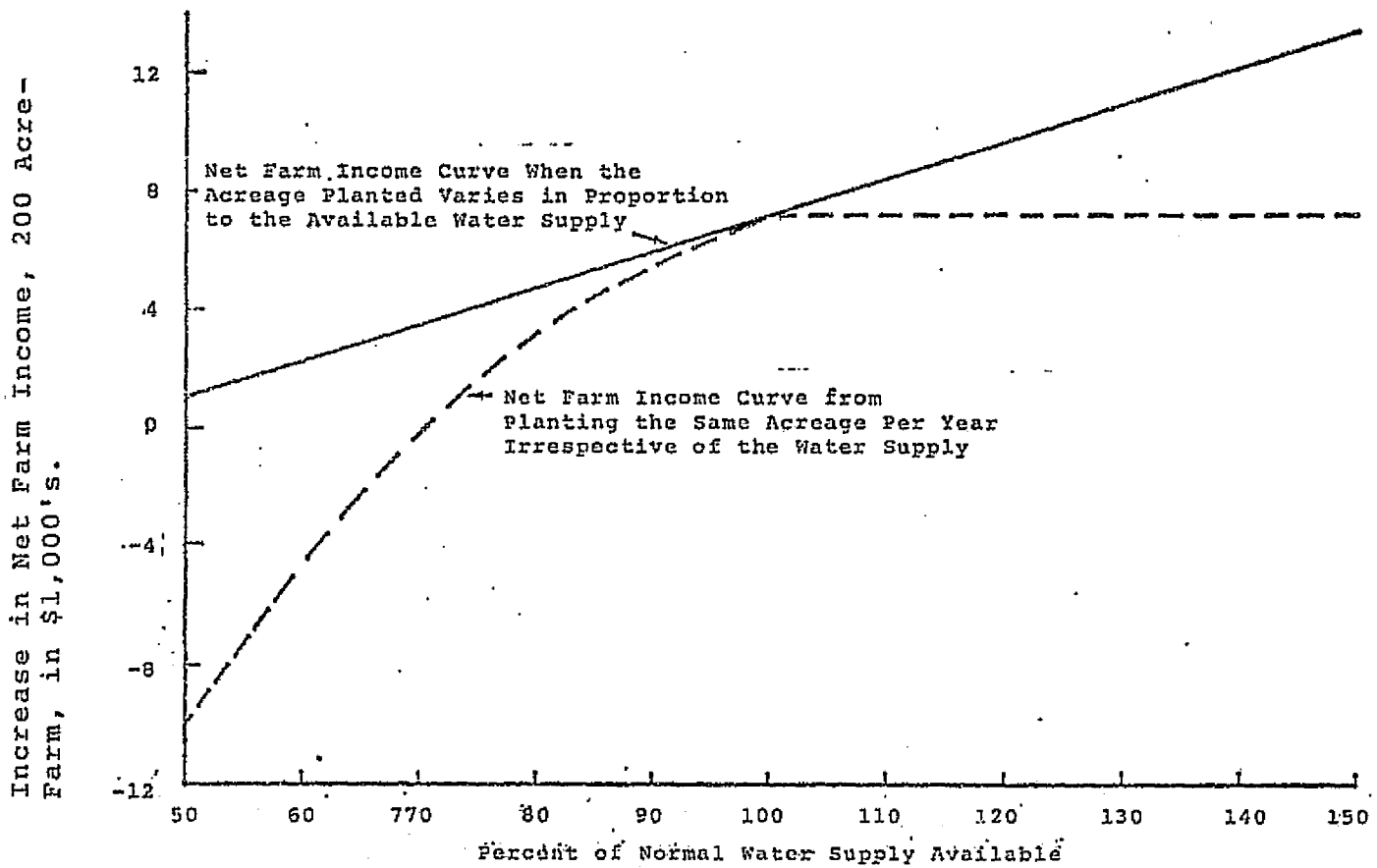

Figure 3.2 Net Farm Income or Loss With and Without Knowing the Available Water Supply Each Year

Source: Soil Conservation Service Handbook.

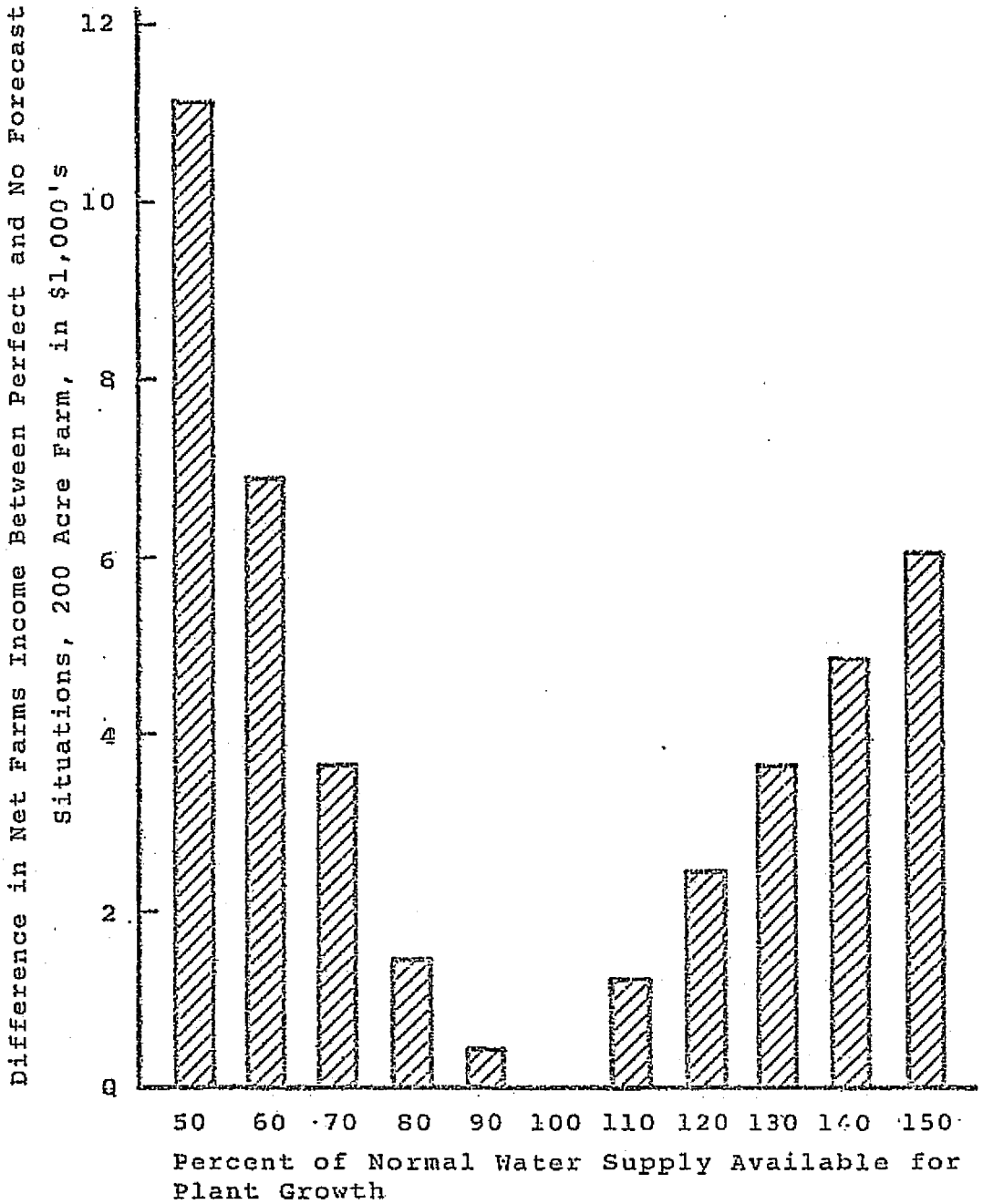

Figure 3.3 Total Value of Knowing the Year's Water Supply for Different Percentages from a Normal Water Supply Year

Source: Soil Conservation Service Handbook.

where

r = net farm income with perfect water supply forecast divided by net farm income without water supply forecast

X = percent of normal water supply available.

For Figure 3.3, the following results can be obtained:

Greater than normal water supply

$$i = -12.4 + .12X \quad (X>100) \tag{3.7}$$

Less than normal water supply

$$i = 48.4 - 1.004X - .0052X^2 \quad (75<X<100) \tag{3.8}$$

where

i = increase in net farm income going from a no forecast case to a perfect forecast use

X = percent of normal water supply available.

The SCS procedure does not present a methodology for analyzing imperfect forecasts. In the absence of such a methodology, a simple rule, such as a linear relationship between the degree of forecast accuracy and forecast benefits is perhaps the best that can be done for the imperfect forecast case, if the SCS procedure were to be used.

3.2.2 Modifications Required to Apply SCS Results to Our Case Study

We now present a methodological discussion of how these SCS results could be applied to our case study. We believe that the time and resources required to go through the actual calculation would not be justified in the light of our conclusions on snow cover. However, in Section 3.2.4, a simplified procedure is presented as a means of calculating the irrigation benefits of better forecasts.

To have Equations 3.5 through 3.8 applicable (in order of magnitude terms) to our case study, the following income adjustment measure is needed:

$$q = \frac{\bar{I} \text{ (California, 1974)}}{\bar{I} \text{ (Idaho, 1960)}} \tag{3.9}$$

where

q = the income adjustment factor and

$\bar{I}$ = the average net farm income per irrigated acre. The geographical place and year for which this data would be calculated is given by the information in parentheses.

In order to obtain results roughly applicable to California in 1974, the lefthand sides of Equations 3.5 through 3.8 would be multiplied by the income adjustment factor q. To make these results apply on a per-acre basis, the lefthand side of these equations would be divided by 200.

A probability density function of forecasted water supply also would have to be determined. This function would indicate what proportion of the terms the forecasted water supply was X percent of the normal water supply.

To calculate the weighted average net dollar benefit per acre, the net farm income results obtained for each X value in Equations 3.7 and 3.8 would be multiplied by the probability of such an X value occurring. This, in effect, means that Equations 3.7 and 3.8 would be multiplied by this probability density function. These results would then have to be scaled up by applying the number of acres irrigated in a normal water year.

3.2.3 University of Michigan Model

A stochastic linear programming model is used in the University of Michigan Report for determining the approximate increase in expected income from increased accuracy in forecasts.* The variable that is maximized in this program is expected net farm income. A description of the mathematics of this model and how it differs from a standard linear program is presented on pages 106 to 121 in the Michigan Report. This model is based on an article** and book by Day,*** and an article by Henderson,† and an article by Hall and Burns.†† In comparison to the Soil Conservation Service and the Earth Satellite Corporation models, this model is far and away the most sophisticated and advanced of the three. A mathematical representation of the linear program developed by Day††† and modified by a water constraint in the Michigan Report is shown below:

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*University of Michigan Report, op. cit.

**Richard H. Day, "An Approach to Production Response," Agricultural Economic Research, XIV, No. 4 (1962), pp. 134-148.

***Richard H. Day, Economic Analysis: Recursive Programming and Production Response (Amsterdam: North Holland Publishing Company, 1963).

†James M. Henderson, "The Utilization of Agricultural Land: A Theoretical and Empirical Inquiry," Review of Economics and Statistics, XLI, No. 3 (1959) pp. 242-259.

††Warren A. Hall and Nathan Burns, "Optimum Irrigated Practice Under Conditions of Deficient Water Supply," Transactions of the American Society of Agricultural Engineering, IV, No. 1 (1961), pp. 131-134.

†††Economic Analysis: Recursive Programming and Production Response, cited above.

$$
\left.
\begin{aligned}
&\text{Max } \pi(X) = Z_1X_1 + \ldots\ldots Z_iX_i + \ldots\ldots + Z_nX_n \\
&X_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \leq (1 + B_1 \max)X_1^* \\
&\ldots\ldots\ldots X_i \ldots\ldots\ldots\ldots \leq (1 + B_1 \max)X_1^* \\
&\ldots\ldots\ldots\ldots\ldots\ldots X_n \leq (1 + B_n \max)X_n^* \\
&-X_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \leq -[1 - B_i \min)X_1^* \\
&\ldots\ldots\ldots -X_i \ldots\ldots\ldots\ldots \leq -(1 - B_i \min)X_i^* \\
&\ldots\ldots\ldots\ldots\ldots\ldots -X_n \leq -(1 - B_n \min)X_n^* \\
&X_1 + \ldots\ldots\ldots K_i + \ldots\ldots\ldots X_n \leq X \\
&W_1X_1 + \qquad W_iX_i \qquad W_nX_n \leq \overline{W}
\end{aligned}
\right\} \quad (3.10)
$$

where:

$\pi(X)$ = net regional income

Z_i = net return per acre

$Z_i = P_iY_i - C_i$

P_i = price of ith crop

$\overline{W}$ = total water available

B_i = percent adjustment, up or down

Y_i = yield per acre of ith crop

C_i = variable cost per acre of ith crop

$\overline{X}$ = total land available

X_i^* = planned acreage based on previous years planting

W_i = per acre water requirement of the ith crop

The above model was used as a starting point in the development of the stochastic linear program in the Michigan Report.

The model examines the maximum area (i.e., 21,000 acres) served by an average ditch company in three Colorado basins. Seven crops typically grown under irrigation in Colorado (alfalfa, barley, dry beans, corn, onions, potatoes,

and sugar beets) are assumed to be the crops grown by the farms under the ditch company.

Two major cases were examined in the Michigan Report. In Case One, a variable surface water supply is assumed, with ample supplies of higher cost reservoir and well water available to farmers in adverse surface supply conditions. In Case Two, the same variable surface water supply is assumed, but the supplies of reservoir and well water are sharply reduced. The economic effects of increased forecast accuracy were tested in each of these cases.

The percentage increase in certainty for the four forecast accuracy levels examined in the Michigan Report are 4, 11, 15, and 33 percent.* The expected net farm income in Case One for different accuracy levels and different forecasted levels of water supply are given in Table 3.2. The corresponding results for Case Two are presented in Table 3.3.

As can be seen from Case One and Case Two, for forecasts of less than average water supply, the measure of benefit decreases as the certainty of forecast increases. This result clearly contradicts what could be expected from better forecasts. The apparent crucial error that this result represents is much more likely to have been caused by some computer programming error than to a fundamental error in the theoretical model. Whatever the cause, the University of Michigan results cannot be used as reliable estimates of benefits. This is unfortunate, since the University of Michigan report presents a very fine and very high quality analysis.

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*The precise definition of certainty as used in the Michigan Report is highly technical and involves several long discussions in that report.

Table 3.2 Case One Expected Net Farm Income (in thousands of 1959 dollars)

Water Supply Forecast	Percent Increase in Certainty			
	4	11	15	33
Very Low	937	890	879	796
Low	950	931	933	870
Low-Average	1,013	1,025	1,047	1,058
Average	1,095	1,127	1,143	1,173
High-Average	1,137	1,203	1,206	1,252
High	1,168	1,233	1,257	1,291
Very High	1,176	1,247	1,270	1,307
Weighted Average of Water Supply Forecasts	1,137	1,203	1,206	1,252

Table 3.3 Case Two Expected Net Farm Income (in thousands of 1959 dollars)

Water Supply Forecast	Percent Increase in Certainty			
	4	11	15	33
Very Low	629	566	555	472
Low	652	628	624	564
Low-Average	738	760	796	796
Average	827	890	909	948
High-Average	901	995	1,003	1,063
High	935	1,026	1,062	1,107
Very High	945	1,042	1,074	1,127
Weighted Average of Water Supply Forecast	798	851	872	882

3.2.4 Benefits to Irrigation in Our Case Study

Instead of analyzing benefits in terms of the returns per acre of irrigated land, benefits can be analyzed in a conceptually simpler way by measuring the value of an acre-foot of water. The free-market price of irrigation water would provide an excellent measuring rod for determining the benefits of additional irrigation water. Unfortunately, for analytical purposes, the price of water to different users is not determined by free market forces, but is set by public or quasi-public agencies. Therefore, instead of contractual prices for irrigated water, free-market prices for irrigated water need to be simulated by an analytic model.

Agricultural studies analyzing the value of water for irrigation were conducted by Brown and McGuire in 1967. Using demand functions fitted to two different sets of data, one from the California study for districts served by the Kern County Water Agency (KCWA), they obtained estimates of approximately $19 per acre-foot for the first set of data and $15 per acre-foot for the function fitted to the farm budget study. For the Feather River area the total equivalent unit charge per acre-foot is $13.46, which is low in comparison to the rest of the state. Table 3.4 presents the marginal values of water in the district of the KCWA. However, the bulk of the irrigation water provided by the Feather River is transported via the California Aqueduct to central and southern California. Kern County appears to be fairly representative of the counties receiving this irrigation water.

Given the theoretically proper prices of irrigation water as it applies to Kern County and the Feather River Basin, a price of $15 per acre-foot in 1967 dollars appears to be reasonable. With the implicit GDP price index rising 36.6 percent between I 1967 and IV 1973, the 1974 price of this water, assuming that it rises in step with the price index, is $20.49 per acre-foot.

Is there enough currently fallow but potentially irrigable land available in the Sacramento River Basin to make use of additional water? The answer is affirmative, as indicated by Figure 3.4. Having answered this question, how much additional economically usable water could be available for irrigation? The average annual spill for the period 1968-1973 is 620,139 acre-feet. If there were no spill, all of this water theoretically could be applied for irrigation purposes. The OROSIM model, which covers a 26 year period, has, with no improved information, an average annual spill of 206,000 acre-feet. But from the results given in Section 4.3, even with perfect information on water inflow four weeks into the future, simulated spills of 1,902,332 acre-feet occurred over a 26 year period, or about 73,000 acre-feet per annum. It would be more realistic to observe the effects of a 50 percent improvement in semi-monthly inflow forecasts made on the 1st and 15th of each month. These would result in a reduction in spills from 5,343,790 acre-feet to 4,474,000 acre-feet, or about 33,400 acre-feet per annum. Using the 33,400 figure as a realistic target improvement level, the irrigation value of the spilled water is $684,400 per annum.

The other reservoirs in the State of California Water Project have a combined capacity that is approximately two-thirds that of Lake Oroville. Therefore, assuming spillage characteristics of these reservoirs are comparable to those at Oroville, $456,300 per annum can be assigned to irrigation benefits in the rest of California as a result of reduced spillage. From the Earth Satellite Corporation Report,* the potential net benefit for irrigation activities in California is approximately 40 percent of the total for ten western states. Therefore, an estimate of the nationwide benefit of reducing water spillage in irrigation is $2,852,000 per annum.

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*Earth Resources Survey Benefit Cost Study, op.cit.

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Table 3.4 Prospective Marginal Values of Water in the Irrigation Districts of KCWA under Optimum Allocation

District	Annual delivery 1,000 acre-feet	Delivered price (= marginal value) per acre-foot, $ (1967)	
		Case 1	Case 2
Belridge, W.S.D.	206	18.25	$14.60
Lost Hills, W.D.	168	14.50	10.85
Rosedale-Rio Bravo W.S.D.	70	19.20	15.55
Semitropic W.S.D.	127	17.70	14.05
W. Kern County W.D.	3	22.50	18.85
Antelope Plain W.D.	59	23.20	19.55
Wheeler Ridge-Maricopa W.S.D.			
No. 1	142	23.30	19.65
No. 2	29	28.75	25.10
Kern River Delta & Others	309	18.00	14.35

Source: Brown and McGuire, A Socially Optimum Pricing Policy for a Public Water Agency. Water Resources Research, Vol. 3, No. 1, 1967, pp. 33-43.

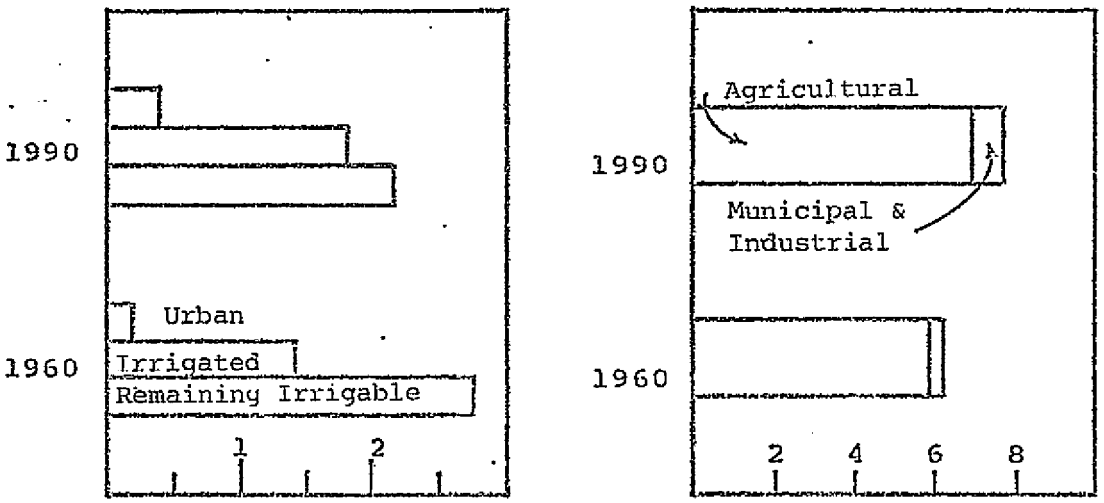

Figure 3.4 Sacramento Basin Hydroelectric Area Statistics (Includes Feather River)

Source: Bulletin No. 160-66, "Implementation of the California Water Plan", March 1966, State of California, Department of Water Resources.

Does the seasonal timing of spilled water occur when such water could be used by agriculture? Since most spills take place in January (see Section 3.1), saving such water from spill would have a definite economic payoff in irrigation. Indicative of this is the planting season for different crops grown in California as shown in Figure 3.5. With the exception of the crop flower period, water availability during the planting season is much more valuable than water availability at other times in the crop cycle. However, benefits that could be realized from the availability of this additional water depend on the ability to make reasonably accurate two- to four-week forecasts of water inflow (see Section 4.3).

Irrigation benefits could also be obtained from better forecasts of the April-July seasonal inflow. However, these benefits would be limited to a significant degree because the initial published forecast date of February 1 is too late to influence the pre-irrigation or planting decisions on certain crops. In Kern County, California, a major agricultural area that receives the largest irrigation benefit from water supplies from the Feather River, it is too late to affect the planting decisions on sugar beets, spring potatoes, or barley.

Reinforcing the limited impact of seasonal forecasts is the fact that annual entitlements of State of California Project water to counties and water districts are made under long-term contracts and are independent of annual, seasonal or short-term water supply forecasts. In addition, we have shown in Section 2.1.4 that increasing the accuracy of measuring the water content of snow cover will not lead to improved forecasts of seasonal inflow into the Feather River.

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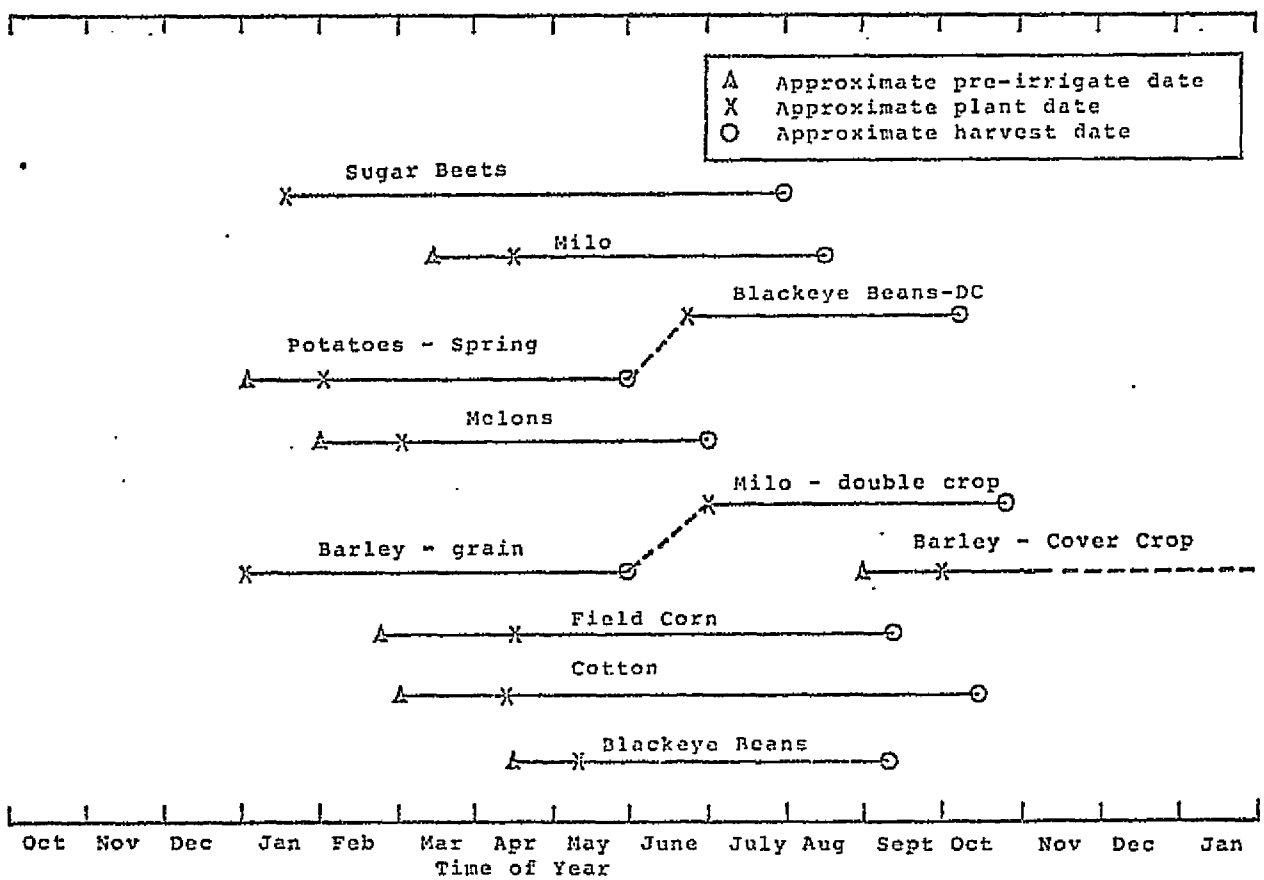

Figure 3.5 Pre-irrigation, Planting and Harvesting Schedules for Selected Crops, Kern County

Source: N. A. MacGillivray, Department of Water Resources, State of California, Bakersfield, March 1966.

4. ANALYSIS OF RESULTS USING THE OROSIM SIMULATION MODEL

4.1 Description of Original Oroville Simulation Model*

The analytic model of hydropower benefits that was described in Section 3.1 of this report did not contain the important flood control, power generation, and demand constraints that impact importantly on hydropower benefits. It would have been exceedingly difficult to correctly incorporate these constraints into the analytic model. Therefore, we have used a simulation model of operations at Oroville (called OROSIM) that incorporates these constraints in order to determine the benefits in hydropower, under constrained conditions.

The OROSIM program is capable of simulating operations at the Oroville reservoir and the power produced at the Hyatt power plant. The model proceeds through a weekly cycle to determine optimal outflows, given actual hydrological data, physical constraints, legal requirements and other specified release rules.

The model was conceived and developed by Mr. William Cy Cook** for the purpose of investigating the efficiency of various general release rules. The optimal rule would have the highest probability of minimizing the quantity of inflow that would have to be spilled to accommodate federal flood control criteria and contractual requirements. As a result of Mr. Cook's

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* Parts of this section are from a draft description written by William Cook entitled Oroville Weekly Simulation Model.

** William Cy Cook, Associate Engineer, Water Resources, P.O. Box 388, Sacramento, California; also W. B. Meirke, Associate Engineer, Chief of Project Operations Study Section, Sacramento, California. Please note that OROSIM does not represent official State Department of Water Resources policy, nor does it represent the policy of the involved utility companies.

preliminary work on OROSIM, "Rule B"* was chosen as optimal and in this form the model was given to ECON, Inc., for the Feather River case study. The documentation that follows describes the model as it was when received from Mr. Cook.

The hydrological data used in the model are gauged streamflow near Oroville, Feather River Basin precipitation records, and the April through July forecasted runoff based on snowmelt predictions. Though daily observations of streamflow exist from water year 1902 to present, regular precipitation observations for all recording stations are available only from 1946. The daily streamflow data for 1947 to 1972 were obtained from the U.S. Geological Survey on magnetic tape. The daily flows were converted into 52 weekly acre-feet sums on a water year basis. The precipitation data were provided by the National Weather Service office in Sacramento, and were summed into weekly precipitation values. The eight index precipitation stations used were: 1) Oroville Ranger Station, 2) Brush Creek, 3) DeSalbla, 4) Comptonville, 5) Downieville, 6) Canyon Dam, 7) Quincy Ranger Station, and 8) Sierraville. The monthly snowmelt predictions for the winter and spring months were produced by the Snow Survey Section of the California State Department of Water Resources.

4.1.1 The Main Program

Prior to the start of the simulation, historical and technical data are read into memory. This includes the number of years the program is simulated; streamflow data, reservoir constants, statistical hydrology data, and starting reservoir

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* Rule B essentially dictates that the reservoir is brought down to the November 1st storage level and allowed to operate according to constraints until the end of January when the snowmelt constraint is applied. The length of the application of the snowmelt constraint is dependent upon the April-July runoff prediction. When the snowmelt constraint is removed, the reservoir is allowed to follow the flood control parameter.

storage. On the second week of each simulation year, the precipitation is read into storage for each of eight index stations. The "continuity" equation for the reservoir for the weekly time increment is:

$$QIN + .0833\ (PREC - EVAP \cdot PANFAC)(AREA) - QOUT = SORV2 - SORV1 \qquad (4.1)$$

where

QIN = weekly gauged inflow into Oroville Reservoir

PREC = weekly precipitation on the reservoir in inches

EVAP = weekly evaporation in inches

AREA = average area of reservoir surface during week

QOUT = total controlled outflow and spill from Oroville Reservoir

SORV2 = storage at the end of weekly time period

SORV1 = storage at the beginning of the weekly time period

PANFAC = pan factor.

In an effort to simulate real-life conditions, it was assumed that the decision on the quantity of outflow for the coming week is made at the beginning of the week. After Subroutine Rule computes the tentative weekly release, all the above variables are known except weekly ending storage, SORV2, and consequently the continuity equation takes the following form:

$$SORV2 = QIN + .5\ (PREC - EVAP \cdot PANFAC)(AREA) - QOUT - SORV1. \qquad (4.2)$$

After the end of week storage has been calculated, a check is made to determine if the predicted outflow gives a weekly operation that is consistent with the constraints. If this is not true, an adjustment is made in the outflow to bring the operation into conformity with the system constraints. See Figure 4.1.

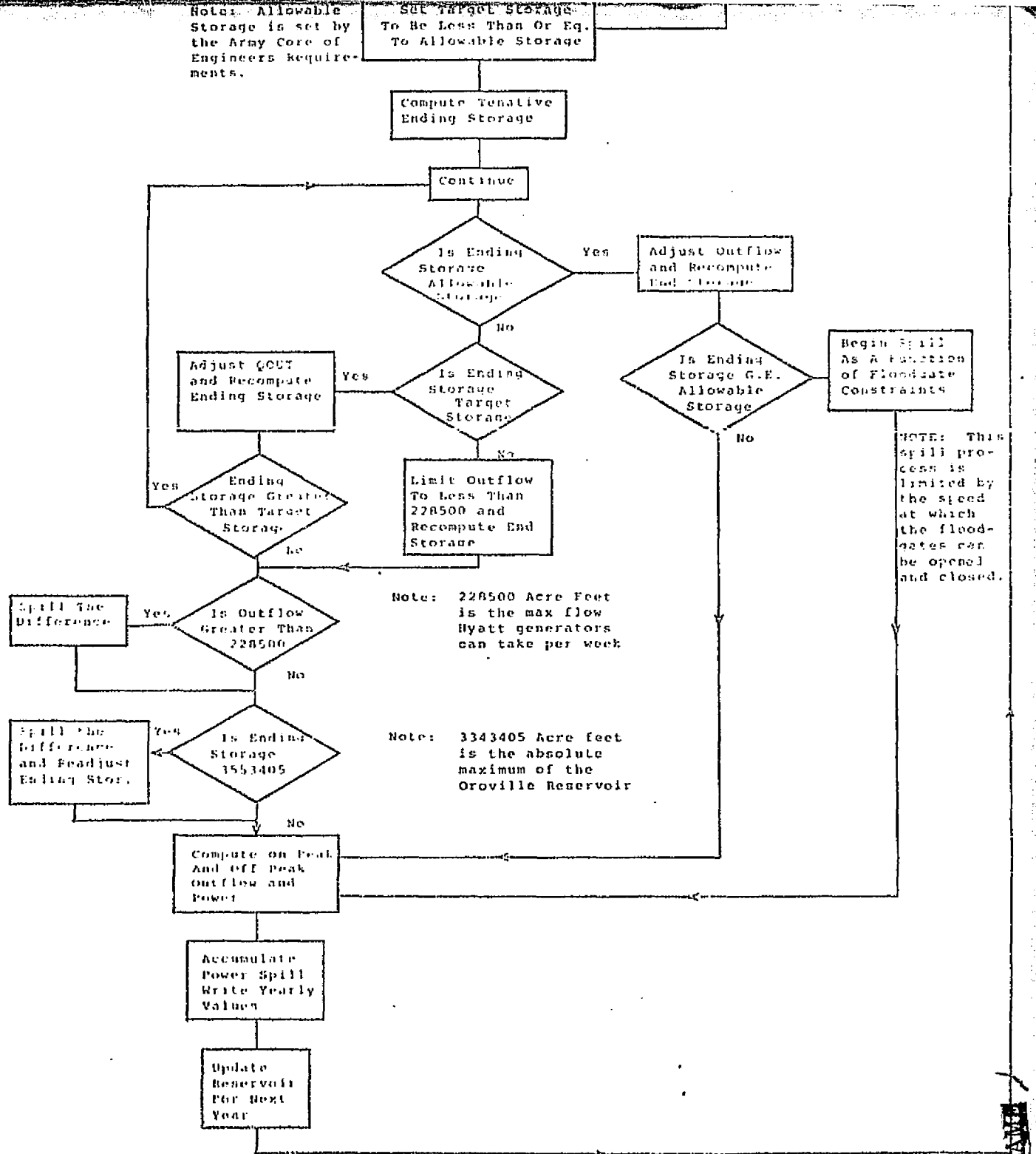

Figure 4.1 Decision Logic for Main Program

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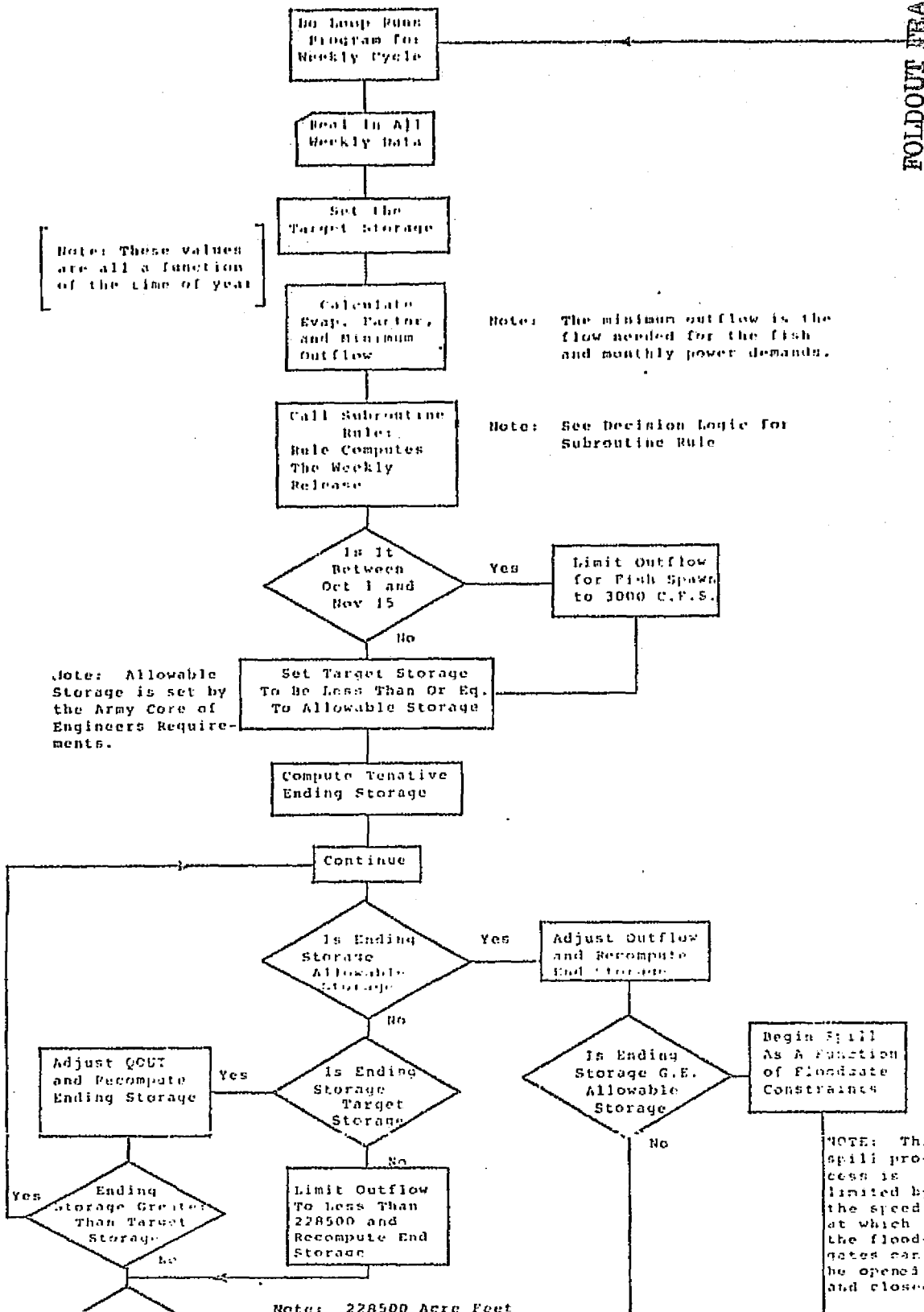

The above cycle is repeated week by week to simulate reservoir operations over the entire water year. When the continuity equation has been solved and the decision has been made regarding the quantity of release to be made, the power and energy calculations are made. The power factor, which is a function of reservoir elevation, was determined by polynomial regression.

$$POWFAC = -1.256883146 + 3.443417349E\text{-}3\ AVGEL - 1.523805837E\text{-}6\ AVGEL^2 \quad (4.3)$$

where

POWFAC = power factor to calculate megawatt-hours per acre-feet of release at the Hyatt Power Plant.

AVGEL = average weekly elevation of the reservoir.

4.1.2 Snowmelt Adjustments

The snowmelt predictions of the April to July runoff made by the Snow Survey Section of the California Department of Water Resources is used in the model in calculating the outflow and adjusting for operating constraints. An operating volume (STOMAX) is checked for each weekly cycle beginning the fifth week of every year. The number of weeks the program keys on or off of this volume is a function of the April-July predicted inflow. If this prediction is 4,000,000 acre-feet or greater, the program will continue to key on the variable through the 21st week. The number of weeks this variable is effective can be adjusted by varying the limits (PLIM) against which a check is made to determine whether there is enough potential runoff remaining in the snow pack to constrain the reservoir.

4.1.3 Subroutine Rule

Subroutine Rule is the internal subroutine of the model that computes the weekly release. Upon entry to the subroutine the precipitation from the index stations are summed and the weekly flood control parameter is calculated, which is:

$$PAR = .8078 + \frac{SUMPCP}{SUMBAR}\ 40.32 \quad (4.4)$$

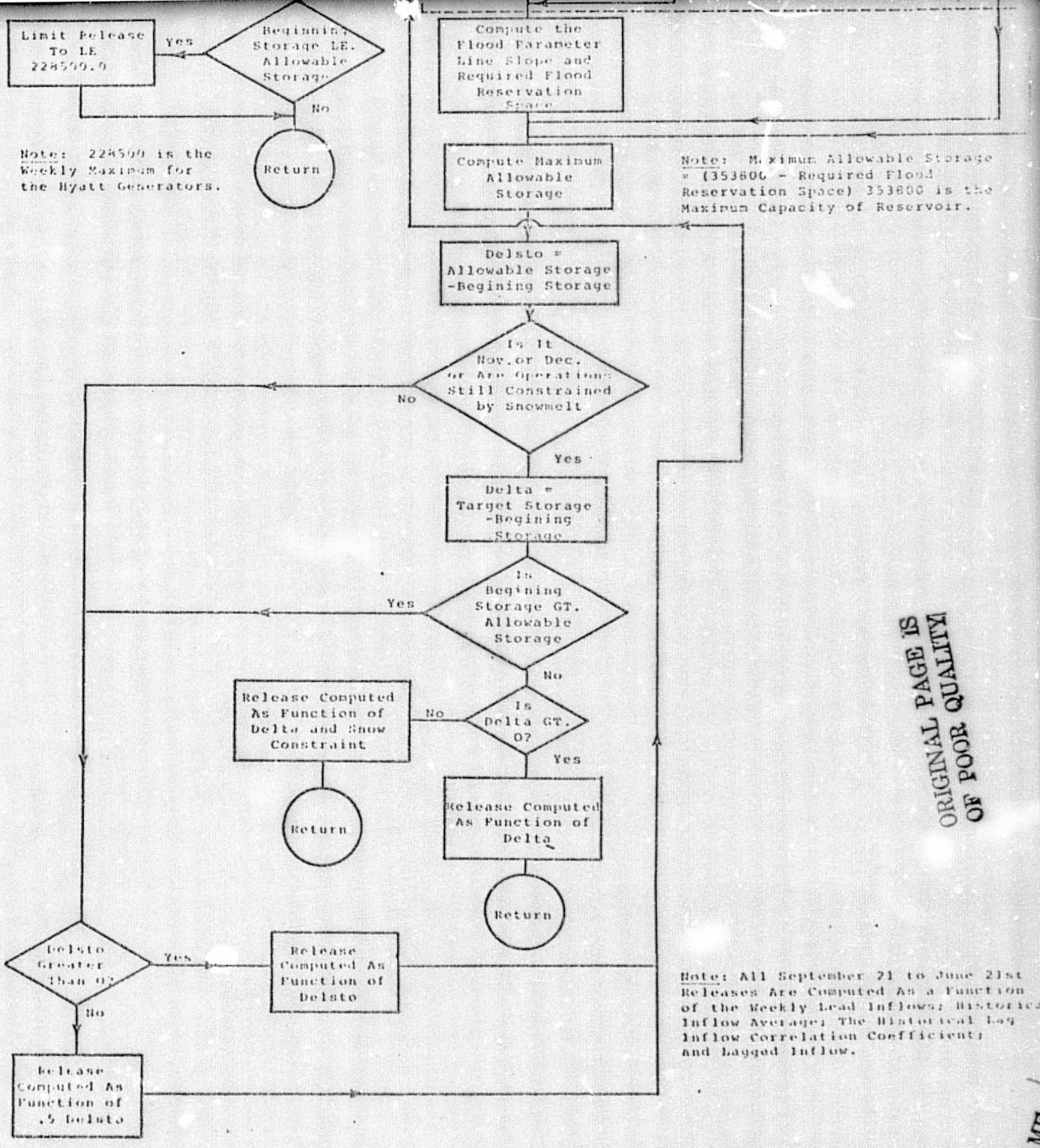

Figure 4.2 Decision Logic for Subroutine Rule

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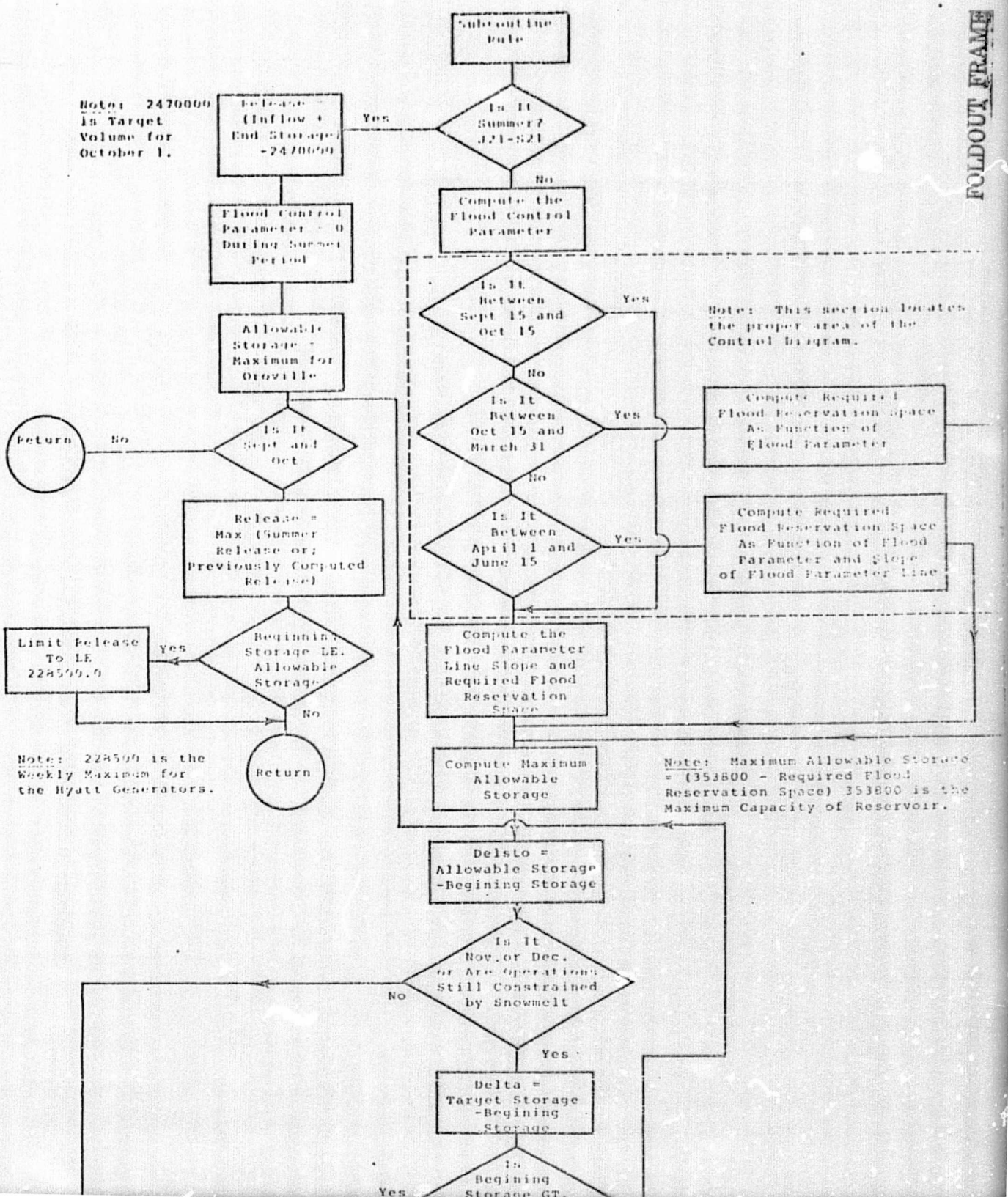
Subroutine Rule
Is It Summer? J21-S21
Yes
No
Release = (Inflow + End Storage) -2470000
Note: 2470000 is Target Volume for October 1.
Flood Control Parameter = 0 During Summer Period
Compute the Flood Control Parameter
Allowable Storage = Maximum for Oroville
Is It Between Sept 15 and Oct 15
Is It Between Oct 15 and March 31
Is It Between April 1 and June 15
Note: This section locates the proper area of the Control Diagram.
Compute Required Flood Reservation Space As Function of Flood Parameter
Compute Required Flood Reservation Space As Function of Flood Parameter and Slope of Flood Parameter Line
Return
No
Is It Sept and Oct
Release = Max (Summer Release or; Previously Computed Release)
Limit Release To LE 228599.0
Beginning Storage LE. Allowable Storage
Note: 228599 is the Weekly Maximum for the Hyatt Generators.
Return
Compute the Flood Parameter Line Slope and Required Flood Reservation Space
Compute Maximum Allowable Storage
Note: Maximum Allowable Storage = (353800 - Required Flood Reservation Space) 353800 is the Maximum Capacity of Reservoir.
DelsTo = Allowable Storage -Begining Storage
Is It Nov.or Dec. or Are Operations Still Constrained by Snowmelt
Delta = Target Storage -Begining Storage
Is Begining Storage GT.

where

PAR = weekly flood control parameter

SUMPCP = sum of the precipitation at the eight index stations

SUMBAR = sum of the mean annual precipitation of the index stations reporting.

The program then calculates the amount of reservoir capacity that must be reserved for flood control and also the maximum allowable storage, see Figure 4.2.

Essentially Subroutine Rule calculates the outflow as a function of the week number. As an example, consider the following release calculation for weeks 25 through 39:

$$QOUT = QIN + (SORV2 - 2470000) / (39-J) \quad (4.5)$$

where

J = week number that runs from 25 to 39 in this case

SORV2 = end of week storage

QIN = weekly inflow

2470000 = target volume for the reservoir on October 1, in acre-feet

QOUT = weekly release.

During the remainder of the year, when the flood control constraint is of primary importance, the release equation is computed generally as follows:

$$QOUT_j = QBAR_j + CORRE_j\ (QIN_{j-1} - QBAR_{j-1}) - K\ (DELTA) \quad (4.6)$$

where

$QOUT_j$ = weekly release

$BARQ_j$ = historical weekly average

$CORRE_j$ = correlation coefficient for the present week with respect to the previous week

DELTA = the difference between the end and the beginning of week storage and the maximum flood control storage

K = a weighting factor usually .5 when DELTA is positive and 1.0 when DELTA is negative.

The above equation is somewhat modified when the target storage is greater than the beginning storage, or when the beginning storage is greater than the allowable storage. See Figure 4.2.

4.1.4 Functions

The three functions used by the simulation model concern the various geometrical relationships of reservoir elevation, storage and area. The function ELEVOR calculates the elevation of the reservoir for any volume furnished as a parameter. The basic equation that is solved is:

$$V = B_1 + B_2 Y + B_3 Y^2 + B_4 Y^3, \qquad (4.7)$$

The function uses a Newton-Raphson type algorithm to solve for the root of the equation and returns to the calling statement an elevation for any given reservoir volume.

Where

V = Volume of reservoir

B_1, B_2, B_3, B_4 = Predetermined coefficients calculated by polynomial regression from the data of the area - capacity curves

Y = Vertical height above a given base elevation.

The reservoir area, function AREAOR, is calculated by solving the derivative of the above equation, given the elevation:

$$A = dv/dy$$

$$A = B_2 + 2B_3 Y + 3B_4 Y^2.$$

The function STOROR solves (4.7) directly for the volume when given an elevation as an argument. These functions then enable the simulation model to solve the continuity equation in a repetitive fashion with the greatest amount of generality and flexibility.

4.1.5 Program Option

Since precipitation data for the index stations used in computing the flood control parameter are available only since 1947, the program has the option of reading in the end-of-month flood control space for Oroville Reservoir. When this option is taken, the weekly flood control parameter is computed as a straight line function between monthly values that are read into the program at the beginning of each year. Subroutine NORAIN approximates the precipitation directly on the reservoir from the mean precipitation curve of the Oroville Ranger Station. For this case study the above option was not used.

4.2 Modifications of the OROSIM Simulation Model by The Incorporation of Improved Forecasts

The maximum weekly outflow that can be used by the Hyatt generators at Oroville is 228,500 acre-feet. If this constraint were to be ignored, then power would be maximized by having the target level of water at Oroville follow the flood reservation diagram. This would mean, in effect, that the operational rule would be for weekly outflows to equal weekly inflows during the October 15th to April 1st period. Because of the 228,500 acre-feet constraint, the average level of water from October 15th to April 1st is kept below the level given by the flood control diagram. The most up-to-date rule followed in the original OROSIM program is given in Section 4.1. With that rule, the forecast of the actual inflow is given by the following formula:

$$\hat{I}_{t,a} = \bar{I}_t + r\ (\bar{I}_{t-1,a} - I_{t-1}) \qquad (4.8)$$

where

$\hat{I}_{t,a}$ = forecasted weekly inflow for week t

$\bar{I}_{t-j}$ = historical average weekly inflow in week t-j (j=1 or 0)

$I_{t-1,a}$ = actual weekly inflow in week t-1.

The rule used to determine outflow is given by:

$$\hat{Q}_t = I_{t,a} + f(S_t, E_t) \qquad (4.9)$$

where

Q_t = weekly outflow for week t

$\hat{I}_{t,a}$ = forecasted weekly inflow for week t

S_t = storage maximum for week t

E_t = actual storage at beginning of week t

$f(S_t, E_t)$ = the adjustment in outflow as a consequence of the relationship between beginning of week storage and maximum flood control storage.

With a perfect forecast we can write

$$Q_t = I_{t,a} + f(S_t, E_t) \qquad (4.10)$$

where

$I_{t,a}$ = the actual weekly inflow.

Thus, for any degree of improved accuracy of forecast, we can write

$$Q_t = \delta_1 I_t + (1-\delta_1) \hat{I}_t + f(S_t, E_t) \qquad (4.11)$$

where

δ_1 = the degree of improvement in the accuracy of the forecast of the week's inflow.*

If $\delta = 0$, then we have the original rule Equation 4.9

If $\delta = 1$, then we have the perfect forecast rule Equation 4.10

If $\delta = .5$, then we have made a 50 percent improvement in the accuracy of the forecast. For example, if a perfect forecast gave an inflow of 70,000 acre-feet and if a forecast using Equation 4.8 gave an estimated inflow of 50,000 acre-feet, the δ of .5 means that the improved forecast will give an estimated inflow of 60,000 acre-feet.

Experiments were carried out to improve the term f(S,E) by adding a constant term, i.e. f(S,E) + c for weeks 44 to 8, but at the level examined (i.e. c = 10,000 acre-feet per week), a small reduction in both spill and power occurred. The reasons for adding the c term resulted from the observations that (a) an adjustment for the 228,500 acre-foot constraint appears desirable to reduce spills and (b) the bulk of the spills occurred between weeks 48 and 8. However, in terms of hydropower generation, the reduction in spills was more than offset by the lower average water elevation in non-spill weeks. Probably there is some positive level less than 10,000 acre-feet per week that would both reduce spills and increase power generated, but the quantitative effects are likely to be negligible. This result, combined with the analysis in Section 4.3 indicates that improving the function f(S,E) will not make much difference if the goal is to maximize power output. Furthermore, from an examination of the results in Section 4.3, it is clear, for reasons explained in that section, that improving a one-week forecast will have much less payoff than a four-week forecast in terms of increased hydropower. Even less hydropower payoff is obtained by improving the daily forecast. Thus, the important conclusion is reached that relatively limited hydropower benefit will occur by improving information used in making daily or single week water inflow forecasts.

One important improvement with present day information can be made in the equation that determines weekly outflow. That improvement is to consider the expected weekly inflow over several weeks and to base the weekly outflow on the expected average weekly inflow over those several weeks. Thus, in a low inflow week, more would be released than under the present rule

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* While the δ parameter appears to be deterministic, in fact, it perturbs the forecasted inflows in a stochastic manner. In effect, an increased value of δ reduces the "constant" variance between the forecasted inflow and the actual inflow. See Appendix J for a fuller explanation.

in anticipation of a high inflow week, and conversely, less would be released under the present rule for a high inflow week. The effect of this change would be to reduce spill and increase hydropower.

A possible new operating rule with present-day information could be:

$$Q_t = \frac{1}{1+\alpha_1+\alpha_2+\alpha_3+\ldots+\alpha_n} \left[\bar{I}_t - r_o (I_{t-1,a} - \bar{I}) + \alpha_1 \bar{I}_{t+1} + \alpha_2 \bar{I}_{t+1} + \alpha_3 \bar{I}_{t+2} + \ldots + \alpha_n \bar{I}_{t-n}\right] + f(S_t, E_t) \quad . \tag{4.12}$$

The α weights could be of the form

$$\alpha_1 = r_o r_1$$

$$\alpha_2 = \alpha_1 r_2$$

$$\alpha_3 = \alpha_2 r_3 \qquad \text{etc.}$$

where r_t = the correlation coefficient between week t and week t + 1 inflow.

The incorporation of the concept of more accurate forecasts in Equation 4.11 can be extended to more than a single week. The way in which this additional information would be used to determine weekly outflow is to obtain a weighted average water inflow. The weights would be a function of the degree of improvement in the forecasts of the additional weeks inflow. The averaging concept is used for the same reason as that stated previously, namely, to lower spills by increasing outflow in low inflow weeks in order to make possible a reduced outflow in high inflow weeks.

For example, an inflow of 100,000 acre-feet in week t and 400,000 acre-feet in week t + 1 produces, under the cur-

rent operating rule, an outflow of 100,000 acre-feet through the generators in week t and an outflow through the generators in week t + 1 of 228,500 acre-feet.* A spill in week t + 1 of 171,500 acre-feet occurs. The total amount of water passing through the Hyatt generators over this two week period is 328,500 acre-feet. If an average of the two weeks inflow is used to determine outflow, then a weekly outflow of 228,500 acre-feet through the generator and a weekly spill of 21,500 acre-feet would occur. The total flow through the generators would be 457,000 acre-feet, which would be a significant increase over the 328,500 acre-feet of the present-day rule. Notice in our example that even having information on two weeks inflow leads to some spill (43,000 acre-feet). To determine the importance and implications of this averaging concept, an examination of the frequency, magnitude and duration of inflows over 228,500 acre-feet is given in Section 4.3.

To incorporate more accurate weekly forecasts made several weeks into the future, Equation 4.11 has been modified in the following way:

$$Q_t = \frac{\delta_1}{\delta_1+\delta_2+\delta_3+\delta_4} \left[\delta_1 I_t + (1-\delta_1)\hat{I}_t + f(S_t,E_t) + \frac{\delta_2}{\delta_1}\left(\delta_2 I_{t+1} + (1-\delta_2)\hat{I}_{t+1}\right) + \frac{\delta_3}{\delta_1}\left(\delta_3 I_{t+2} + (1-\delta_3)\hat{I}_{t+2}\right) + \frac{\delta_4}{\delta_1}\left(\delta_4 I_{t+3} + (1-\delta_4)\hat{I}_{t+3}\right)\right], \quad (\delta_1 \geq \delta_2 \geq \delta_3 \geq \delta_4) \qquad (4.13)$$

* For simplicity, we have ignored the term f(S,E) which will reduce, on average, the amount of spill.

where I_j = actual weekly inflow in week j

$\hat{I}_j$ = equation 4.8 for week t and equals the historical average inflow $\hat{I}_j$ for week j

δ_j = the degree of weekly improvement in the accuracy of the forecast in week j

Q_t = outflow in week t.

The properties exhibited by Equation 4.13 are well designed for our purposes. If all the δ's equal zero, then Equation 4.13 reduces to the present-day situation represented by Equation 4.9.*

* In the computer program, we have added a small number ε to δ to insure that the term $\delta_1/(\delta_1+\delta_2+\delta_3+\delta_4) = 1$ when all δ's equal 0.

If δ_1 equals one and all the other δ's equal zero, then Equation 4.13 reduces to Equation 4.10. If all the δ's equal one (i.e. perfect forecasts of all four weeks inflow), then we have

$$Q_t = \frac{1}{4} [I_t + I_{t+1} + I_{t+2} + I_{t+3} + f(S_t,E_t)] \qquad (4.14)$$

which is the simple average of the four weekly inflows plus the term .25 $f(S_t,E_t)$. This is exactly what we desire for the averaging concept.*

If the first three δ's equal one and the fourth δ equals zero, then we would have

$$Q_t = \frac{1}{3} [I_t + I_{t+1} + I_{t+2} + f(S_t,E_t)] . \qquad (4.15)$$

Equation 4.15 indicates that the averaging concept holds correctly as we eliminate weeks from Equation 4.13. The interested reader can easily test this out for other cases.

If δ_1 equalled one and all the other δ's equalled one-half, then we would have

* It can be noted that the term $f(S_t,E_t)$ should be reduced in importance with improved forecasts, as it is in Equations 4.13 and 4.14.

$$Q_t = .4 \left[I_t + f(S_t, E_t) + .25\, I_{t+1} + .25\, \hat{I}_{t+1} + .25\, I_{t+2} + .25\, \hat{I}_{t+2} + .25\, I_{t+3} + .25\, \hat{I}_{t+3} \right] . \quad (4.16)$$

For weeks t + 1, t + 2, and t + 3, equal weight is given to the proxy for current forecast ability $\hat{I}$ and to perfect forecast ability I, exactly as would be expected with δ_2, δ_3, and δ_4 all equal to .5. But also note that the sum of the weights (1 for I_t and .25 for the other I terms) equals 2.5, which when multiplied by the outside weight of .4 gives an overall weight of 1. This indicates that the equation is not "biased" to produce either too high or too low an outflow with a partial improvement in forecasting ability. It is suggested that the interested reader may wish to test out this assertion with other δ values.

We have used the general Equation 4.13 to test out a number of interesting cases. The results of these tests are given in the next section.

The equations in OROSIM use a one-week forecast update frequency. How would the results of OROSIM be modified by a two-or a three-week forecast update frequency? Imagine a two-week forecast update frequency for a two-week forecast. In the first week of the forecast, the benefit would be the same as a two-week forecast updated weekly. In the second week of the forecast, the benefit would be the same as a one-week forecast updated weekly. Hence, a two-week forecast updated every two weeks has a benefit equal to the average benefit derived from a one-week updated frequency for a one-week forecast and for a two-week forecast. Similarly, the benefit from a three-week forecast updated every three weeks can be calculated from the one-week update frequency results. In the first week, the benefit is the same as a three-week forecast updated weekly, in the second week it is the same as a two-week forecast updated weekly and in the third week the benefit is the same as a one-week forecast

updated each week. Thus, a three-week forecast updated every three weeks has the same benefit as the average of a one-week, a two-week, and a three-week forecast, all updated each week.

4.3 Simulation Results

What has been the actual seasonal spill pattern at Oroville in the years 1968 to 1973? An answer to this question will provide important clues as to when and how spills can be reduced and hydropower increased. Table 4.1 presents the historical pattern of spills as they actually occurred for the 1968-1973 period. Appendix G gives, in the form of flood control diagrams, the behavior of the level of water at the Oroville Dam for each day of the year, the amount and pattern of spill, and the behavior of the flood control parameter.

We observe from Table 4.1 that the bulk of the spills occur between January 10th and February 10th. This is a remarkably short time span of one month. Slightly over 75 percent of the spills (in acre-feet) took place within this short time span. The average spill during this period was 713,762 acre-feet compared to an average spill of 97,062 acre-feet for the pre-January 10th period and an average spill of 167,916 acre-feet in the post-February 10th period. The average duration of spill also was considerably larger in the January 10-February 10 period. Whereas the pre-January 10 and post-February 10 periods had average spill durations of 10 days and 7.5 days, respectively, the average spill duration during the January 10 to February 10 period was 14.5 days. This duration result has an important implication for the length of the forecast period that is desirable. It indicates that even an accurate 5-day forecast of inflow will not prevent a large volume of spill from taking place. An accurate 1-day forecast of inflow will be almost worthless in terms of preventing spills.

The same general pattern of spill concentration is evident using the OROSIM program. OROSIM is designed to test

Table 4.1 Historical Spill Pattern at Oroville (in acre-feet)

Water Year	Spill Beginning Date	Duration of Spill (in days)	Time of Year		
			Before Jan. 10	Jan 10 to Feb 10	After Feb 10
1968	1/20/69	16		614,286	
1969	12/23/69	9	73,901		
	1/12/70	22		1,553,266	
	3/01/70	4			10,974
	3/08/70	4			3,438
1970	3/26/71	8			81,890
1971					
1972	1/15/73	6		218,071	
1973	11/15/73	11	120,223		
	1/15/74	14		469,425	
	3/29/74	14			575,361
Totals			194,124	2,855,048	671,663

Note: Total Spill for 1968-1973 is 3,720,835 acre-feet.

Table 4.2 Spills Using OROSIM Program With Present Day Forecasts (in acre-feet)

Water Years	Weeks of the Year			Spill Total
	44-50	51-6	7-43	
1948-1952	127,569		223,335	350,904
1953-1957		1,315,771	113,850	1,429,621
1958-1962			448,800	448,800
1963-1964		1,313,355	232,460	1,545,815
1968-1972		1,568,650		1,568,650
Totals	127,569	4,197,776	1,018,445	5,343,790

Table 4.3 Weeks With Inflow Greater Than 228,500 Acre-Feet

Week	Calendar Years								
	1947	1948	1949	1950	1951	1952	1953	1954	1955
1									
2							528,200		
3							307,200		
4					271,300				
5						305,700			
6				290,600	260,800	229,300			
7					252,500				
8									
9									
10								239,000	
11									
12									
13									
14						343,900		229,900	
15						424,300			
16		281,700				375,900			
17						427,000	244,600		
18						430,200			
19						358,000			
20						316,800			
21						298,900			
22						272,100			
23-40									
41									
42-46									
47				447,100					
48									
49				398,700					
50				307,400					
51									991,000
52					252,200				623,400
Yearly Totals	0	281,700	0	1,443,800	1,036,900	3,782,100	1,080,000	468,800	1,614,400
Yearly Totals Over 228,500	0	53,200	0	529,800	122,800	1,266,600	394,500	11,800	1,157,400

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Table 4.3 Weeks With Inflow Greater Than 228,500 Acre-Feet (continued)

Week	Calendar Years								
	1956	1957	1958	1959	1960	1961	1962	1963	1964
1									
2									
3	473,300								
4	279,900								
5									
6			235,200		369,000				
7			330,600				292,800		
8	298,100		368,700						
9		375,900	412,000						
10									
11									
12			229,700						
13									
14			284,000					269,400	
15			236,000					344,500	
16			301,500					281,300	
17			261,800						
18			243,800						
19	233,100		270,400						
20			243,400						
21			233,900						
22									
23-40									
41							478,300		
42-46									
47									
48									
49									
50									
51									731,000
52									847,900
Yearly Totals	1,384,400	375,900	3,651,000	0	369,000	0	771,100	895,200	1,578,900
Yearly Totals over 228,500	370,400	147,400	680,500	0	140,500	0	314,100	209,700	1,121,300

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Table 4.3 Weeks With Inflow Greater Than 228,500 Acre-Feet (continued)

Week	Calendar Years								Weekly Totals	Weekly Totals Over 228,500
	1965	1966	1967	1968	1969	1970	1971	1972		
1	364,600								364,600	136,100
2	296,100								824,300	367,300
3					351,100	700,600			1,832,200	918,200
4	230,500		258,800		786,300	1,015,600			2,843,400	1,472,400
5			437,600		237,800	281,900			1,263,900	349,000
6									1,384,900	242,400
7					239,100				1,115,000	201,000
8				340,500					1,007,300	321,800
9									787,900	330,900
10									239,000	10,500
11									0	0
12			299,500						529,200	72,200
13							393,200		393,200	164,700
14					281,700				1,408,800	266,200
15									1,904,800	319,300
16	269,900								1,510,300	387,800
17	263,000				248,500				1,444,900	301,400
18									674,000	217,000
19					280,700				1,142,200	228,200
20			240,200		262,600				1,063,000	149,000
21			340,400						873,200	187,700
22									272,100	43,600
23-40									0	0
41									478,300	249,800
42-46									0	0
47									447,100	218,600
48									0	0
49									398,700	170,200
50									307,400	78,900
51					264,800				1,996,900	1,301,300
52									1,721,500	1,039,000
Yearly Totals	1,424,100	0	1,576,500	340,500	2,952,600	1,999,100	393,200	0	27,319,100	
Yearly Totals Over 228,500	281,600	0	434,000	112,000	896,100	1,313,600	164,700	0		9,724,600

out and incorporate improvements in operational rules, so that average spills with the OROSIM program will be lower than the historical average. From Table 4.2, we observe that about 75 percent of the spill occurs between week 51 of the calendar year and week six of the next calendar year.

The explanation for this temporal pattern of spill is given by the temporal pattern of the historical weekly inflow of water into the Oroville Reservoir. Since current short-term forecasts of water inflow extend over only a 5-day period, spills will tend to occur in weeks with an inflow greater than 228,500 acre-feet. Table 4.3 records those weeks from 1948 to 1972 when inflows have been greater than 228,500 acre-feet. The next to last column gives the total inflow in weeks with inflows greater than 228,500 acre-feet. These inflows are at a peak during the January period. More relevant, however, is an examination of the inflow in excess of 228,500 acre-feet given in the last column of Table 4.3. The excess inflows show a more pronounced temporal pattern, with January being the peak excess inflow month. Also useful is to look across each column of this Table to examine the consecutive number of weeks of excess inflow. Several consecutive weeks of excess inflow sharply increases the need for forecasted periods of more than one week. Table 4.4 shows the frequency distribution of consecutive weeks of excess inflow.

Table 4.4 Distribution of Consecutive Excess Inflows* (i.e. Inflows Greater than 228,500 acre-feet)

	Weeks of Inflow				
	1	2	3	4	5
Number of Occurrences	21	7	3	4	2

*For example, the number 7 under the 2 weeks of inflow column means that on 7 separate occasions there were two consecutive weeks of excess inflow.

Table 4.4 shows that the occurrence of consecutive excess inflows is not a rare phenomenon. Sixteen occurences out of thirty-seven involved consecutive excess inflows, some of which were of relatively long duration. On four occasions there were four consecutive weeks of excess inflow and on two occasions there were five weeks of excess inflow. The fact that on six occasions four or more excess inflows occurred, means that even a perfect monthly forecast of water inflow will not prevent some spillage. Table 4.5 presents the results of having perfect forecasts of inflow for four consecutive weeks (i.e., δ_1, δ_2, δ_3, and δ_4 in equation 4.13 of the OROSIM Model all equal to one).

Even with perfect four-week inflow forecasts, 1,902,332 acre-feet of water are spilled. This represents a reduction of about 65 percent in spill from the current information case shown in Table 4.2.

Table 4.5 Spills Using OROSIM Program with Perfect Four-Week Inflow Forecasts (in acre-feet)

Water Years	Weeks of the Year			Spill Total
	44-50	51-6	7-43	
1948-1952	93,225	--	--	93,225
1953-1957	--	445,500	--	445,500
1958-1962	--	--	113,850	113,850
1963-1967	--	481,682	--	481,682
1968-1972	--	768,075	--	768,075
Total	93,225	1,695,257	113,850	1,902,332

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Table 4.6 Summary of Hydropower Results for Nine Cases Examined with the OROSIM Model*

Case Number	Case	Spill (in AF)	Total Hydropower (in MWH)	Increase in Hydropower (in MWH)	Annual Dollar Benefit at Oroville
1	No Improved Forecasts	5,343,790	59,841,000	—	—
2	Perfect Forecast, One Week Period	5,312,484	59,921,000	80,000	$ 62,000
3	50% Forecast Improvement; Two Week Period	4,474,004	60,223,000	382,000	$294,000
4	Perfect Forecast, 1st Week; 50% Improvement, 2nd Week	4,760,839	60,159,000	318,000	$245,000
5	50% Forecast Improvement Three Week Period	3,375,765	60,566,000	725,000	$558,000
6	Perfect Forecast Two Week Period	3,748,178	60,594,000	753,000	$579,000
7	50% Forecast Improvement Four Week Period	2,620,907	60,665,000	824,000	$634,000
8	Perfect Forecasts Three Week Period	2,685,325	60,868,000	1,027,000	$790,000
9	Perfect Forecast Four Week Period	1,902,332	60,988,000	1,147,000	$882,000

* An additional sixteen cases were run. Four cases each at a 25, 33.3, 66.7, and 75 percent accuracy improvement level were run.

Except for case 4, the results presented in Table 4.6 behave in the theoretically expected way, i.e., the greater the improvement in the accuracy of forecasts, the greater the hydropower benefit. With improved forecasts, spill is reduced and hydroelectric power generation is increased. The reason case 4 gives an anomalous result is that the current and new information operating rules in OROSIM are not optimum but are only close to optimum.*

4.4 Policy Change Effects: Additional Hydropower from Different Management Policies

4.4.1 Parametric Change of Flood Control Reservation at Oroville

The flood control reservation (FCR) at Oroville is held to a large value depending on daily ground wetness index (DWGI) in the months October through March. For instance, if the value of this index is maximal (DWGI $\geq$ 11.0), the FCR level is 750,000 acre-feet. This is because October through March is the rainy season and large storms can be expected then. Beginning April 1, the FCR can safely be reduced progressively to zero in May, and the Oroville Flood Control Diagram** shows such reduction along a sloping line on the chart with a daily rate of about 10,000 acre-feet.

Spills occur after April 1 in some years (e.g., 1974) whenever the storage level in the reservoir exceeds the appro-

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* In Section 4.2, operating rules were suggested that probably are an improvement over current and new information operating rules now in the OROSIM program. But because of the 228,500 acre-foot constraint and the pattern and variability of weekly inflows, implementing these suggested operating rules will probably only result in a marginal quantitative improvement in spill and power generation. Qualitatively, however, anomalies such as case 4 should be eliminated with the suggested operating rules.

**See Appendix G of this report.

priate line on the chart depending on ground wetness. If improved information on snowmelt were available from LANDSAT imagery, the daily rate of reduction of FCR could be increased and thus the spills could be reduced without added risk. The Oroville Flood Control Diagram would correspondingly be changed to increase the slope of the lines from April 1 forward. In 1974 for instance, the spill reduction might have been 500,000 AF,* but in other years it would have been zero since no spills occurred after April 1.

If the hypothetical spill reduction of 500,000 AF for 1974 were all applied to hydroelectric power generation, it could have two possible effects:

- either the efficiency of the hydroelectric power generation at Oroville would have been increased by the higher water elevation (e.g., an increase from 760 ft. to 800 ft. average elevation causes an increase from 0.48 to 0.53 megawatts per acre-foot) if generators were running at full capacity in April, May, and June (228,500 acre-feet per week) for 1974,

- or the amount of hydroelectric power output would have been directly increased if the generators were not running at full capacity during April, May, and June 1974.

Table 4.7 shows the excess of Oroville weekly inflows over the rated capacity of the Hyatt generator for the years 1947-1972. If the dam had existed throughout this period instead of from 1968 onwards, these acre-feet could have been used, partially or in totality, to increase hydroelectric power efficiency following the recommended change in flood control reservation procedures for April through June. The average year, in this 26 year period, offers an excess 6643 acre-feet per week during the 12 spring weeks. Translating this into additional hydropower at an average rate of 0.50 MWH per acre-foot,** twelve weeks in April, May, and June would

*Assuming a daily reduction of FCR by 20,000 AF.
**Corresponding to water elevation in Oroville of 780 feet: actually higher values may easily be reached.

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Table 4.7 Excess of Inflow at Oroville Over Generation Capacity* for April, May, and June, 1947-1972

Week	1947	1952	1953	1954	1956	1958	1963	1965	1967	1969	1947-1972 Total
April											
1-7		115,400		1,300		55,000	40,000			53,200	265,800
8-14		195,800				7,500	116,000				319,300
15-21	53,200	147,400				73,000	52,800	41,500			367,900
22-28		198,500	16,100			33,300		26,300		20,000	294,200
30-6		201,700				15,300					217,000
May											
7-13		129,500			4,600	41,900				52,200	228,200
14-20		83,300				14,900			11,700	34,100	149,000
21-27		70,400				5,400			111,700		187,500
28-4		43,600									43,600
June											
5-11											
12-18											
19-25											
26-2											
3 Month Total	53,200	1,190,00	16,100	1,300	4,600	246,300	209,700	67,800	123,400	159,500	2,072,500

*The maximum weekly outflow that can be used by the Hyatt Generators at Oroville is 228,500 acre-feet.

allow 39,856 MWH of additional power production which has a marginal value or net benefit (following Chapter 3 for valuation) of $797,120.00 in 1975 dollars.

The benefits quoted above are derived from an ad hoc change in the flood control charts based on the assumption that improved information on the snowmelt contribution would allow such changes with no increase in the risk of flooding. The entire spillage reduction which led to economic benefits was limited to the months April, May, and June because that is the timespan within which improved information due to ERS-derived snowmapping is expected. In order to examine the full extent of the potential for increased hydropower through changes in management policy, the next two sections (4.4.2 and 4.4.3) consider more drastic departures from the existing management policies. Section 4.4.2 studies the simulated effects of a 50 percent reduction in Flood Control Reservation at Oroville (1947-1972) through OROSIM. Section 4.4.3 compares the OROSIM results from managing Oroville with improved runoff forecasts with the results of a University of California study* which presented the optimal hydropower production for Oroville.

4.4.2 Results of OROSIM Simulation Exercise with Reduced Flood Control Reservation Space

In using OROSIM, one must be aware that the calculated amount of water spilled is derived from the Oroville Flood Control Diagram prepared by the Army Corps of Engineers. The use of these flood control regulations with altered storage levels in view of the improved forecasting, but with equal risk of flooding, would be logical. Legally the use of the existing policy unaltered is in force, but this section will ignore the legal constraint and assume a change in the flood control reservation space.

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*William A. Ingram, "A Risk Model Analysis for the State Water Project," Operations Research Center, University of California, Berkeley, March 1974, ORC74-10.

To derive the corresponding change in flood control reservation for a particular improvement in forecast capability is beyond the scope of this study. We have taken an ad hoc position and considered a 50 percent reduction in the flood control reservation at all times. For example, when the Daily Ground Wetness Index is 7.0 during the months October through March, the flood control reservation is 562,500 acre-feet, which corresponds to a level of 2,975,000 acre-feet of reservoir storage for the same conditions. We arbitrarily reduced the flood control reservation by 50 percent to 281,250, bringing the storage level up to 3,256,250. This would have resulted in a spillage reduction of 73,901 acre-feet in December, 1969, and January, 1970, and that much more water through the generators.

The results of the OROSIM simulation runs with 50 percent less flood control reservation for three different levels of improvement of four-week forecasts are shown in Table 4.8, and graphically depicted in Figure 4.3. Using no forecasting improvement there is a potential net benefit of $712,300 annually from additional on-peak power. When the four-week forecast is improved to perfect accuracy, this marginal value of extra hydro-power drops to $349,200. This is partly because the improved information has already achieved a 4.23 percent increase in on-peak power generation and a 64 percent reduction in spillage before the new management policy effect is brought into consideration. The remaining part of this effect is due to the somewhat arbitrary rules in OROSIM for allocating production to on-peak and off-peak power (see Section 3). Note that the total annual power production does not drop with improved information.

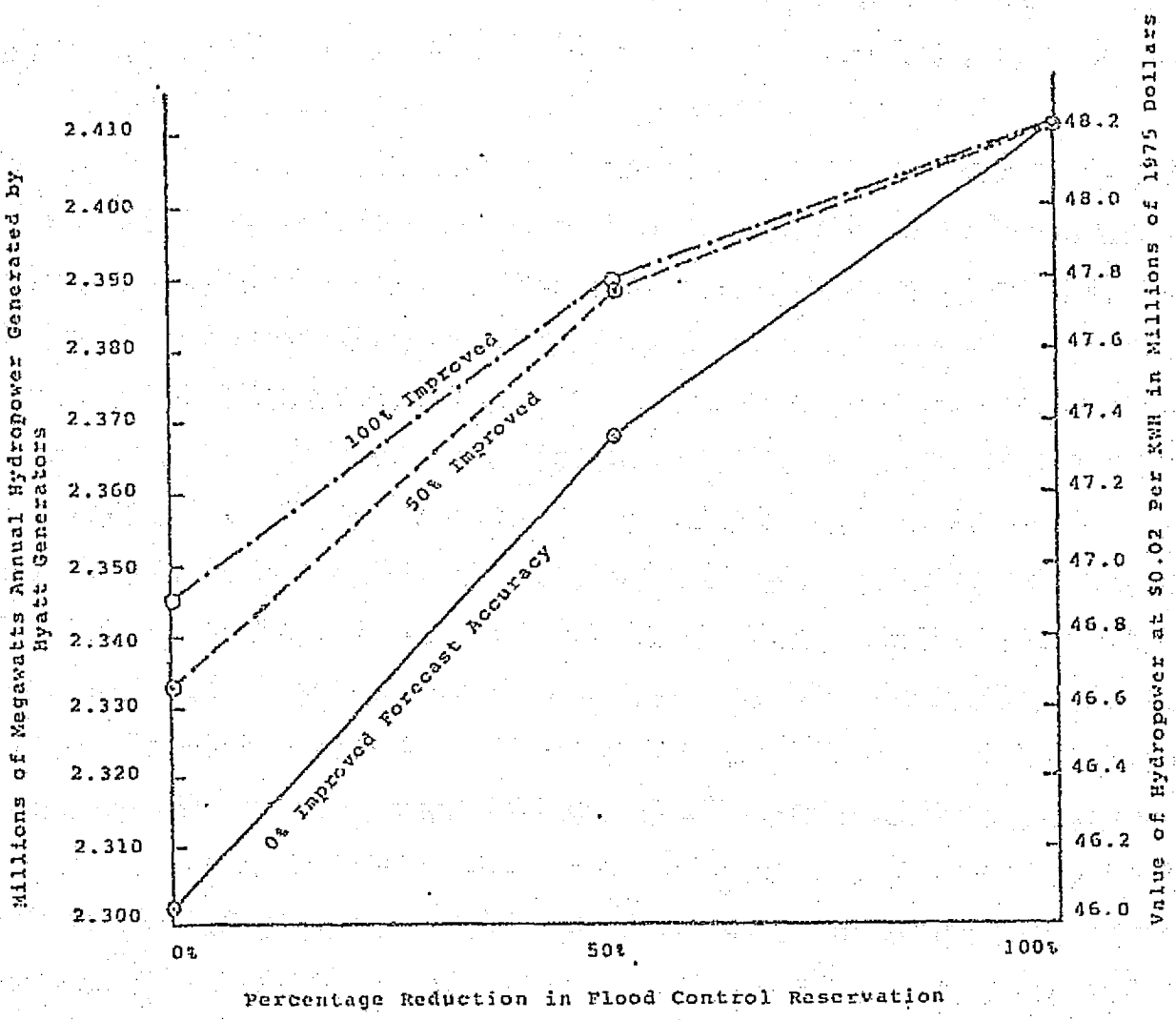

Figure 4.3 The Economic Effects (Potential) of Policy Changes (Hydropower Only)

Note: Percent values are "increases in forecast accuracy." They can be defined as:

$$100 \times \frac{\text{(Std. Dev. of Current Forecast Error - Std. Dev. of Improved Forecast Error)}}{\text{Std. Dev. of Current Forecast Error}}$$

Note: Four-week forecast range was used for improvements.

Table 4.8 Results of OROSIM with 50% Less Flood Control Reservation

		Percentage Improvement Towards Perfect 4-Week Forecast		
		0%	50%	100%
Existing FCR	Annual Spill	205,352 AF[1]	100,800	73,166
	On-Peak Power	1,957,500 MWH[2]	2,047,900	2,040,310
	Off-Peak Power	344,000 MWH[3]	285,350	305,380
	Total Power	2,301,500	2,333,250	2,345,690
50% Less FCR	Annual Spill	140,040	31,737	20,230
	On-Peak Power	1,993,115	2,068,350	2,057,770
	Off-Peak Power	374,650	320,920	332,690
	Total Power	2,367,765	2,389,270	2,390,460
Net Change Due to Reduction	Annual Spill	-65,512	-69,663	-52,936
	On-Peak Power	35,615	20,450	17,460
	Off-Peak Power	30,650	35,570	27,310
		66,265	56,020	47,770
1975 Value of Additional On-Peak Power		$712,300.00[4]	409,000.00	349,200.00

Footnotes:

(1) All spills and spill reductions are measured in acre-feet (AF)

(2) On-peak power generated annually - average over 26 years - in megawatt-hours (MWH)

(3) Off-peak power generated annually - average over 26 years - in megawatt hours (MWH)

(4) Dollar values per year obtained from $00.02/KWH for additional on-peak power following discussion in Chapter 3.

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4.4.3 Comparison of OROSIM Results with Optimized Hydropower Generation for Oroville

The University of California, Berkeley, study by William A. Ingram, mentioned above, considered the problem of maximizing the expected power production at Oroville while operating at a specified "risk" level, in relation to commitments for firm power. The results of the optimization summarized in Table 4.9, quoted from this report, show Oroville on-peak power (MWH) generation by month.

The power obtained from this operation averaged 404.3 megawatts on-peak. By contrast, the installed combined Thermalito

Table 4.9 Oroville On-Peak Generation

Month	Mean MWH	Standard Deviation MWH
Jan.	323.3	227.9
Feb.	410.3	212.5
Mar.	356.6	239.9
Apr.	387.2	240.9
May	399.0	180.9
June	364.6	155.9
July	412.0	159.3
Aug.	415.6	165.4
Sep.	413.2	216.0
Oct.	503.7	147.2
Nov.	485.1	154.6
Dec.	361.0	203.0

Source: University of California*

*William A. Ingram, "A Risk Model Analysis for the State Water Project," Operations Research Center, University of California, Berkeley, March 1974, ORC 74-10.

and Hyatt power capacity is 759.35 megawatts. The average annual generation for Oroville for the year 1972 was 2,858,000 MWH.* If the assumption is made that this generation required 8760 hours (i.e., 24 hours per day), the average power generation rating at Oroville was 326.3 MW. In actual fact, the true average was certainly higher, because the Thermalito and Hyatt generators were not run 24 hours a day. To avoid exaggeration of potential benefits from optimized power production, we will compare only the estimated on-peak power production in the following paragraphs. Furthermore, we will take the best, i.e., highest, OROSIM power output based on existing reservoir management policies.

The OROSIM simulation model, using perfect four-week forecasts of inflow to Oroville, shows an average annual power production of 2,040,308 MWH, on-peak, and an additional 305,385 MWH off-peak. At average power rating of 326.3 MW and using 365 days for the year's length, the implied daily average on-peak generation is 17.133 hours. Using the optimized power rating 404.3 MW on-peak, and running the generators for 17.133 hours per day, 365 days, one obtains an average annual power production of 2,528,308 MWH, which exceeds the OROSIM value by 488,000 MWH. The marginal value of this additional hydropower is $9,760,000.00** annually.

These potential benefits of nearly $10 million annually are based on considerations of power generating efficiency. The increased efficiency is obtained by using the month-to-month predictive correlations between streamflows to optimize the planning of hydropower generation. The result shows that, even with

*Federal Power Commission, "Hydroelectric Power Resources of the United States: Developed and Undeveloped," Jan. 1, 1972.

**Valued at 20.00 mills per KWH as in Chapter 3.

perfect four-week forecasting, the existing management policies* cannot capture all of the advantages which are found in improved streamflow information; in fact, they do not take advantage of the historical streamflow record either. This implies a difficulty for any attempt to estimate benefits from improved runoff forecasts based on existing management policies, as noted elsewhere in this report. Nevertheless, it would be possible to capture a significant fraction of the $10 million in benefits if improved information on streamflows at Oroville were efficiently utilized in planning power production over the year. Furthermore, this is a conservative estimate of potential benefits since it is based on a comparison with the simulated on-peak power production which would be possible using existing power planning management.

*To the extent that OROSIM faithfully reflects these policies.

5. CONCLUSIONS

5.1 The Basic Conclusions in Summary

This study has examined the benefits of improved run-off forecasts for Oroville with two points of view regarding usage of this information:

(1) The existing management policies for the reservoir remain in force, and the improved information on the water supply is used to obtain more water for hydropower and irrigation and greater efficiency in the use of the water.

(2) The management policies are changed in line with the concept that improved information on the water supply can be used to selectively raise the storage level in the reservoir without increasing the risk of flooding.

With reference to (1), the annual net benefit from increased hydropower at Oroville is $633,847: assuming a 50 percent improvement in the accuracy of forecasting weekly inflows with a four-week forecast range. In relation to (2), the benefits from improved accuracy of forecasts are unknown. However, the optimization of the month-to-month planning of power production promises some fraction of $9,760,000 annually, if legal constraints to policy change are removed. It is not possible within the present case study to relate this fraction to the improvement of information on water supply. In either case additional benefits from improved irrigation are possible and, for case (1), are quantified in 3.2. These are less likely to be related to improvements in the April to June seasonal flow forecast accuracies, however.

5.2 The Conclusions Without Policy Change

A 50% improvement in accuracy (i.e., error reduction) for the four-week forecast of weekly inflows generates net annual benefits from increased hydropower of $633,847, expressed in 1975 dollars. This figure is based on a marginal value of $0.020 for each additional KWH of hydropower. The Oroville power plants (excluding Thermalito) have an average power generation of 2,858,000 kilowatt-hours per year. As determined by Appendix H, the other hydroelectric plants with a generating capacity above 200,000 kilowatts that have a potential for significantly benefiting from improved runoff forecasts have an average power generation of 27,754,000 kilowatt-hours per year. In addition, there are plants with a hydroelectric capacity between 100,000 and 200,000 kilowatts not covered in Appendix H whose average hydropower generation is 14,666,000 kilowatt-hours per year. Therefore, to obtain an estimate of a nationwide hydropower benefit from better inflow forecasts, bearing in mind that conditions among river basins can vary greatly, the Oroville results are scaled up by the factor 15.84 i.e., (2,858 + 27,754 + 14,666)/2,858. This rough order of magnitude calculation, which is subject to highly restrictive caveats, yields a nationwide annual benefit of $10,040,134.

For irrigation, the annual benefit at Oroville from a 50 per cent improvement in a two-week water inflow forecast is $684,400 and the annual rough order of magnitude nationwide benefit, again subject to highly restrictive caveats, is $2,852,000 (see Section 3.2.4). However, better measurements of snow cover in the Feather River Basin may not lead to substantial improvements in short-term inflow forecasts.

Figures 5.1 and 5.2 show, respectively, the dollar amount of benefit in hydropower and irrigation at Oroville from

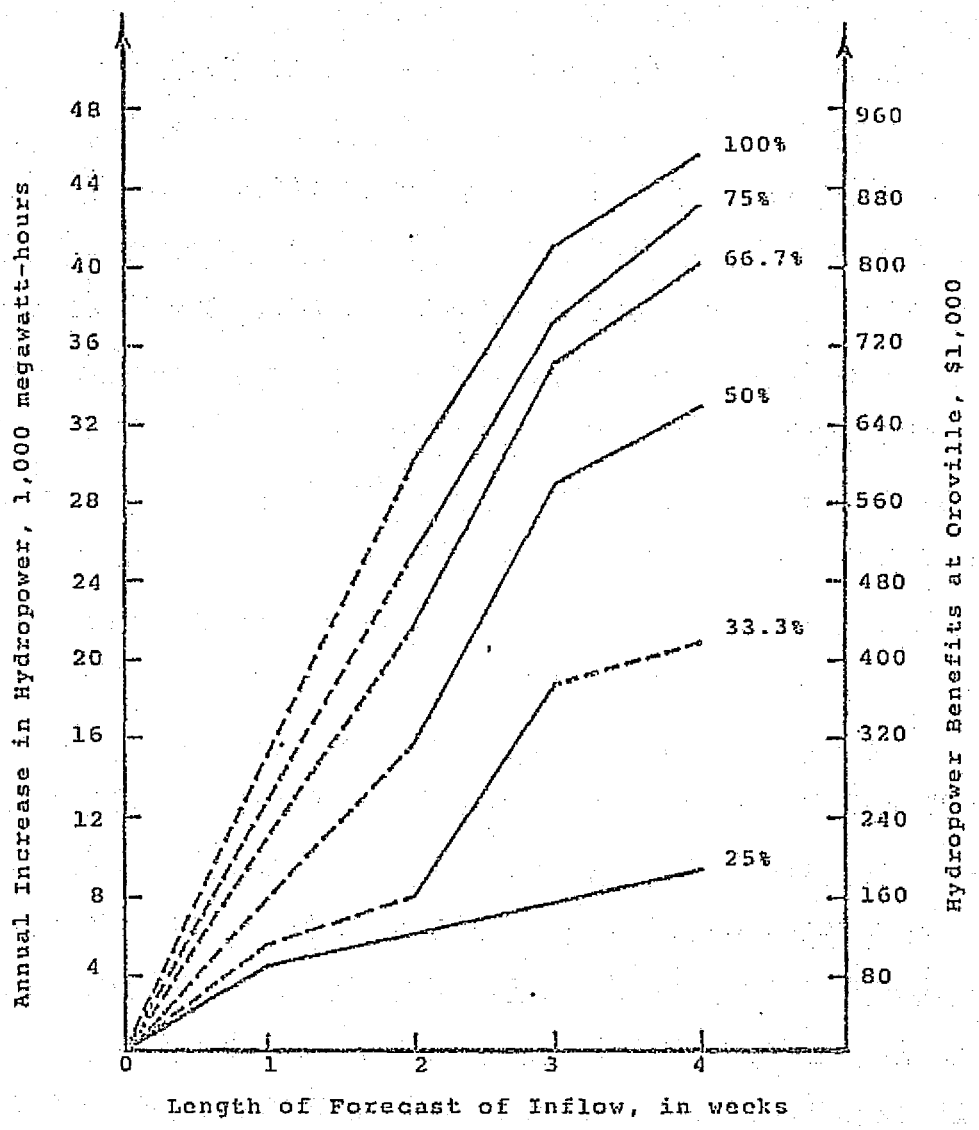

Figure 5.1 Hydropower Benefits at Oroville from Increased Forecast Accuracy and Length of the Forecast Period

Note: Percent valuer are "increases in forecast accuracy." They can be defined as:

$$100 \times \frac{\text{(Std. Dev. of Current Forecast Error - Std. Dev. of Improved Forecast Error)}}{\text{Std. Dev. of Current Forecast Error}}$$

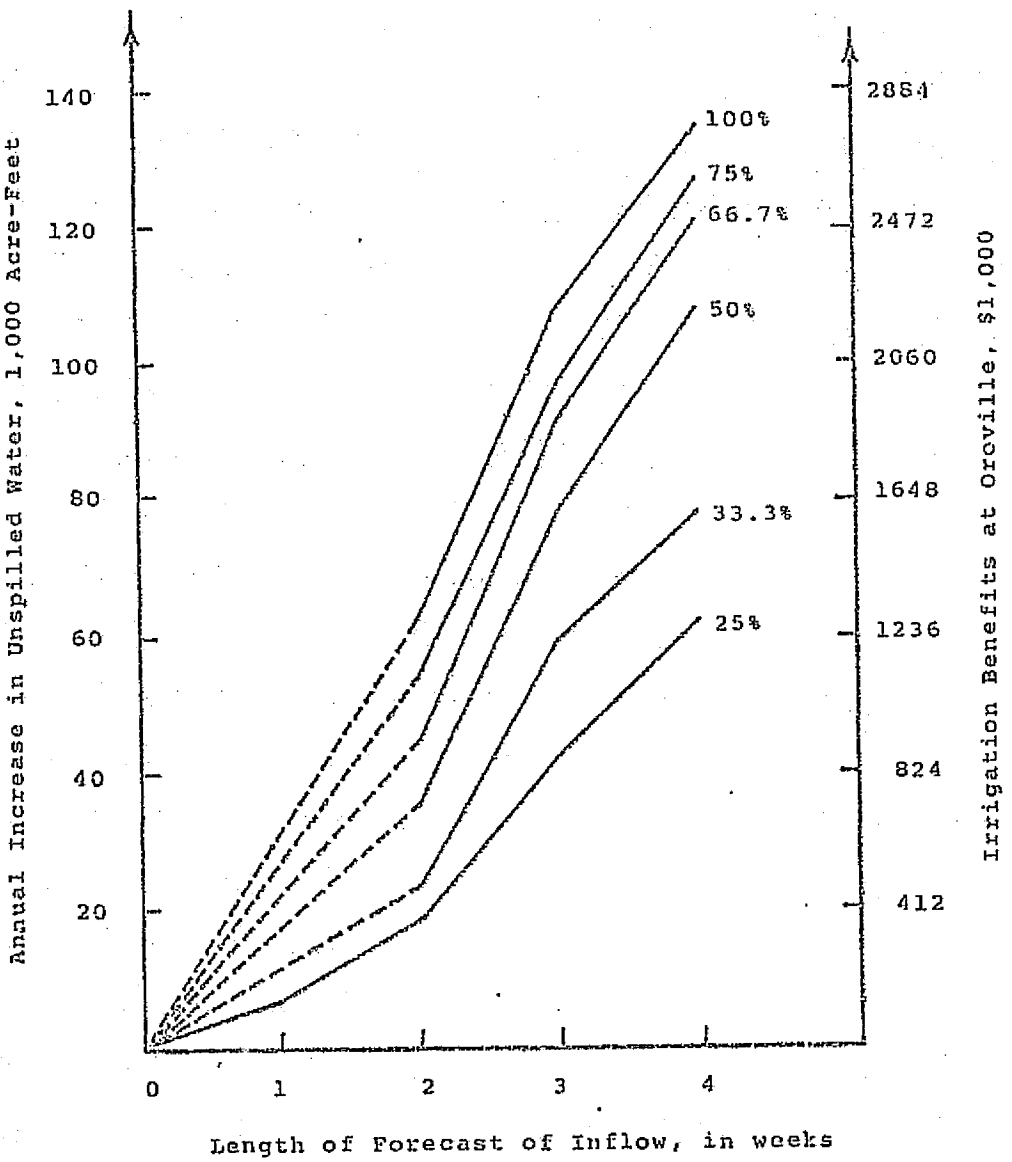

Figure 5.2 Irrigation Benefits at Oroville from Increased Forecast Accuracy and Length of the Forecast Period

Note: Percent values are "increases in forecast accuracy." They can be defined as:

$$100 \times \frac{(\text{Std. Dev. of Current Forecast Error} -- \text{Std. Dev. of Improved Forecast Error})}{\text{Std. Dev. of Current Forecast Error}}$$

more accurate water inflow forecasts made for different lengths of the forecast period. The points shown on these figures are results obtained from the OROSIM program. The benefits indicated by the OROSIM program for one-week forecasts at the 100, 75, and 50 percent improvement levels are not shown in Figures 5.1 and 5.2 because those results show implausibly low values. Consequently, we have estimated the one week benefits in these cases by a linear interpolation between the origin and the two week results.

The results given in Figures 5.1 and 5.2 are for forecasts made just before the beginning of the forecasted period. If there is a one-week delay in making a forecast, then the curves shown on these figures are shifted one week to the right (see Section 2.1.4), and the benefit results that had applied to an n-week forecast now apply to an n+1-week forecast. Similarly, if there is a two week delay, then these curves are shifted two weeks to the right, and the n-week forecast results now apply to an n+2-week forecast result.

The possibility of achieving the various percentage improvement levels in forecasting from improved snowmapping at Oroville is subject to doubt, because it is not clear how much of the inaccuracy of the forecast is due to inaccuracy of the snow measurements, and how much is due to uncertainty regarding future precipitation. Our own statistical investigation of errors* in the April 1 forecast revealed that, apparently, most of the forecast error can be explained by uncertainty regarding future precipitation (April-July).

An April 14, 1975 progress report entitled "Interpretation of Snow Cover From Satellite Imagery for Use in Water

*Section 2.4.

Supply Forecasts in the Sierra Nevada", by Sierra Hydrotech, Placerville, California, indicated that there is an error range for the Feather River inflow to Oroville of 380,000 acre-feet on June 1 (where the range is the sum of both positive and negative errors) at the 80 percent confidence level. If all or most of this error could be ascribed to inaccuracy in the measurement of the water content of snow cover, then, under certain conditions, considerably more potential benefits than presented in this section might be obtained.

Appendix H presents considerable information on those reservoir systems that could potentially benefit from remote sensing in the areas of hydropower and irrigation, provided that the information conditions are favorable to these systems. Technical data which appear to be particularly relevant to potential economic benefits obtainable from better information, such as the degree of variability in streamflow, the relationship between streamflow variability and reservoir capacity, the installed amount of hydropower capacity, etc., are given in this appendix.

Since the Western U.S. river basins have widely differing characteristics, it would be unwise to make categorical nationwide generalizations of the results obtained for the Feather River. Other studies are needed which focus on the information conditions for other river basins before valid generalizations can be made.

5.3 The Conclusions with Policy Change

It is difficult to derive the benefits of new information from a system which is not directly responsive to changes in the quality of information. The improved information must be rationally employed in the system for benefits to be generated at all. Taking full advantage of the improvement requires optimizing the management of the system. Studies such as the

one by William A. Ingram* show that much additional hydropower can be obtained from an optimized management policy at Oroville. The total supply of water is not increased, but the efficiency of using the water to produce economic goods (electricity) is increased by the policy change.

In this case study of Oroville, it has not been possible to relate fully the improvement of forecasts, much less the improvement of snowmapping using satellites, to the increased hydropower. Nevertheless the concepts are clear enough:

1) Better information on the expected inflows allows the manager to increase the static head, i.e., storage level in the Oroville dam, selectively through time, without increasing the risk of flooding. This increased head, in turn, allows more efficient power generation.
2) On the other hand, the manager may, at other times, draw down the reservoir farther in anticipation of large inflows, and put water through the generators which would have had to be spilled.

Our rough order of magnitude calculation suggests that total potential gains from optimized management are about $10,000,000 annually,** as detailed in Section 4.4.3. But since optimizing the management of a system depends critically on information about flows through the system, it appears reasonable to suggest that improved runoff forecasting, month by month, will contribute to the improvement of management policy, and that some fraction, which is presently not known, of the $10,000,000 annual gains would be obtained as net benefits. These benefits pertain specifically to Oroville. If they are scaled to the entire installed hydroelectric capacity of the United States, the relevant figure for potential annual economic gains from increased hydropower would be on the order of $150,000,000. Of course, only a fraction of this amount could be attributed directly to the improved runoff forecasting.

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*Op. cit., Section 4.4.3.
**Marginal value at $0.020 per KWH, 1975 dollars.

APPENDIX A. FLOOD CONTROL CRITERIA BASED ON THE ACCURACY, FREQUENCY AND TIMELINESS OF FORECASTS

A.1 Statistical Model to Determine Proper Flood Reservation Space

The amount of empty space theoretically required in a reservoir to prevent floods (called the flood reservation space) depends on a number of variables. Some of these variables are: (1) the degree of confidence that one desires in preventing a flood, (2) the accuracy of a forecast, (3) the frequency of a forecast, and (4) the timeliness of a forecast. The degree of confidence, or its reciprocal, the probability of having a flood, is discussed in Section A.2 on the refinements of the statistical model developed in this Appendix. From a statistical standpoint, using a very conservative approach, what should be the flood reservation space given the following parameters?:

1) The maximum permitted release rate per day that prevents downstream flooding (parameter "a")
2) The recorded maximum sustained unimpaired inflow rate per day (parameter "b")
3) The forecast error in the quantity of water runoff at the y percent level (parameter "d")
4) The recorded maximum fraction of forecast water runoff that has runoff over a short period of time (parameter "f").

The maximum possible buildup rate per day (c) is given by subtracting the maximum permitted release rate per day (a) from the recorded maximum sustained unimpaired inflow rate per day (b), i.e.,

$$c = b - a \qquad (A.1)$$

The unadjusted critical number of days of inflow (e) is given by dividing the forecast error (d) by the maximum sustained inflow rate per day (b), i.e.,

$$e = \frac{d}{b} \,. \tag{A.2}$$

Inflow rates less than (b), of course, are easier to handle and would give a larger number of days of inflow.

The adjusted number of days of inflow (g) is given by multiplying the unadjusted critical number of days of inflow by the water runoff fraction (f), i.e.,

$$g = ef, \tag{A.3}$$

Therefore, the flood reservation safety requirement (h) under this procedure is the product of the adjusted number of days of inflow (g) and the maximum buildup rate per day (c), i.e.,

$$h = gc. \tag{A.4}$$

In terms of our original parameters, the flood reservation safety requirement is

$$h = \frac{df(b-a)}{b} \,. \tag{A.5}$$

However, since recorded historical data only cover a limited time span (~70 years), statistical techniques are required that permit replacement of maximum recorded values by higher parameter values. These higher values can be derived from the probability distributions discussed in Section A.2 of this Appendix. It should be noted that we have been treating the parameter values as being statistically independent, which hardly seems to be a valid assumption. This assumption leads to overly conservative safety requirements, but the conditional probability distributions of these parameters are apparently unknown. They can be estimated

from a sufficient amount of historical data.[1] What would be required is an estimate of either of the following two conditional probability distributions.

$$\text{Prob } (b|D(i),f) \text{ or Prob } (f|D(i),b).$$

D(i) is a specified exceedance probability level on the Forecast Range function. A set of different i's falling within the historical range of data would be used, and the corresponding set of Prob (b|)'s or Prob (f|)'s would be recorded. Fitting some reasonable distribution function (a normal distribution?) to these results would provide an estimate of the conditional probability distributions

$$\text{Prob } (b|D(d),f) \text{ or Prob } (f|D(d),b) \qquad (A.6)$$

where d is the forecast error at the y percent level.

To repeat, with the parameter values treated as statistically independent, the flood reservation safety requirement is

$$h = \frac{df(b-a)}{b} \qquad (A.7)$$

What relationship does this formula have to the effects of better information? Let d_0 and d_1 be the y percent level forecast error for the current and the new (higher) levels of information, respectively. Then, the reduction in required flood reservation space is given by

$$\Delta h = (d_0-d_1)f[(b-a)/b] \qquad (A.8)$$

This additional amount of space available in the reservoir can store economically beneficial water, as described in

[1] However, it is highly probable that far too little data exist to make these conditional probability distribution calculations.

Chapters 3 and 4 of the text. So far, we have been discussing the parameters needed to estimate the flood reservation space. However, if we assume the current flood reservation space is proper, given the current level of information, then estimation of the parameters a, b, and f is unnecessary. Under this assumption, estimation of only two parameters, (1) the current y percent forecast error level (d_0) and (2) the better information y percent forecast error level (d_1) yields the new flood reservation space (h_1), i.e.,

$$h_1 = h_0 \hat{d}_1 / \hat{d}_0 \quad . \tag{A.9}$$

A.2 Refinements in the Statistical Model on Flood Control Criteria

The discussion so far has presented a statistical model to measure the effect of accuracy, timeliness, and frequency of forecast on the required size of the flood reservation space. For expositional purposes, certain more complex statistical considerations have not been given in the earlier section, but will now be presented. Runoff levels above the base runoff level are potentially hazardous and, therefore, will be called "hazard events".[1] Runoff levels far above base runoff levels will be called "exceedance events".[2] Based on the analysis of Shane and Lynn, a close approximation of the actual distribution of the magnitude of

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[1] Borgman, L.E., "Risk Criteria", Journal of the Waterways and Harbors Division, SCE, Vol.89, No.WW3, August 1963, pp.1-35.

[2] Shane and Lynn use the terminology "exceedance events" to refer to a flow larger than the design flow for that structure. Shane, R.M. and Lynn, W.R., "Mathematical Model for Flood Risk Evaluation", Journal of the Hydraulics Division, SCE, Vol.90, No.HY6, November 1964, pp.1-20.

hazard events is given by the following distribution function of exponential form shown in Figure A.1

$$f(y|v) = 1 - e^{-(y-v)/\tau} \qquad y>v,\ \tau>0\ . \qquad (A.10)$$

The density function that corresponds to this distribution function is given by

$$f(y|v) = (1/\tau)e^{-(y-v)/\tau} \qquad y>v,\ \tau>0 \qquad (A.11)$$

where

v = base flow
τ = a parameter
y = magnitude of hazard event.

If we let the exceedance value be defined as y_0, then the probability of reaching the exceedance value is given by[1]

$$P(y_0) = e^{(-y_0-v)/\tau}\ . \qquad (A.12)$$

Since the economic loss that results from a flood is very large relative to the economic loss that results from too little water, it has been the practice in water impoundment management to use a very large margin of safety in determining the reservoir space left unfilled (called the flood reservation space). This would correspond to a very small probability $P(y_0)$.

For the Feather River, it is necessary to determine the parameter values v (base flow) and τ and decide on an acceptable probability of exceedance ($p[y_0]$).[2] The parameter

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[1] Proof of this result is given in Shane and Lynn, ibid.

[2] It is also necessary to determine the time span over which the exceedance event occurred.

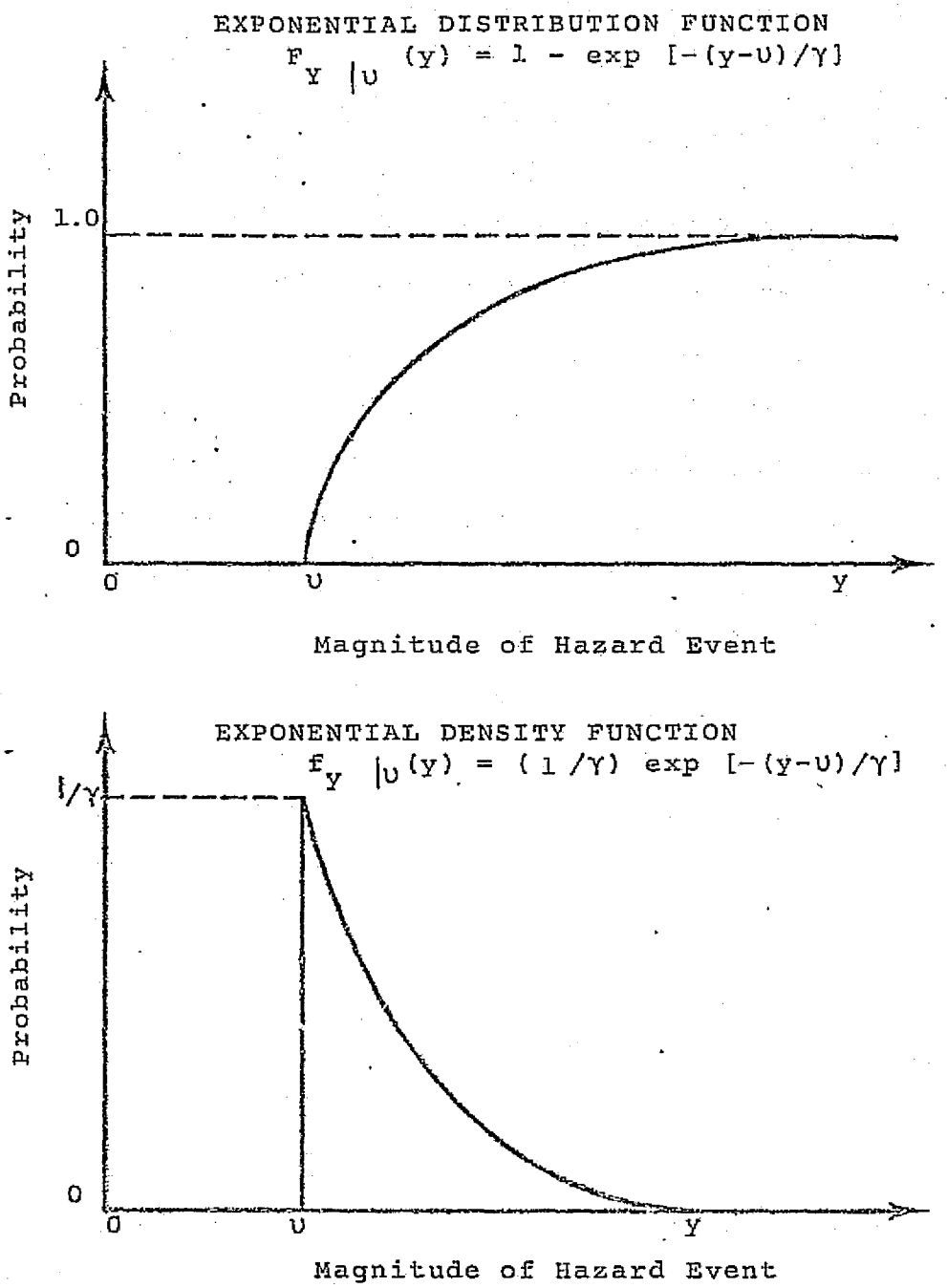

Figure A.1 Typical Exponential Distribution and Density Factors

values v and τ can be derived from data in the U.S. Geological Survey Water Supply Papers which list peak flows above a given base for each year of record. However, the acceptable probability of exceedance is a subjective question. A reasonable approach perhaps is one that implies that the exceedance event is unlikely to occur during a multiple of the design life of the structure. For example, if the design life of the Oroville Dam were 100 years, then a probability that implied an exceedance event once every 500 years perhaps is an acceptable value ($p[y_0]=.002$). Another approach would be to calculate the present value of flood damage as a function of their frequency and magnitude. The physical magnitude of the flood would be given by the volume of water above the exceedance value. Therefore, a low probability of exceedance limits flood damage both by its low frequency of occurrence and by the reduction in damage that would occur from a flood. Theoretically, the probability of exceedance should be set such that the expected present value of flood damage equals the expected present value derived from additional economically useful water. To do this evaluation on a conservative basis, a low discount rate should be used.[1] Also conservative would be a calculation that required the present value of additional economically useful water to be several times the present value of flood damage. This can be justified on the grounds that the variance in the present value of flood damage is much higher than the variance in the present value of economically useful water. In practice, it is difficult to calculate these present values because of the great uncertainty about the relationship between the physical magnitude

[1] A low discount rate would give a rare event, such as a flood, a much higher expected loss value than a high discount rate.

of a flood and the economic losses that it induces and because of the fact that the present value of flood damage is not independent of the present value of increased economically useful water.[1]

According to the Corps of Engineers, preproject flood damages along the Feather River below Oroville were:[2]

Floods	Damages (in 1968 dollars)
December 1964	4,452,000
February 1963	760,000
October 1962	458,000
February 1958	348,000
December 1955	82,215,000
December 1937	2,500,000

These estimated damages are based on 1968 prices and conditions. After the closure of the Oroville Dam, a large increase in agricultural development and production occurred along the Feather River Floodway. Therefore, to translate the above flood damages into current dollars and conditions, the subsequent agricultural development and the inflationary conditions prevailing over the last several years would have to be taken into account. Thus, in current dollars and conditions, a sharp upward revision would occur in the above flood damage figures.

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[1] After a certain threshold value, the greater the amount of economically useful water, the greater the frequency and magnitude of flooding.

[2] Report on Reservoir Regulation for Flood Control, Oroville Dam and Reservoir, Feather River, California, Department of the Army, Sacramento District, Corps of Engineers, Sacramento, California, August 1970.

For purposes of flood control, a forecast range diagram probability line much greater than 90% is required. A .999% line, for example, would be more appropriate. However, at least a thousand years of historical data would be required to obtain that kind of line directly from the data. Therefore, indirect methods are required to estimate a .999% line from the limited amount of recorded data. From the considerably wider distance of probability bands above the mean forecast line relative to those corresponding bands below the forecast line, it can be concluded that the probability distribution is definitely skewed toward the upper end of the runoff levels.[1] Because of this skewness, a log-normal distribution fitted to each forecast date (February 1, March 1, April 1, May 1, and June 1 rather than, for example, a normal distribution) would provide an apparently reasonable method for estimating the probability bands for other probability levels.

[1]This skewness probably occurs because of the boundary condition that it is impossible to have a negative unimpaired runoff.

APPENDIX B. CORPS OF ENGINEERS FLOOD CONTROL CRITERIA

A report by the Corps of Engineers specifies the flood control criteria that will be followed in the operation of the Oroville Dam and Reservoir.[1] These criteria are based on an examination of the quantitative characteristics of previous floods along the Feather River, but not along the statistical lines suggested in Appendix A. The general characteristics of the 13 largest historical floods at Oroville examined by the Corps of Engineers are reproduced in Table B.1. Using these and other historical hydrology data as a starting point, the Corps of Engineers has developed a "standard project flood" to determine flood control space requirements. A comparison of a "standard project flood" to major historical floods is given in Table B.2.

In addition to flood control space requirements, there also are criteria on permissible rates of outflow. These criteria are based on channel capacities along the Feather River and its tributaries.

The maximum flood control space requirement is 750,000 acre-feet. This empty space must be provided whenever there is a meterological potential for a "standard project storm" and ground conditions are conducive to maximum runoff. This meterological condition is postulated to exist between October 15 of each year and April 1 of the following year. If ground conditions are dry, the maximum flood control

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[1] Report on Reservoir Regulation for Flood Control, Oroville Dam and Reservoir, Feather River, California, Department of the Army, Sacramento District, Corps of Engineers, Sacramento, California, August 1970.

Table B.1 Historical Floods, Feather River at Oroville

Year	Date of Peak Flow	Peak Flow (cfs)	Max. 1-Day (cfs)	Max. 3-Day (ac-ft)	Annual Water-Year (ac-ft)	Mean Annual (cfs)
1964	22 Dec	250,000	156,000	864,800	6,448,000	8,908
1907	19 Mar	230,000	187,000	894,600	9,310,000	12,900
1955	23 Dec	203,000	172,000	818,800	7,303,000	10,060
1963	31 Jan	191,000	125,000	538,700	5,673,000	7,835
1937	11 Dec	185,000	145,000	567,700	8,175,000	11,290
1928	26 Mar	185,000	122,000	642,600	3,650,000	5,030
1940	27 Feb	152,000	131,000	598,600	5,275,000	7,270
1909	16 Jan	140,000	137,000	772,000	7,380,000	10,200
1962	13 Oct	138,000	101,000	455,400	5,673,000	5,825
1960	8 Feb	135,000	95,800	310,200	2,971,000	4,090
1906	18 Jan	128,000	96,300	415,000	6,650,000	9,180
1913	31 Dec	122,000	121,000	616,000	6,540,000	9,030
1904	24 Feb	118,000	106,000	492,000	9,330,000	12,900

Source: Corps of Engineers, Ibid, p. 11.

Table B.2 Comparison of Standard Project Flood to Major Historical Floods

values to those of the major floods, is tabulated as follows:

Flood	Peak Flows		72-hour Volumes	
	Flow (1000 c.f.s.)	Ratio (SPF/Flood)	Volume (1000 ac-ft.)	Ratio (SPF/Flood)
Standard Project	440	1.0	1,520	1.0
Dec 1964	250 *	1.76	886 *	1.72
Mar 1907	230	1.91	895	1.70
Dec 1955	203	2.17	830	1.83
Probable Maximum	720	0.61	2,510	0.61

* Computed value.

Source: Corps of Engineers, Ibid, p. 14.

reservation space is 350,000 acre-feet between October 15 and April 1. This is illustrated by Figure B.1. The numbers 3.5 or less, 4.0, 5.0, etc., above the horizontal lines in Figure B.1, indicates the recorded value for the index of ground wetness. The smaller this index, the dryer the ground. For example, in order to meet these flood control criteria, an index reading of 8.0 would indicate that 600,000 acre-feet of dam space would be kept empty of water and that the amount of water in the reservoir would not exceed 2,938,000 acre-feet.

The ground wetness index is computed each day in the following way:

$$Par(t) = 0.97\ Par(t-1) + Precip \qquad (B.1)$$

where

Par(t) = current day's ground wetness index
Par(t-1) = previous day's index
Precip = precipitation occurring since Par(t-1) was computed.

Since Par(t-1) has a weight of 0.97 and Precip has an implicit weight of 1.0, the contribution of each day's precipitation to the ground wetness index is over 50%. This weighting has the direct effect of causing rapid changes in the value of the ground wetness index during a storm. Because of limitations on the allowable release rate of water at Oroville, it is not practical, except for temporary periods that are caused by a storm, to have a flood control space of less than 550,000 acre-feet during the earlier part of the annual flood control period (i.e., October 15 to February 1). To attempt to take advantage of the apparent additional space given by ground wetness indexes of less than 7 would mean a considerable increase in water that would have to be spilled and thereby completely wasted.

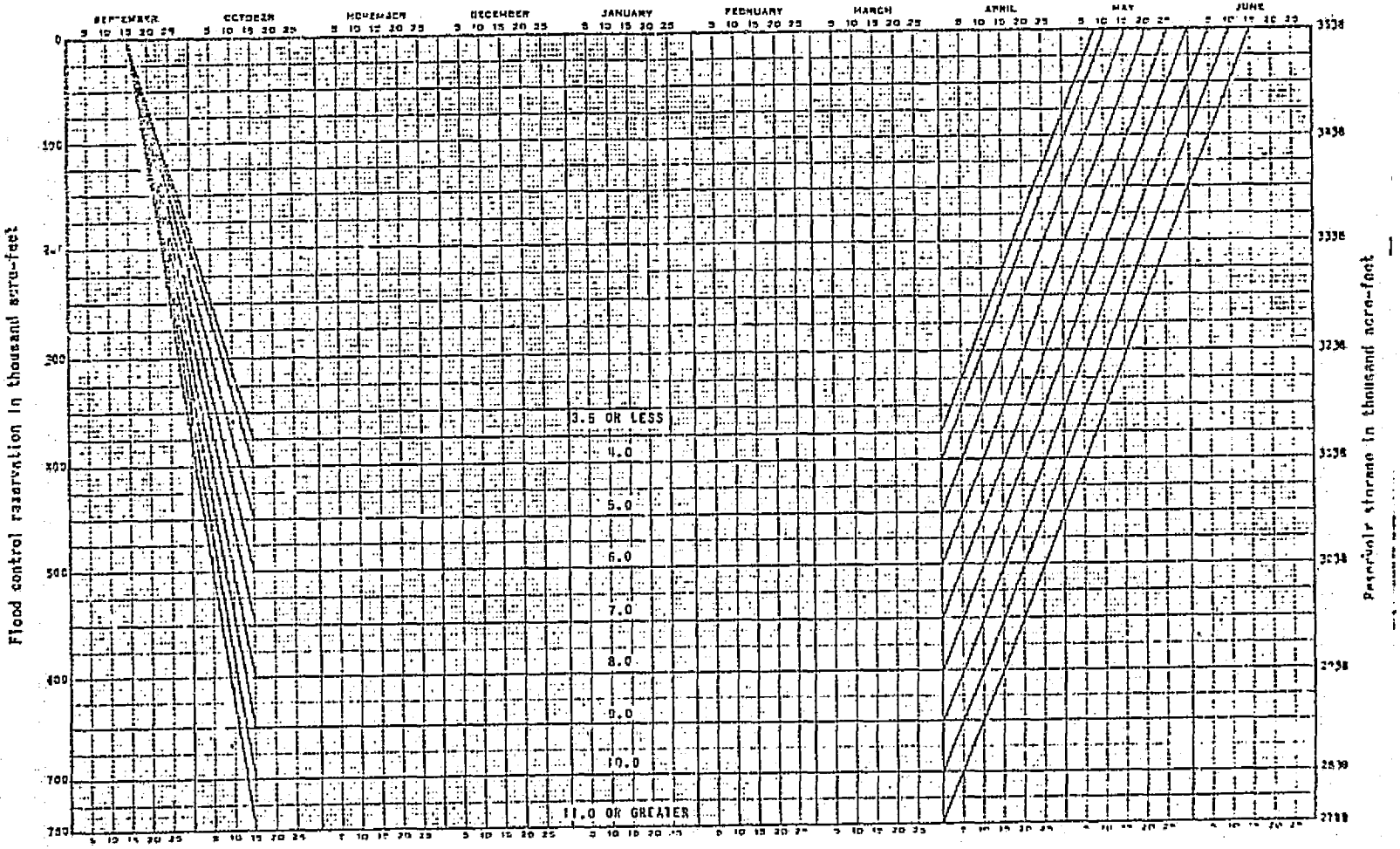

Figure B.1 Flood Control Diagram

As stated previously, in order to prevent downstream flooding in addition to the volume restrictions shown in the Flood Control Diagram (Figure B.1), there are also restrictions on the amount of water that can be released per unit of time. These conditions are:[1]

a. That flows in Feather River above Yuba River do not exceed 180,000 c.f.s.
b. That flows in Feather River below Yuba River do not exceed 300,000 c.f.s.
c. That flows in Feather River below Bear River do not exceed 320,000 c.f.s. insofar as possible
d. That releases are not increased more than 10,000 c.f.s. or decreased more than 5,000 c.f.s. in any 2-hour period.

In concluding this Appendix, it can be stated, based on the discussion in Sections 3.1 and Appendix A, that the flood control diagram is not optimum in terms of preventing floods.

An optimum flood control diagram would require an equal probability of having a flood on any day along the entire length of the line determined to be reserved for flood control. A non-optimum flood control diagram limits to an unknown degree the amount of potential benefit that can be derived from better information.

[1] These conditions may be overriden by releases that are governed by the emergency spillway release diagram currently in force.

Table B.3 Release Schedule

Actual or Forecast Inflow (whichever is greater) c.f.s.	Flood Control Space Used ac-ft	Required Releases c.f.s.
0 - 15,000	0 - 5,000	Power Demand
0 - 15,000	Greater Than 5,000	Inflow
15,000 - 30,000	0 - 30,000	Lesser of 15,000 or maximum inflow
0 - 30,000	Greater Than 30,000	Maximum inflow for flood
30,000 -120,000	----------	Lesser of maximum inflow or 60,000 c.f.s.
120,000 -175,000	----------	Lesser of maximum inflow or 100,000 c.f.s.
Greater than -175,000	----------	Lesser of maximum inflow or 150,000 c.f.s.

APPENDIX C. BOX-JENKINS ANALYSIS OF DAILY FEATHER RIVER STREAMFLOW

Using a Box-Jenkins computer program developed by David Pack at the University of Wisconsin, a second order autoregressive equation was determined to be the most appropriate form to use for the Feather River.[1] The general mathematical form of this equation was:

$$y_t = \eta_t + e_t \qquad (t=0,1,2,3,\ldots,n) \qquad (C.1)$$

where y_t = the natural logarithm of the daily streamflow

η_t = the daily "deterministic" component

e_t = the daily "stochastic" component.

For the deterministic component of daily streamflow

$$\eta_t = \alpha_0 + \alpha_1 \cos \frac{2\pi t}{364} + \alpha_2 \qquad (C.2)$$

where α_0 = the historical average daily streamflow around which the cosine curve of daily streamflow is traced out.

α_1 = the amplitude of the cosine curve

$\frac{2\pi t}{364}$ = the length of time of one cycle of the cosine curve which in this case is a year. (The inverse of this term gives the frequency of the cycle, i.e., once a year.)

α_2 = the shift factor for sliding over the cycle to the proper time of the year.

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[1] This equation was developed by Neil Polhemus for ECON. The initial starting point for the analysis was a streamflow analysis of the Ohio River in an article titled "Stochastic Modeling of Temperature and Flow in Rivers" by Frances Clay McMichael and J.Stuart Hunter in Water Resources Research, Vol.8, No.1, February 1972, pp.87-98.

For the stochastic component of daily streamflow, using the Box-Jenkins notation,

$$e_t = \frac{a_t}{1-\phi_1 B-\phi_2 B^2} \qquad (C.3)$$

where e_t = stochastic errors in streamflow process

a_t = "white noise", i.e., an error term that has zero mean and a constant variance over time

B = the first order backward shift operation

B^2 = the second order backward shift operator

ϕ_1, ϕ_2 = constants determined from the daily streamflow data.

To indicate the meaning of the backward shift operators, let us rewrite (c.3) as:

$$a_t = (1-\phi_1 B-\phi_2 B^2)\, e_t. \qquad (C.4)$$

Multiplying the right hand side of (C.4) by e_t and "decomposing" the shift operator yields:

$$a_t = e_t - \phi_1 e_{t-1} - \phi_2 e_{t-2}$$

$$a_{t-1} = e_{t-1} - \phi_1 e_{t-2} - \phi_2 e_{t-3}$$

$$a_{t-2} = e_{t-2} - \phi_1 e_{t-3} - \phi_2 e_{t-4}$$

$$a_{t-m} = e_{t-m-1} - \phi_1 e_{t-m-2} - \phi_1 e_{t-m-3}.$$

To test this model, coefficients for the water years 1902-1907 and 1960-1965 were obtained. For the 1902-1907 period, the estimated coefficients were:

$\hat{\alpha}_0 = 8.487$ $\qquad$ $\hat{\phi}_1 = 1.120$

$\hat{\alpha}_1 = 1.168$ $\qquad$ $\hat{\phi}_2 = -0.198$

$\hat{\alpha}_2 = 3.130.$

For the 1960-1965 period, the estimated coefficients were:

$$\hat{\alpha}_0 = 8.27 \qquad \hat{\phi}_1 = 1.254$$

$$\hat{\alpha}_1 = 0.574 \qquad \hat{\phi}_2 = -0.319$$

$$\hat{\alpha}_2 = 3.222.$$

The coefficients for these two sets of years appear to come from the same underlying population (judging by the same signs and approximately the same magnitude of the corresponding coefficients for the two periods) but no formal statistical tests were made to confirm this hypothesis. We then ran a Box-Jenkins analysis for the entire period October 1902 to September 1965 (i.e., 23,353 observations of daily streamflow) to obtain the following coefficients:

$$\hat{\alpha}_0 = 8.210 \qquad \hat{\alpha}_1 = 1.113$$

$$\hat{\alpha}_1 = 0.840 \qquad \hat{\alpha}_2 = -0.166$$

$$\hat{\alpha}_2 = 3.184.$$

The estimate of residual variance is given by:

$$s^2 = \frac{796.64094}{23353} = 0.034113$$

(Note: this residual variance is applicable to the transformed data).

We examined the stochastic component of the Box-Jenkins analysis and asked the following question: how does the stochastic component vary as a function of time? In other words, starting on day t, what is the error in the estimate of the streamflow on day t + m, where m is treated as a

variable.[1] For the initial conditions, we took the historical values for e_o and e_1.[2] These values were:

$$e_o = -.0203667 \text{ and}$$

$$e_1 = -.0206933.$$

A computer program was written, using the 1902-1965 coefficient values for the α_i's and the $\hat{\phi}_i$'s, the initial values e_o and e_1 and the estimate of residual variance s^2. A Monte Carlo procedure using a random number generator with mean zero and variance s^2 was used to produce a series of means and standard deviation of the streamflow over a ninety-day period. Five hundred observations per day were used to obtain the daily mean and standard deviation for a thirty-day period. A graph of the thirty-day mean and standard deviation results for the natural logarithm of daily streamflow is shown in Figure 2.8 in the text.

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[1] A theoretical determination of the analytic procedure that could be used to answer this question is given in Appendix D.

[2] The initial starting date (t=0) was October 1, 1902.

APPENDIX D: NOTE ON FORECAST VARIANCE[1]

This appendix presents a procedure for obtaining the forecast variance of the Box-Jenkins model given in Apperdix C.

(1) Given the model: $X_t - \phi_1 X_{t-1} - \phi_2 X_{t-2} = U_t$

let it be written $A(B) X_t = U_t$

where $A(B) = 1 - \phi_1 B - \phi_2 B^2$

and $BX_t = X_{t-1}$ defines the "backward shift" operator

(2) Complex polynomical defined:
let $A(Z) = 1 - \phi_1 Z - \phi_2 Z^2$

(3) Let another complex function, $O(Z)$ be defined:
such that $A(Z)\ C(Z) = 1$

$$\therefore \quad C(Z) = \frac{1}{1-\phi_1 Z-\phi_2 Z^2}$$

(4) Write $C(Z) - \sum_{j=o}^{\infty} C, Z^j$

(5) <u>Theorem</u> The process can be written $X_t = \sum_{o}^{\infty} C_j\ U_{y-j}$

(6) <u>Theorem</u> Forecast variance for m steps ahead is:

$$\sigma_m^2 = \sigma_o^2 \sum_{o}^{m-1} C_j$$

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[1]Written by Francis Sand.

APPENDIX E: BASIN DESCRIPTION[1]

E.1 Description of the Area

a. Feather River Basin lies on the eastern side of the Sacramento River Valley and on the northern end of the Sierra Nevada Range. The location of the basin is shown on Figures E.1 and E.2.

b. Feather River, a major tributary of Sacramento River, rises high in the Sierra Nevada at elevations close to 10,000 feet, and flows for about 200 miles to its junction with Sacramento River on the valley floor. Its upper reaches branch into several forks: West Branch and South Fork lie on the western slope of Sierra Nevada, North and Middle Forks rise on a high plateau East of the mountains. These streams flow in a generally southwesterly direction, cutting through steep rugged canyons to their respective confluences with the main stream in the foothills above the mouth of Feather River Canyon. Oroville Dam is located below the junction of the forks, six miles above the town of Oroville. After leaving the mountains near Oroville, Feather River turns South and flows through the rich agricultural lands of the Sacramento River Valley for about 50 miles to its mouth at Verona on Sacramento River, 20 miles above the city of Sacramento. Feather River has two main tributaries that join it in the valley, Yuba River (with 1,350 square miles drainage area) at Yuba City, and Bear River (with 550 square miles) at Nicolaus.

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[1] Verbatim (with slight alterations) from Chapter II of Report on Reservoir Regulation for Flood Control, Oroville Dam and Reservoir, Feather River, California, Department of the Army, Sacramento District, Corps of Engineers, Sacramento, California.

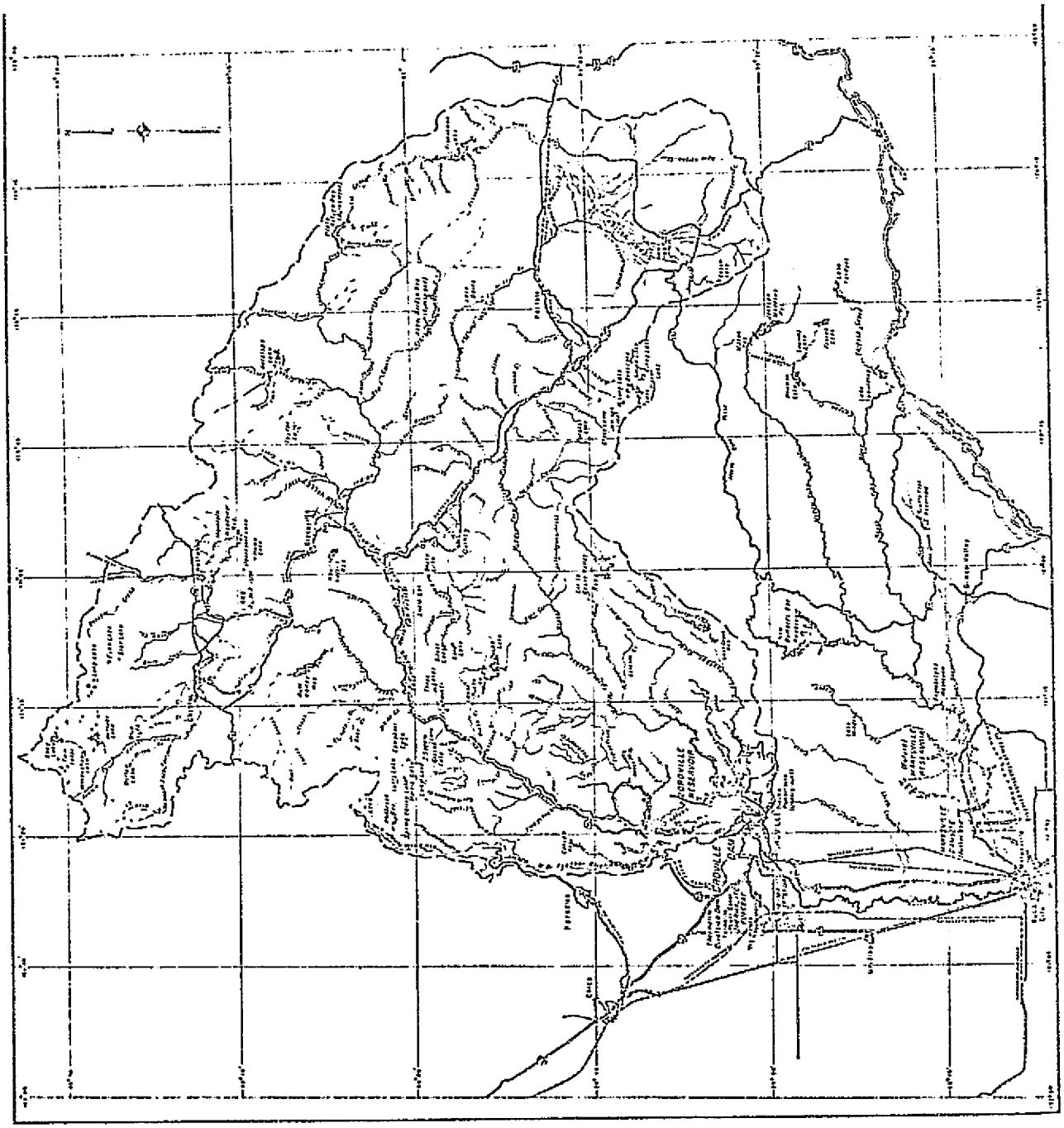

Figure E.1 General Map

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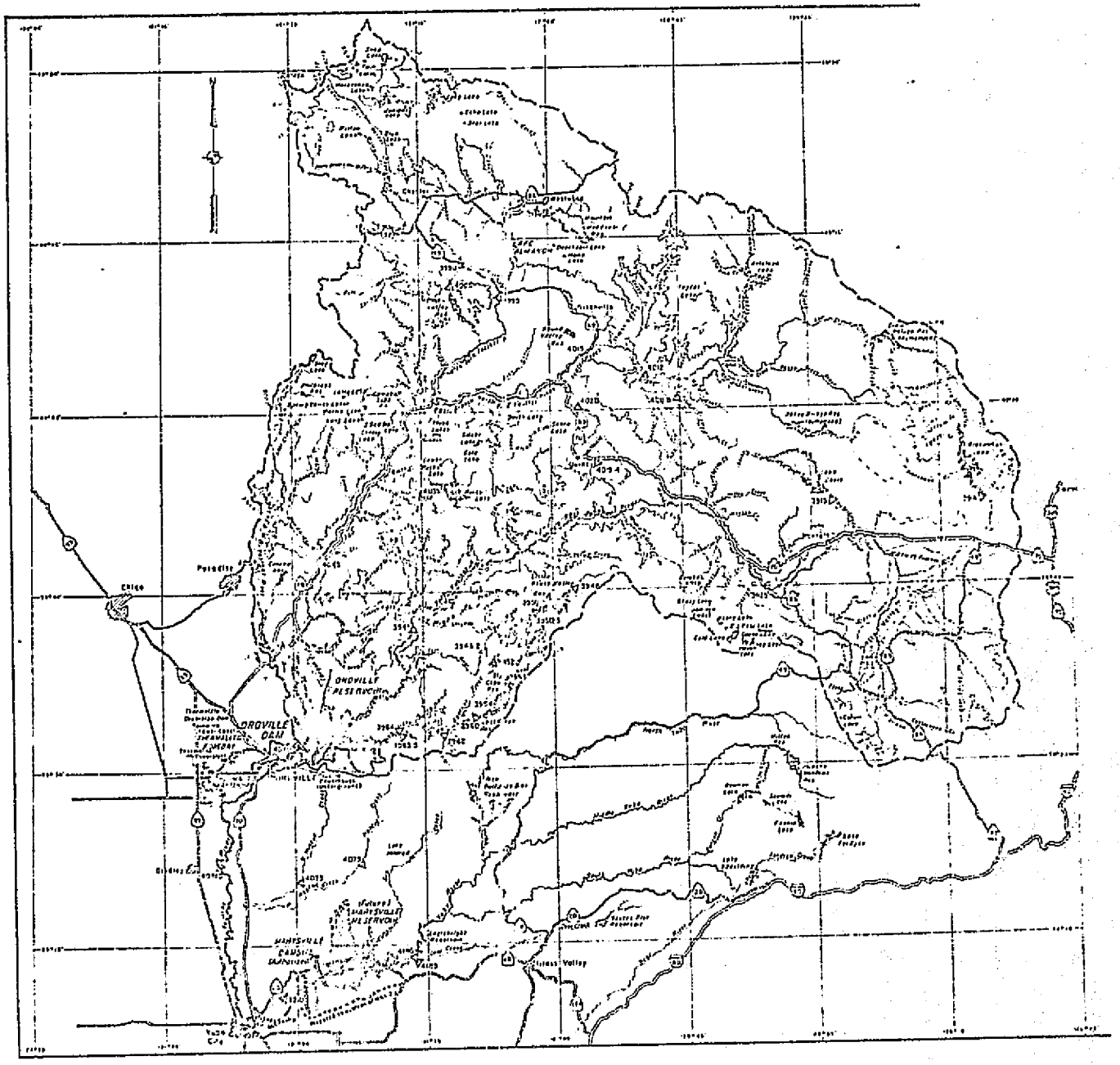

Figure E.2 Topography and Stream Gauging Stations

(1) About 36 percent of the Yuba River drainage basin area is controlled by recently completed New Bullards Bar Reservoir located about 35 miles upstream from the Feather River. The remaining 64 percent will be uncontrolled area until authorized Marysville Dam and Reservoir is built and put into operation. Complete protection on the Yuba River is not possible without the authorized Marysville Reservoir.

(2) The Bear River drainage basin has a total area of about 550 square miles above its confluence with the Feather River. The four existing reservoirs on Bear River have no storage allocated to flood control. The largest of these reservoirs is the New Camp Far West Dam and Reservoir completed in 1963. Studies are being conducted for construction of Garden Bar Dam and Reservoir which would have storage allocated to flood control.

(3) An extensive levee system has been constructed to protect the Feather River flood plain downstream from Oroville Reservoir. A levee extends along the right bank of Feather River from Hamilton Bend to the mouth of Feather River. Levees have also been constructed along the lower reaches of Bear and Yuba Rivers, around the city of Marysville and around a local reclamation district.

c. The watershed above Oroville Dam drains 3,611 square miles and includes mountain crests over 8,000 feet high, mountain valleys at elevations as high as 5,000 feet above sea level, deep canyons, and rolling foothills. Elevations range from 10,466 feet at Mt. Lassen Peak to 900 feet at the damsite.

About 55 percent of the area is above an elevation of 5,000 feet, and only 7 percent is below 2,500 feet. The following tabulation gives area-elevation data for Feather River Basin above Oroville Dam.

Area	Elevation (feet)	Basin Area (sq. miles)	(percent)
Area above	5,000	1,986	55
Area between	5,000-2,500	1,372	38
Area below	2,500	253	7
Total area	10,500-900	3,611	100

The topography of the basin is shown on Figure E.2.

d. The vegetation in the basin varies from heavy timber growth on the mountainous slopes in the western part to a sparse cover on semi-desert valleys on the eastern side. Mixed conifers grow at higher elevations, ponderosa pines and hardwoods appear at lower elevations, native brush and grasses cover the alpine meadows and the foothills, and sagebrush spreads over the eastern slopes. The rich soil of the valley floor below the dam grows a great variety of farm crops.

e. The economy of the area below Oroville Dam depends on irrigation farming, livestock raising, and on industry connected with producing and processing agricultural products. The economy of the basin above the dam is centered around lumbering, mining, and recreation facilities. There are many small mountain communities throughout the basin, with more populous and important towns located in the valley, as shown on Figure E.1.

f. California State Highway 70 (a major east-west connection) and a number of State and county highways serve the area. The Western Pacific Railroad traverses the basin

generally following Feather River Canyon from Oroville into Nevada. The location of highways and railroad is shown on Figure E.1.

E.2 Climate

a. The climate of Feather River Basin is closely associated with the typography of the area and there is a marked difference in temperature and in precipitation within short distances. A detailed discussion of topographic influence on climatic characteristics of the area is included in the Master Manual. In general, the climate of the basin is divided into two seasons: hot, dry summer lasting from May through October, and cold, wet winter with heavy rains and snowfall in the mountains from November through April.

b. In the valley below Oroville Dam the climate is temperate with hot summers and mild winters, without extreme temperature variations, although as high as 118°F. and as low as 16°F. have been recorded. In the mountainous basin above Oroville Dam temperature changes are more pronounced: summer days are dry and warm with 95 percent of possible sunshine and occasional temperatures above 100°F., but summer nights are cool with a chance of frost occurring in any month, especially at higher elevations. Winters are moderately severe with minimum temperatures below freezing during the period from November through April. The monthly distribution of maximum, minimum, and normal mean temperatures at representative stations is as follows:

MONTHLY MEAN TEMPERATURES (F.°)

MONTH	MARYSVILLE El. 64'			OROVILLE 7 SE** El. 530'			QUINCY RS El. 3,409'			SIERRAVILLE RS El. 4,975'		
	Max	Min	Normal*	Max	Min	Average	Max	Min	Normal*	Max	Min	Normal*
January	54	37	46	53	36	45	45	22	33	41	14	28
February	60	41	50	58	40	49	50	24	37	45	18	32
March	66	44	55	63	42	53	55	28	42	61	23	38
April	73	47	61	71	46	58	65	32	48	60	28	45
May	80	52	67	80	51	65	72	37	54	68	34	51
June	89	58	74	89	56	72	81	42	61	76	38	58
July	96	60	79	97	60	79	89	43	66	85	41	64
August	95	59	77	95	58	77	88	41	64	85	39	62
September	89	55	74	90	56	73	81	36	59	78	34	58
October	79	49	64	79	50	64	70	31	51	68	28	49
November	66	42	54	65	42	54	56	28	41	55	22	38
December	55	38	47	55	38	46	46	24	35	45	17	32
Annual			62			61			49			46
Years of Record	57	57		28	28	29	66	66		52	52	

* Normals for all stations are climatological normals based on period 1930-1960, as published by USWB.

** Station closed in February 1961.

Observed temperature extremes for these stations are as tabulated below:

TEMPERATURE EXTREMES

STATION	MAXIMUM		MINIMUM	
	MONTH	F°	MONTH	F°
Marysville	July	118	December	16
Oroville 7 SE	August	115	December	16
Quincy RS	July	106	January	-28
Sierraville RS	July	104	January	-34

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c. Normal annual precipitation over Feather River Basin varies greatly as illustrated on Figure E.3, ranging from about 15 inches on the portion of the basin draining the eastern slopes of the Sierra Nevada to close to 90 inches over the higher ridges on the western slopes near the headwaters of West Branch and North Fork of Feather River. Precipitation during the winter season normally falls as rain at elevations below 5,000 feet, and as snow at higher elevations, although during major warm storms rain may fall over the entire basin. About 88 percent of annual precipitation in the valley, and close to 85 percent in the mountains, occurs during the November-April period. During the summer months precipitation results from isolated thunderstorms that cover small areas and are of short duration. Monthly distribution of precipitation at selected representative stations based on data published by the U.S. Weather Bureau for the period 1931-1960 (except Brush Creek R.S. which is based on averages of the period of record 1937-1967) is given in the following evaluation:

MONTHLY PRECIPITATION

MONTH	MARYSVILLE (El. 64')		OROVILLE BRIDGE (El. 165')		QUINCY RS (El. 3409')		BRUSH CR. RS (El. 3560')		CANYON DAM (El. 4555')		SIERRAVILLE RS (El. 4975')	
	inches:	%	inches:	%	inches:	%	inches:	%	inches:	%	inches:	%
July	0.01	0.0	.01	0.0	0.12	0.3	.04	0.1	0.20	0.5	0.29	1.1
August	0.02	0.1	.03	0.1	0.11	0.3	.17	0.2	0.12	0.3	0.15	0.6
September	0.23	1.1	.37	1.3	0.51	1.3	.72	1.0	0.54	1.4	0.44	1.7
October	1.13	5.5	1.30	4.7	2.43	6.1	4.39	6.3	2.28	5.9	1.83	7.2
November	2.03	9.9	2.90	10.4	4.14	10.4	8.04	11.6	4.03	10.5	2.76	10.9
December	3.88	18.8	5.22	18.7	6.87	17.2	12.39	17.8	6.67	17.4	4.49	17.7
January	3.99	19.4	5.47	19.6	7.21	18.0	13.59	19.5	7.08	18.5	4.94	19.5
February	3.86	18.7	4.93	17.7	7.26	18.1	11.42	16.4	6.86	17.9	4.23	16.7
March	2.68	13.0	3.89	13.9	5.38	13.4	9.44	13.6	5.06	13.2	2.84	11.2
April	1.74	8.5	2.27	8.1	3.21	8.0	5.62	8.1	2.83	7.4	1.63	6.4
May	0.80	3.9	1.16	4.2	2.01	5.0	2.80	4.0	1.90	4.9	1.25	4.9
June	0.22	1.1	0.35	1.3	0.74	1.9	.98	1.4	0.80	2.1	0.54	2.1
Tot-l	20.59	100.0	27.90	100.0	39.99	100.0	69.60	100.0	38.37	100.0	25.39	100.0
Nov-Apr	18.18		24.68	88.4	34.07	85.2	60.50	86.9	32.53	89.8	20.89	82.3

Isohyets of normal annual precipitation and the location of climatological stations are shown on Figure E.3. Average annual precipitation for Feather River Basin above Oroville Dam is estimated as 44 inches.

d. Winter snowfall above about 5,000 feet elevation normally accumulates until about the first of April, when increasing temperatures mark the beginning of the snowmelt season. Snow falling at lower elevations usually melts away within a short period of time. Basin snow pack data for a wet year (1952), a near normal year (1954), and normal 1 April values at selected representative snow courses are given in the following tabulation.

1 APRIL SNOW SURVEY DATA

Snow Course		Elev. in Feet	Depth in Inches		Water Equivalent Inches			% Normal	
No.	Name		1952	1954	1952	1954	Normal	1952	1954
336	Upper Lassen Park	8,500	267	204	131	89	79	166	113
48	Mount Dyer No. 1	7,100	118	66	52	30	25	208	120
280	Rowland Creek	6,700	101	39	44	14	17	259	82
52	Eureka Lake	6,200	166	69	73	33	32	228	103
49	Letterbox	5,600	222	107	106	52	47	226	111
61	Chester Flat	4,600	77	20	29	10	7.3	392	137

A complete list of snow courses and their location is given on chart 5.

E.3 Runoff Characteristics

The runoff of Feather River is produced mostly by intense precipitation in winter, augmented by snowmelt in spring. Highest flows occur normally during the months of

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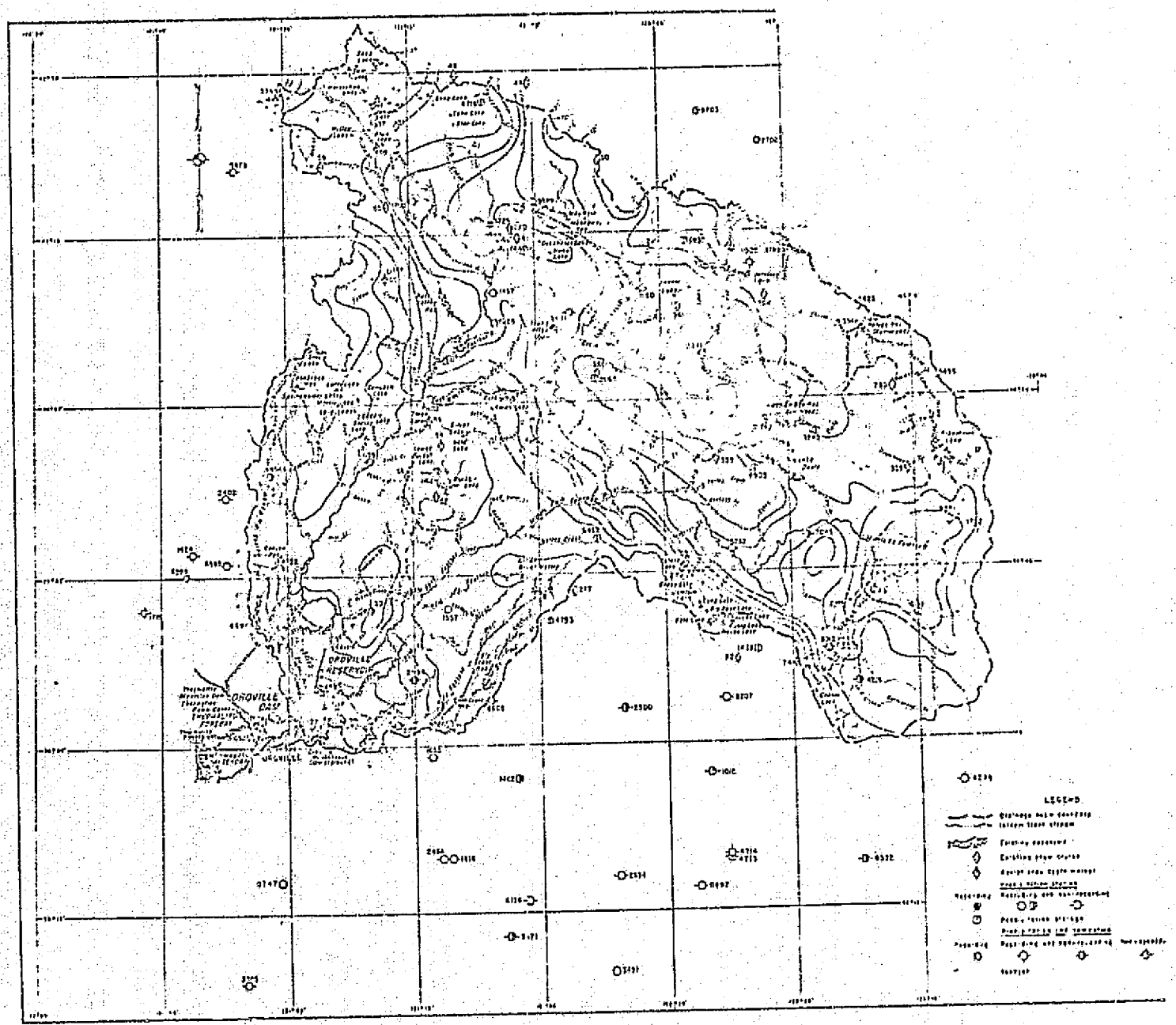

Figure E.3 Normal Annual Precipitation Climatological Stations and Snow Courses

December through June, with the largest sustained flows usually in April and May. Flows decrease during the summer, reaching the lowest ebb in August and September. The monthly distribution of average runoff of various Feather River tributaries including Yuba River at Marysville is as follows:

AVERAGE MONTHLY RUNOFF

MONTH	NO.FK. FEATHER R: AT PULGA (a) DA = 1,953 sq mi		MID FK FEATHER R: NEAR MERRIHAC DA = 1,068 sq mi		SO.FK. FEATHER R: AT ENTERPRISE DA = 132 sq mi		FEATHER RIVER AT OROVILLE (b) DA = 3,624 sq mi		YUBA RIVER NEAR MARYSVILLE (c) DA = 1,340 sq mi	
	Thousand ac-ft	Percent	Thousand ac-ft	Percent	Thousand ac-ft	Percent	Thousand ac-ft	Percent	Thousand ac-ft	Percent
October	101	5.2	24	2.4	1.8	0.8	129	3.1	33	1.8
November	108	5.5	25	2.5	5.8	2.6	182	4.3	52	2.8
December	159	8.1	103	10.3	20.0	9.1	323	7.7	216	11.8
January	167	8.5	95	9.5	25.0	11.4	414	9.8	220	12.0
February	209	10.7	127	12.7	37.0	16.8	530	12.6	252	13.8
March	225	11.5	121	12.1	36.0	16.4	617	14.7	237	13.0
April	292	14.9	204	20.5	44.0	20.0	724	17.2	305	16.6
May	253	12.9	176	17.6	37.0	16.8	604	14.4	314	17.2
June	142	7.2	75	7.6	11.0	5.0	302	7.2	146	8.0
July	109	5.6	25	2.5	1.6	0.7	151	3.6	29	1.6
August	103	5.3	13	1.3	0.4	0.2	120	2.9	12	0.6
September	90	4.6	10	1.0	0.5	0.2	105	2.5	14	0.8
Annual	1,958	100.0	998	100.0	220.0	100.0	4,201	100.0	1,830	100.0
Years of Record	56		15		55		65		23	

(a) Prior to October 1962 published as "at Big Bar"
(b) October 1934 to September 1961 published as "near Oroville"
(c) Prior to September 1957 published as "at Marysville"

Runoff in Feather River and tributaries varies both seasonally and from year to year. The average annual runoff of Feather River at Oroville for 65 years of record is 4,201,000 acre-feet, the maximum recorded value being 9,330,000 acre-feet (222 percent) for the 1903-04 water-year and the minimum, 1,180,000 acre-feet (28 percent) in 1923-24. Recorded and computed data for a comparison of extreme and mean flows in Feather River and tributaries above Oroville are given in the following table.

A list of stream gaging stations, their locations, drainage areas, periods of record, and peak flows is given on Figure E.2.

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Table E.1 - Recorded and Computed Runoff Data

	NORTH FORK FEATHER RIVER AT PULGA (a)			MIDDLE FORK FEATHER RIVER AT HERRIMAC			SOUTH FORK FEATHER RIVER AT ENTERPRISE			FEATHER RIVER AT OROVILLE (b)		
Drainage area(sq. mi.)	1,935			1,062			132			3,624		
PERIOD OF RECORD	- 1910-1966			1951-1966			1911-1966			1901-1966		
YEARS OF RECORD	56			15			55			65		
	Date	cfs	cfs sq mi	Date	cfs	cfs sq mi	Date	cfs	cfs sq mi	Date	cfs	cfs sq mi
INSTANTANEOUS FLOW												
MAXIMIM	22 Dec 64	73,000	37.7	22 Dec 64	86,200	81.2	22 Dec 55	19,200	146	22 Dec 64	250,000(c)	69.0
MINIMUM	25 Jun 61	33	0.02	2 Jan 60	92	0.09	Aug. Sep '50	0	0	9 Nov 31	300	0.08
MEAN DAILY FLOW												
MAXIMIM	22 Dec 64	55,400	28.6	23 Dec 64	51,000	48.0	22 Dec 55	15,400	117	19 Mar 07	187,000	51.6
MINIMUM	23 Jul 58	39	0.02	13 Sep 59	99	0.09	1 Aug 50	0.4	0	3 Oct 33	577	0.16
MEAN		2,890	1.50		1,380	1.30		303	2.30		5,800	1.60
	Water-year	1,000 ac-ft	in.	Water-year	1,000 ac-ft	in.	Water-year	1,000 ac-ft	in.	Water-year	1,000 ac-ft	in.
ANNUAL FLOW												
MAXIMIM	1938	4,200	40.7	1952	2,000	35.3	1938	491.6	69.8	1904	9,330	48.3
MINIMUM	1924	802	7.77	1961	450	7.95	1942	42.7	6.07	1924	1,180	6.11
MEAN		2,094	20.3		996.9	17.6		219.4	31.2		4,201	21.7

(a) Prior to October 1962 published as "at Big Bar"
(b) October 1934 to September 1961 published as "near Oroville"
(c) Computed flow

E.4 Flood Characteristics

a. Damaging floods in the Feather River Basin usually result from winter rain storms, occasionally augmented by melting snow. A typical flood producing storm may last several days, and is actually not a single storm but usually a rapid succession of several individual storms. Runoff produced by these storms may combine to produce high intensity peak flows in all streams in the basin. During large floods a wide range of flooding conditions prevails. Runoff accumulates rapidly in the upstream tributary areas and the floods produced are of high intensity but relatively short duration. In the lower reaches of the Feather River the stream gradient decreases, velocities are less, and prolonged inundation may occur. Large floods may also result in failure or overtopping of existing project levees with consequent flooding of large areas of highly developed farmland and urban-surburban developments.

b. Rain floods are characterized by high-peaks and short durations of a few days, while snowmelt floods have lower peaks and moderately high flows for periods up to several weeks. Flood peaks on the streams in the basin above Oroville Dam are often impaired and delayed by numerous upstream check dams, diversions, and reservoirs. Below the dam, peaks are reduced when the flood flows leave the channel and are stored by flooding over the adjoining flat lands.

c. Flood flows in the streams above Oroville Dam are usually confined within the natural narrow canyon stream channels, descending rapidly without causing extensive damage. Below the dam and below the town of Oroville, flood flows tend to spread over wide areas where not confined by levees. In the leveed reaches of the river when high flows in Feather River coincide with high flows in the downstream tributaries,

the combined flows may exceed the project channel capacity and cause flooding of adjacent protected areas.

d. The largest recorded flow on Feather River at Oroville happened in December 1964, when record breaking peaks were produced on many streams of the Feather River Basin. The flood of December 1964 - January 1965 resulted from a winter rainstorm which followed a meteorological pattern typical of other flood-producing winter storms over the basin. Heavy precipitation occurred in the preceeding 60 days over the general area, with up to 5 inches of rain recorded at some valley stations. The storm came in four distinct waves. The first wave, which occurred during 18-20 December, was cold, and deposited 2-3 inches of snow in the mountains down to the 3,000 foot level. The following wave brought rising temperatures and heavy rains up to 6,000 feet elevation. Within the 4 day period, 20-23 December, about 13 inches of rain fell. The warm winds and rain melted most of the new snow accumulated during the initial storm. Another cold wave, occurred during 26 December-4 January, and brought rain to lower elevations and snow to the mountains. The final wave of this storm series occurred 4-6 January when from 3 to 10 inches of precipitation fell on the Feather and Yuba River Basins. A local storm of high intensity occurred on 26 December over the mountain slope south of Oroville causing the highest recorded runoff in South Honcut Creek, a small tributary entering Feather River below Oroville. Inflow to Oroville Reservoir peaked at 250,000 cubic feet per second, compared to the previous maximum of 230,000 c.f.s. at Oroville in 1907. Flow at Oroville was controlled by the partially constructed dam to a maximum out flow of 158,000 c.f.s. Peak flows of Feather River and its tributaries at various stations in 1964 and the previous maximums are tabulated as follows:

Stream	Gaging Station	1964 Peak Flow (c.f.s.)	Previous Maximum (c.f.s.)	Date
No. Fork Feather R.	at Pulga	73,000	72,400	Dec 1955
Mid " " "	near Merrimac	86,200	65,400	Feb 1963
So. " " "	at Enterprise	11,800	19,200	Dec 1955
West Br. " "	near Paradise	26,300	21,200	Jan 1963
Feather River	inflow to Oroville res	250,000	230,000	Mar 1907
Feather River	at Orovill	158,000	290,000	Mar 1907
South Honcut Creek	near Bangor	17,600	8,280	Oct 1962

* The Oroville embankment temporarily stored 155,000 acre-feet of flood water, reducing the peak flow from 250,000 c.f.s. to 158,000 c.f.s. and delaying the peak for about 20 hours.

Major flood flows also occurred in March 1907, December 1955, and January-February 1963. The flood of March 1907 occurred when heavy rainfall accompanied by unusually warm weather caused rapid melting of snow and runoff second only in magnitude to the flood of 1964, with the peak flow at Oroville, reaching 230,000 c.f.s. The flood of December 1955 had the third highest peak at Oroville, 203,000 c.f.s., and was also the result of excessive rain and snowmelt, as were most of the other floods on Feather River. The floods of 1907, 1904, 1937, 1909, and 1955 produced the largest annual runoff volumes, while the floods of 1907, 1964, 1955, 1909, and 1928 had the highest 3-day volumes. Preliminary data indicate that 1969 water year will rank among the larger floods on Feather River. The peak inflow to Oroville Reservoir of about 125,000 c.f.s. occurred 21 January 1969, with a maximum 3-day flow of about 543,000 AF.

APPENDIX F. DATA USED IN ANALYSIS OF COVARIANCE IN SECTION 2.4 OF THIS REPORT

Table F.1 Data Used in Analysis of Covariance

Year	Actual Runoff	April 1 Forecast(F)	Forecast Error (E)	Snow Variables(S^2)	October-March Precipitation(P_1)	April-July Precipitation(P_2)
1942	2883	1968	-915	114.49	126	362
1943	1914	1834	-80	94.09	122	135
1944	1571	1506	-65	110.25	74	150
1945	1563	1756	193	114.49	101	150
1946	1605	1983	378	141.61	112	26
1947	889	1064	175	10.24	80	95
1948	2486	1168	-1318	34.81	78	460
1949	1420	1699	279	151.20	73	84
1950	1988	1753	-235	127.60	93	199
1951	1511	1710	199	44.89	136	142
1952	4676	4787	111	600.25	176	97
1953	2405	1821	-584	127.60	101	266
1954	1965	1760	-205	118.80	99	158
1955	1230	1075	-155	38.40	65	181
1956	2732	2861	129	237.16	160	154
1957	1508	1171	-337	30.25	81	254
1958	3350	2914	-436	285.60	138	220
1959	1014	1238	224	49.00	78	91
1960	1213	1306	93	49.00	86	115
1961	1136	1230	94	49.00	77	152
1962	1904	2495	591	259.21	104	76
1963	2651	1440	-1211	10.89	124	378
1964	1169	1208	39	53.20	72	127
1965	2264	1879	-385	75.69	138	196
1966	1324	1515	191	100.00	81	89
1967	3042	2589	-453	166.41	169	283

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APPENDIX G. GRAPHICAL REPRESENTATION OF HISTORICAL BEHAVIOR OF RESERVOIR STORAGE AND SPILL AT OROVILLE, 1968-1973

This appendix presents in graphical form the historical behavior through time of the volume of water stored at Oroville Reservoir and the amount of spill that occurred. If the volume of water in storage exceeds the volume shown under the daily ground wetness index, then flood control regulations require that the water volume above the daily ground wetness index be spilled. The amount of spill is indicated by the bottom sections of Figures G.1 through G.6.

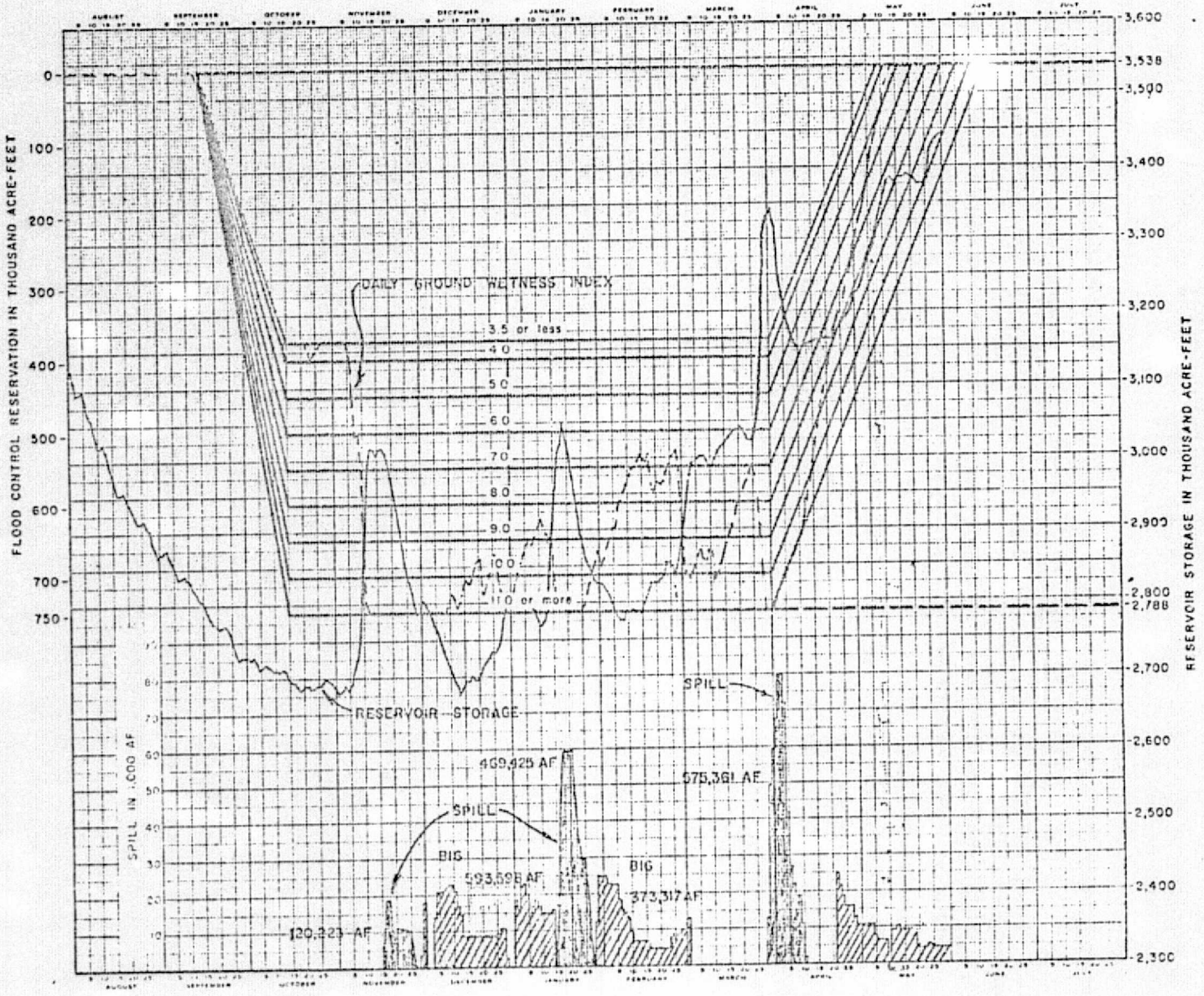

Figure G.1 Oroville Flood Control Diagram, 1973-1974

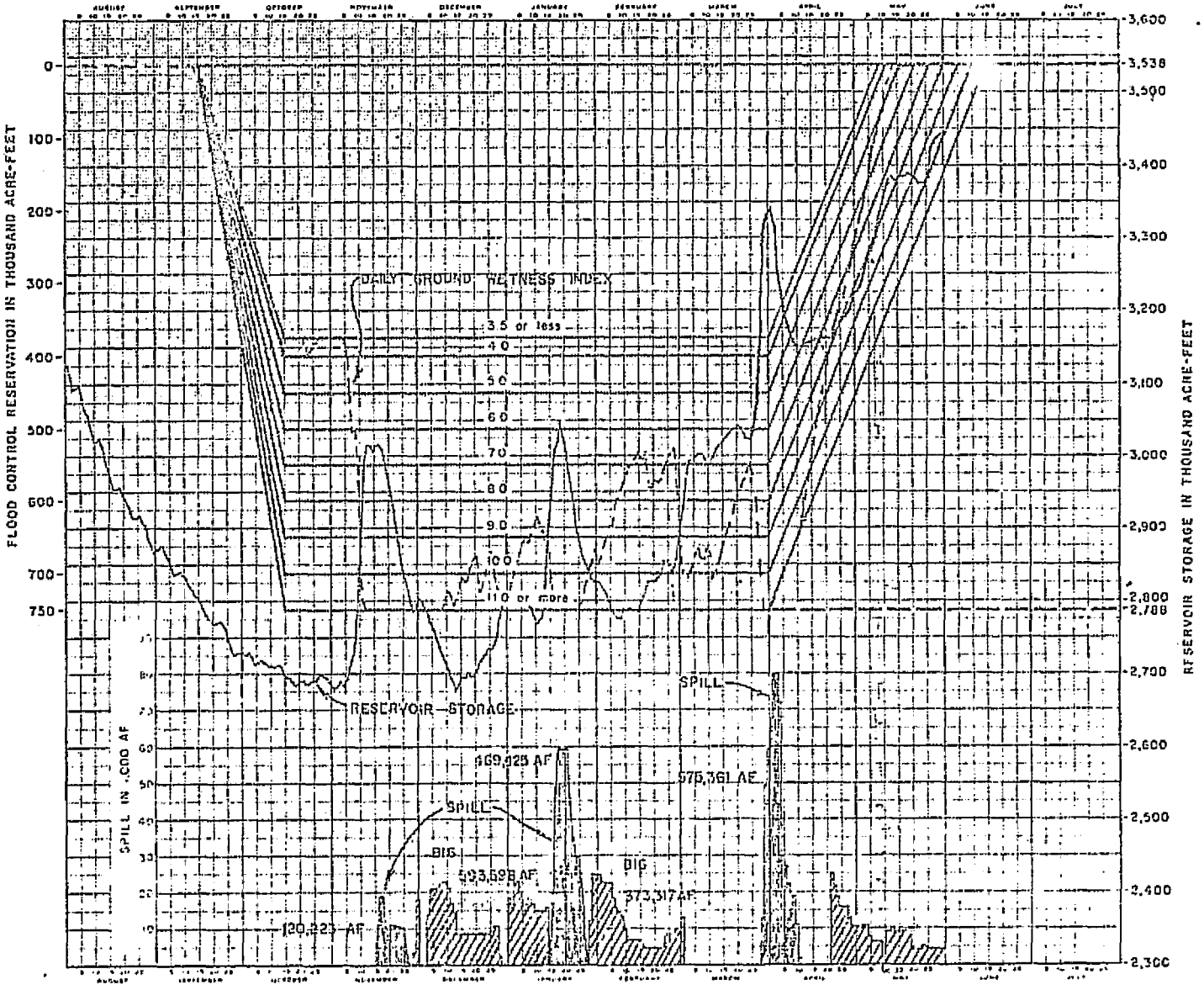

Figure G.1 Oroville Flood Control Diagram, 1973-1974

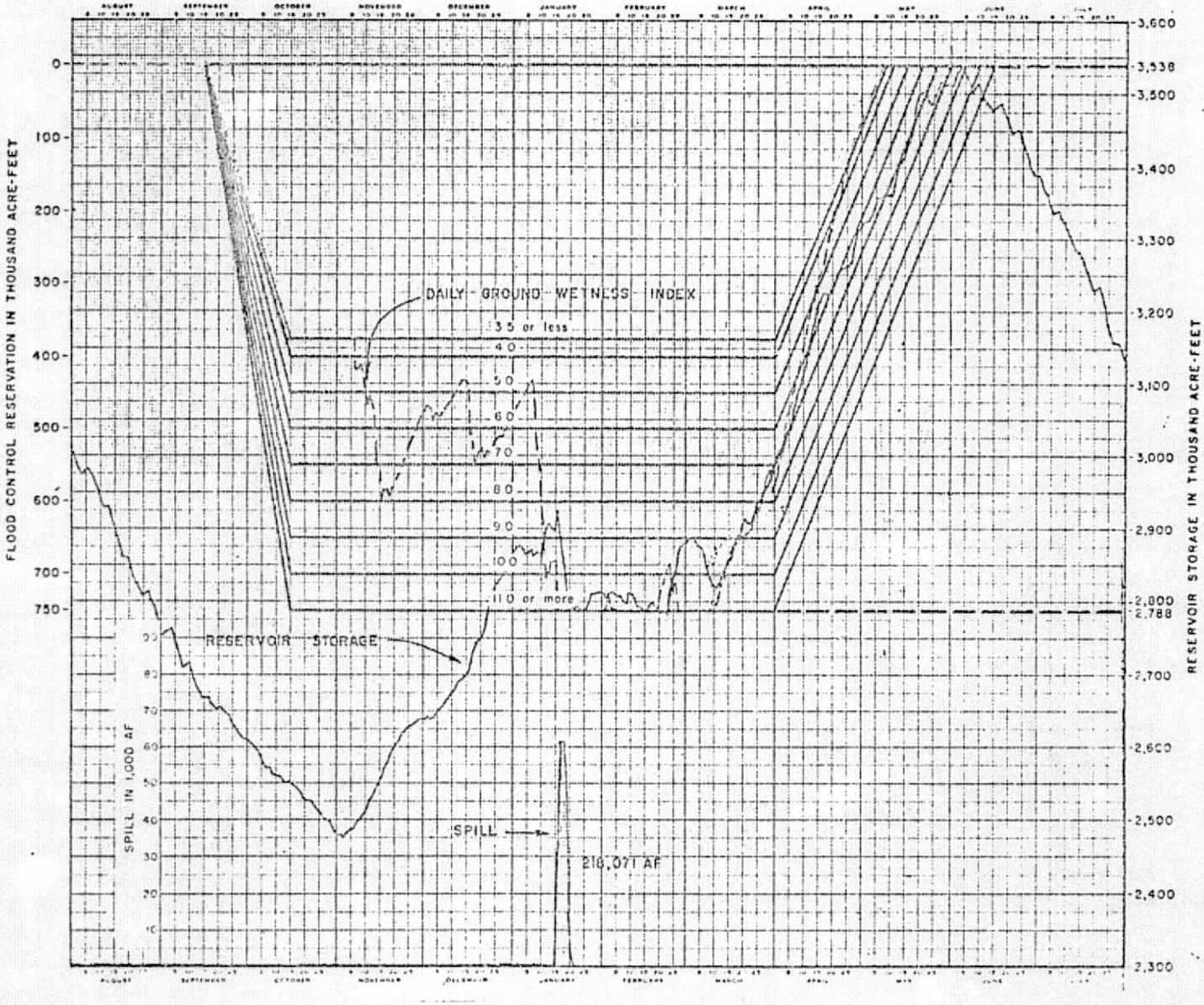

Figure G.2 Oroville Flood Control Diagram, 1972-1973

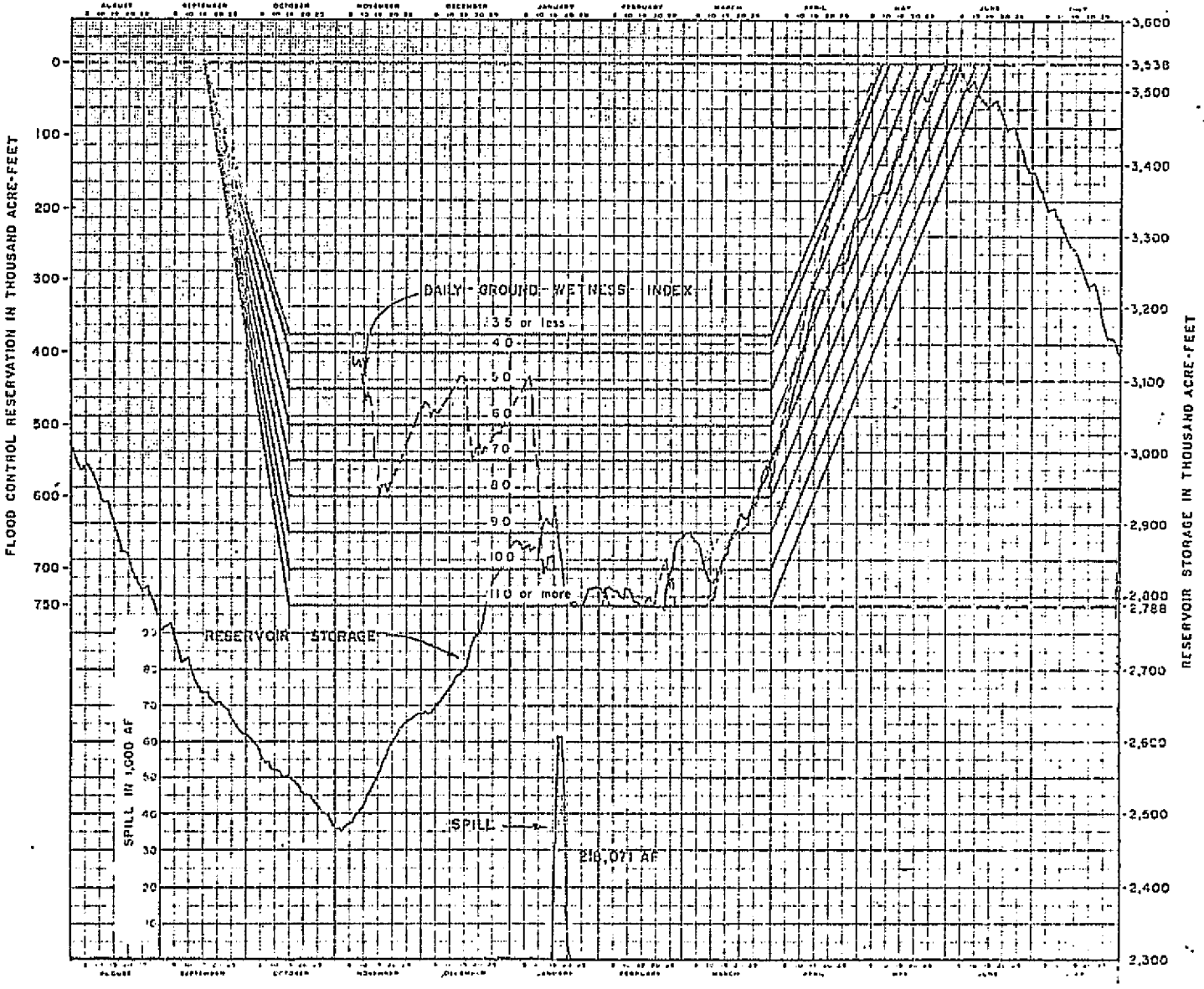

Figure G.2 Oroville Flood Control Diagram, 1972-1973

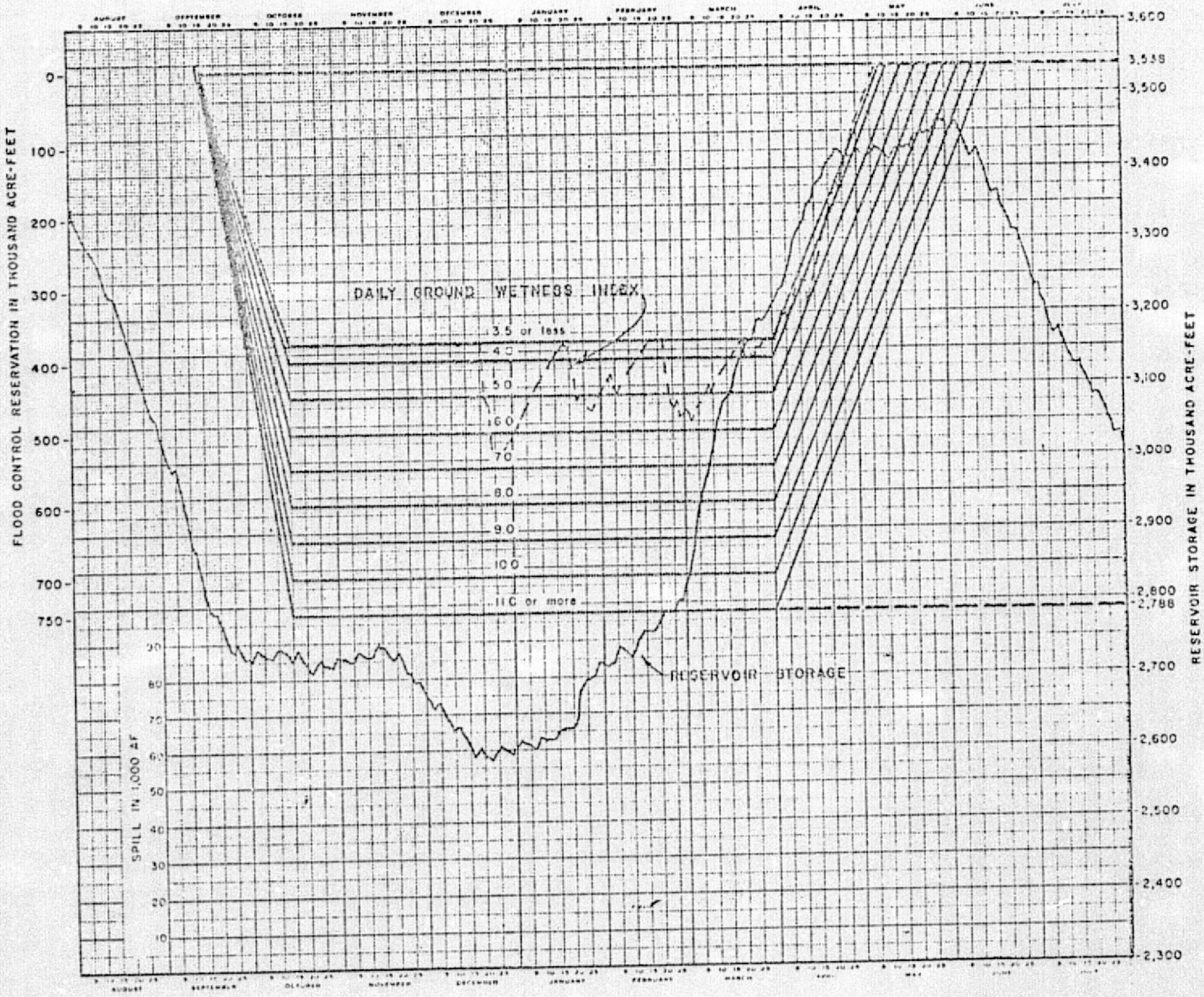

Figure G.3 Oroville Flood Control Diagram, 1971-1972

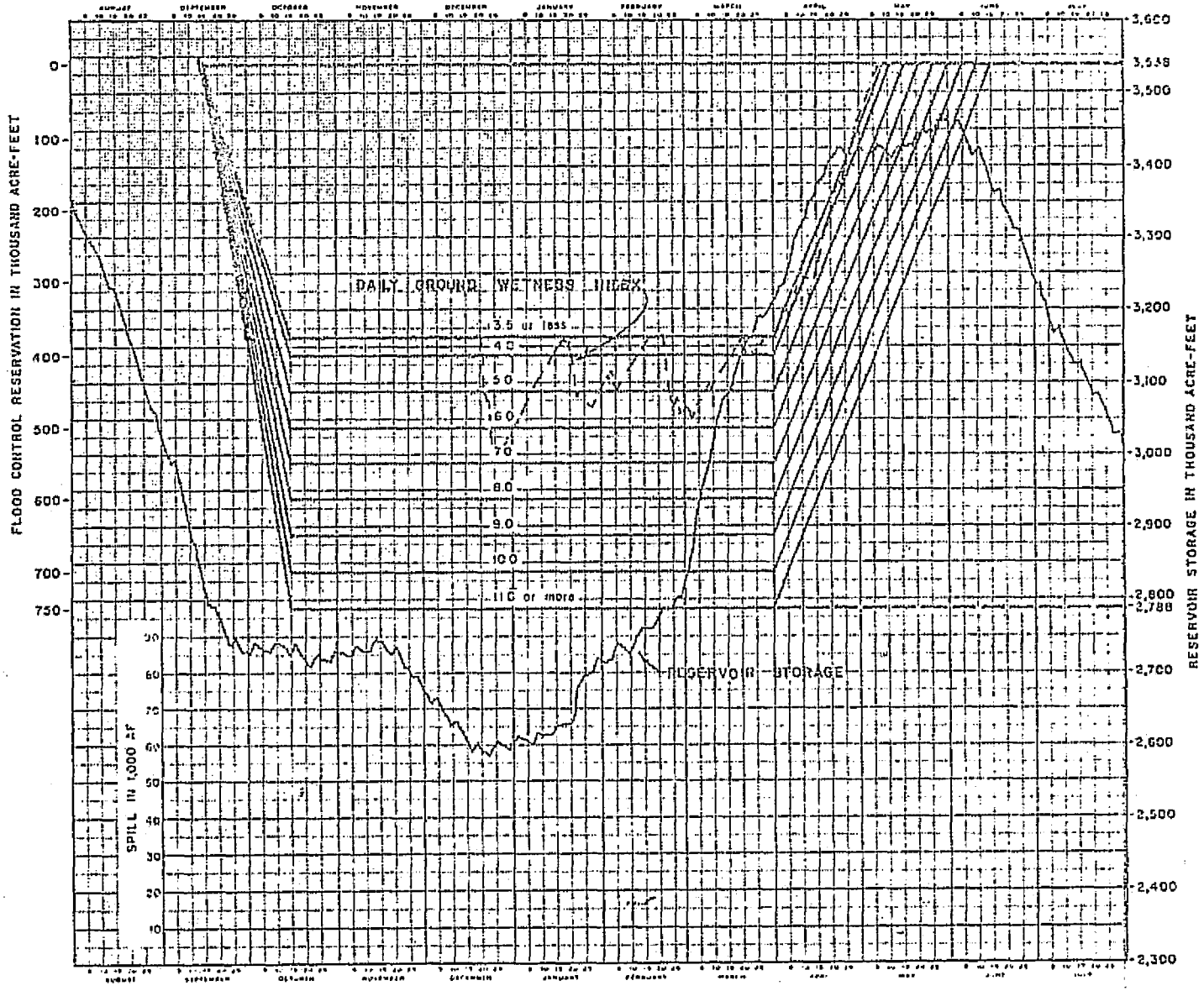

Figure G.3 Oroville Flood Control Diagram, 1971-1972

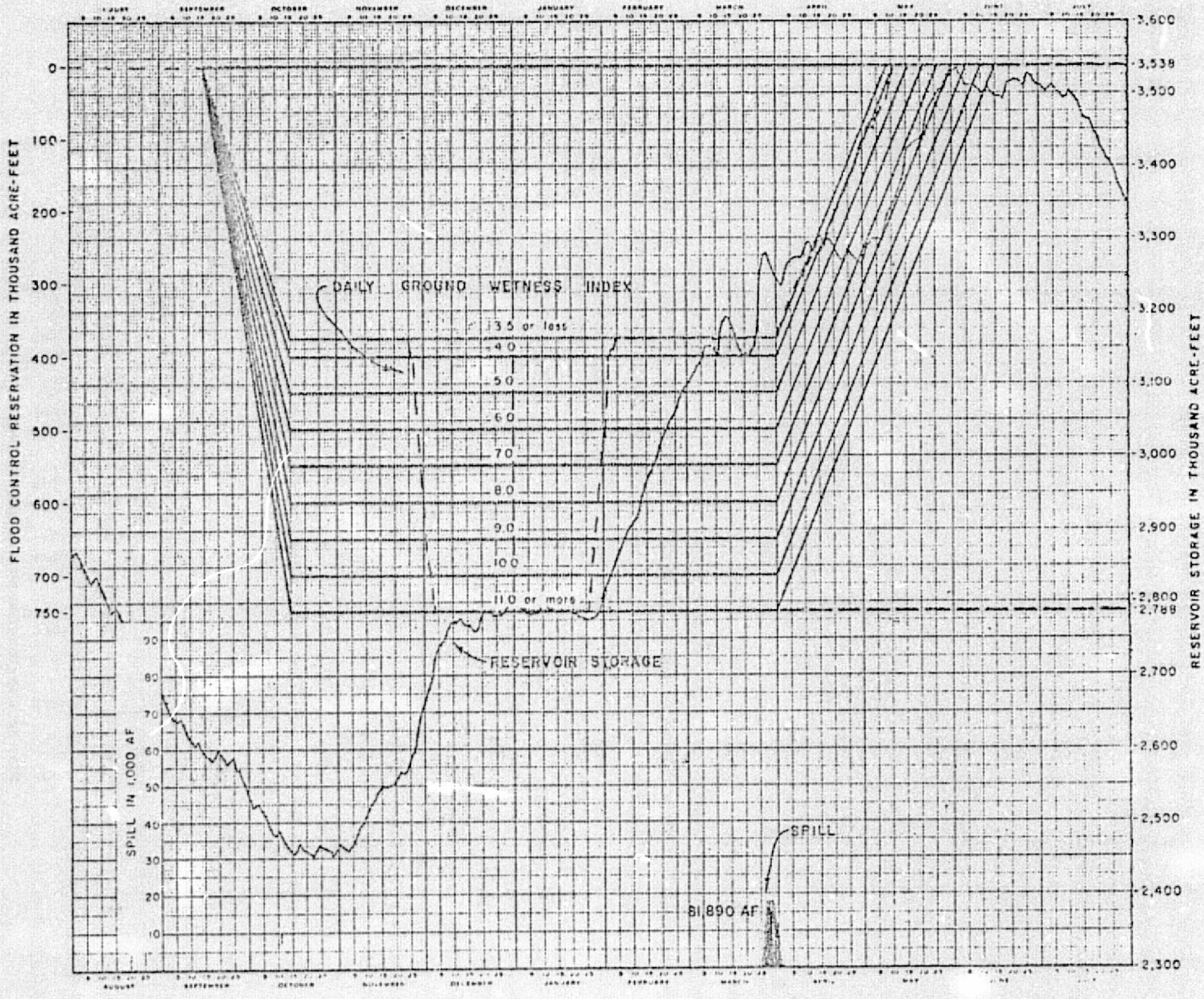

Figure G.4 Oroville Flood Control Diagram, 1970-1971

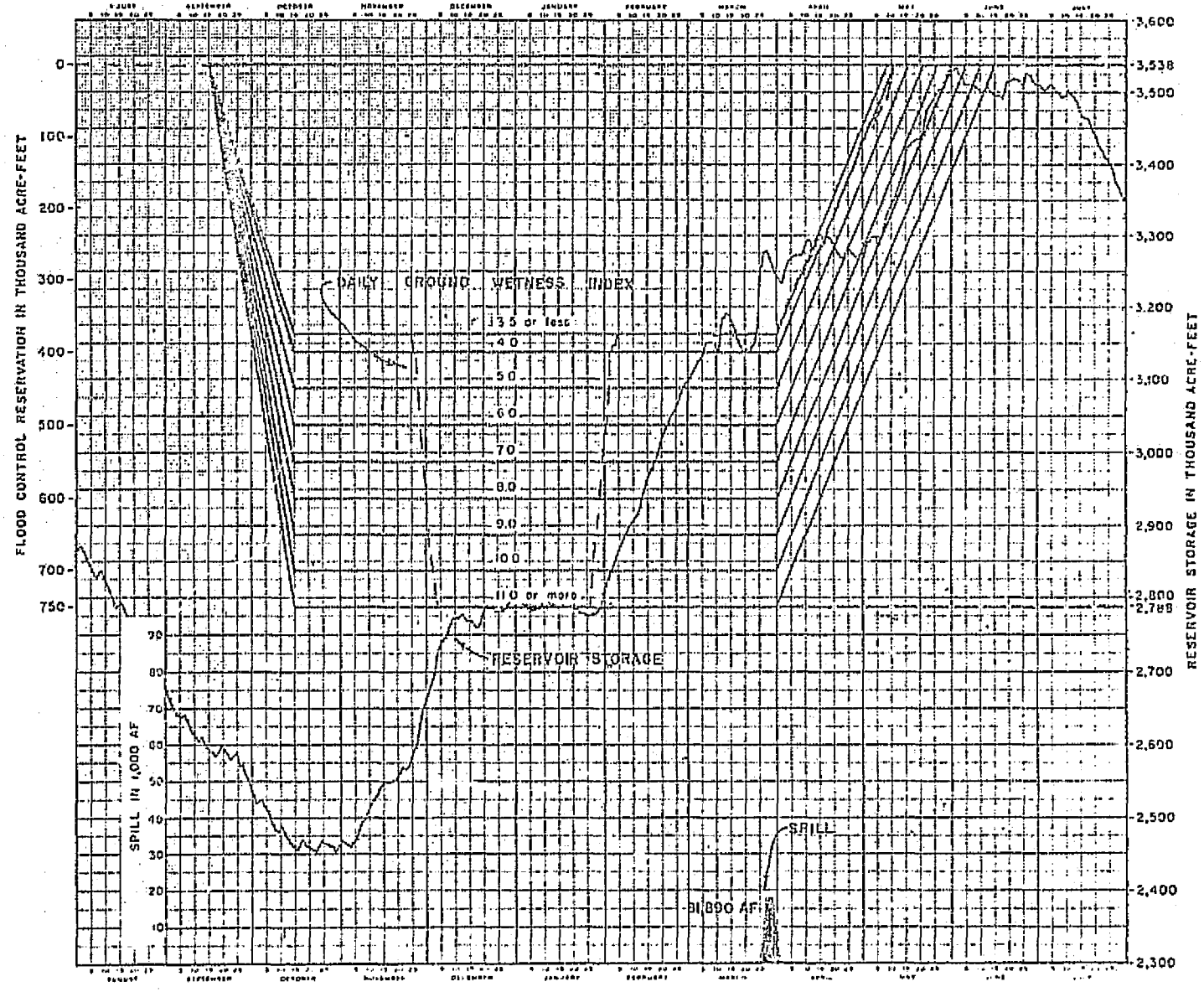

Figure G.4 Oroville Flood Control Diagram, 1970-1971

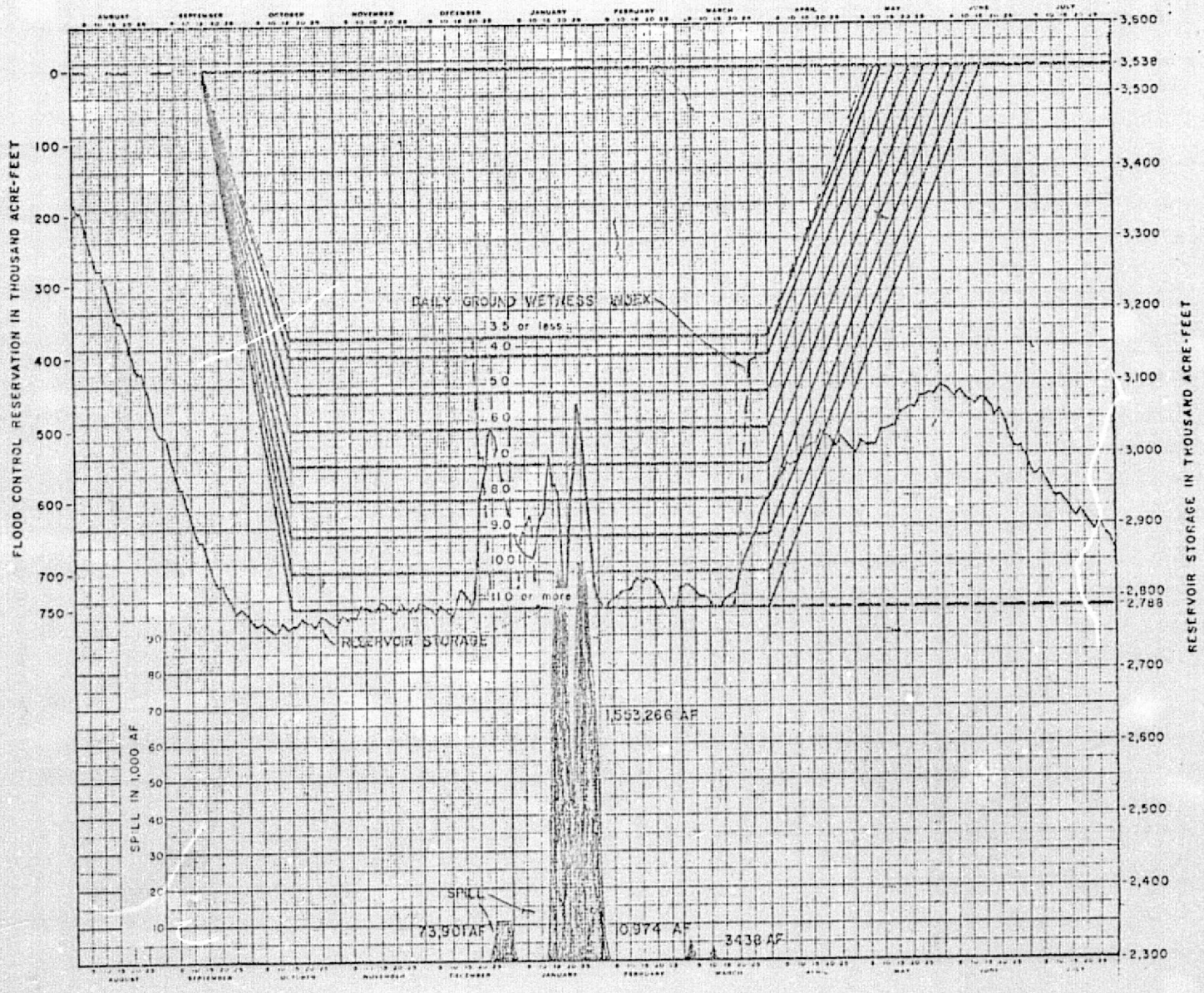

Figure G.5 Oroville Flood Control Diagram, 1969-1970

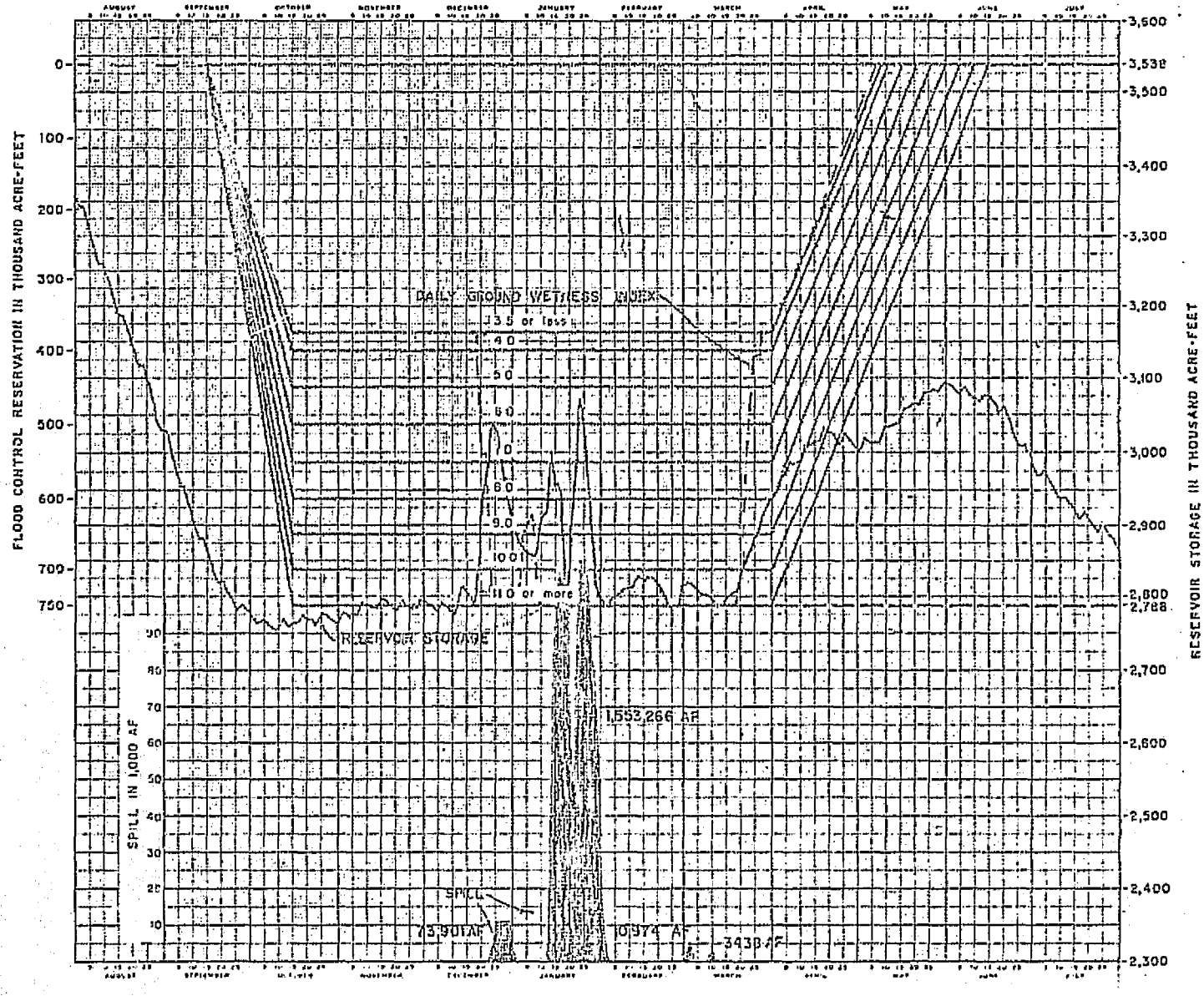

Figure G.5 Oroville Flood Control Diagram, 1969-1970

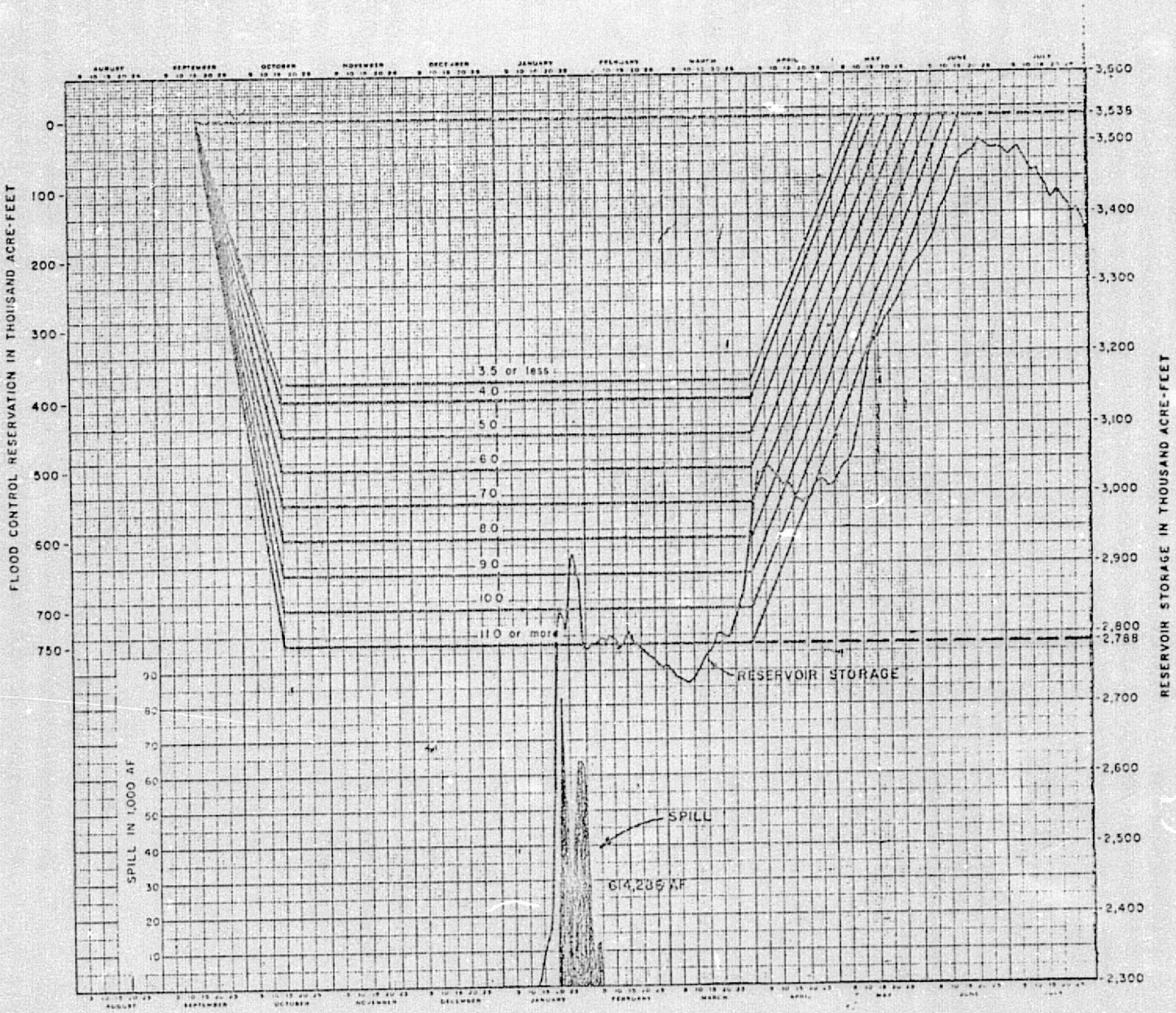

Figure G.6 Oroville Flood Control Diagram, 1968-1969

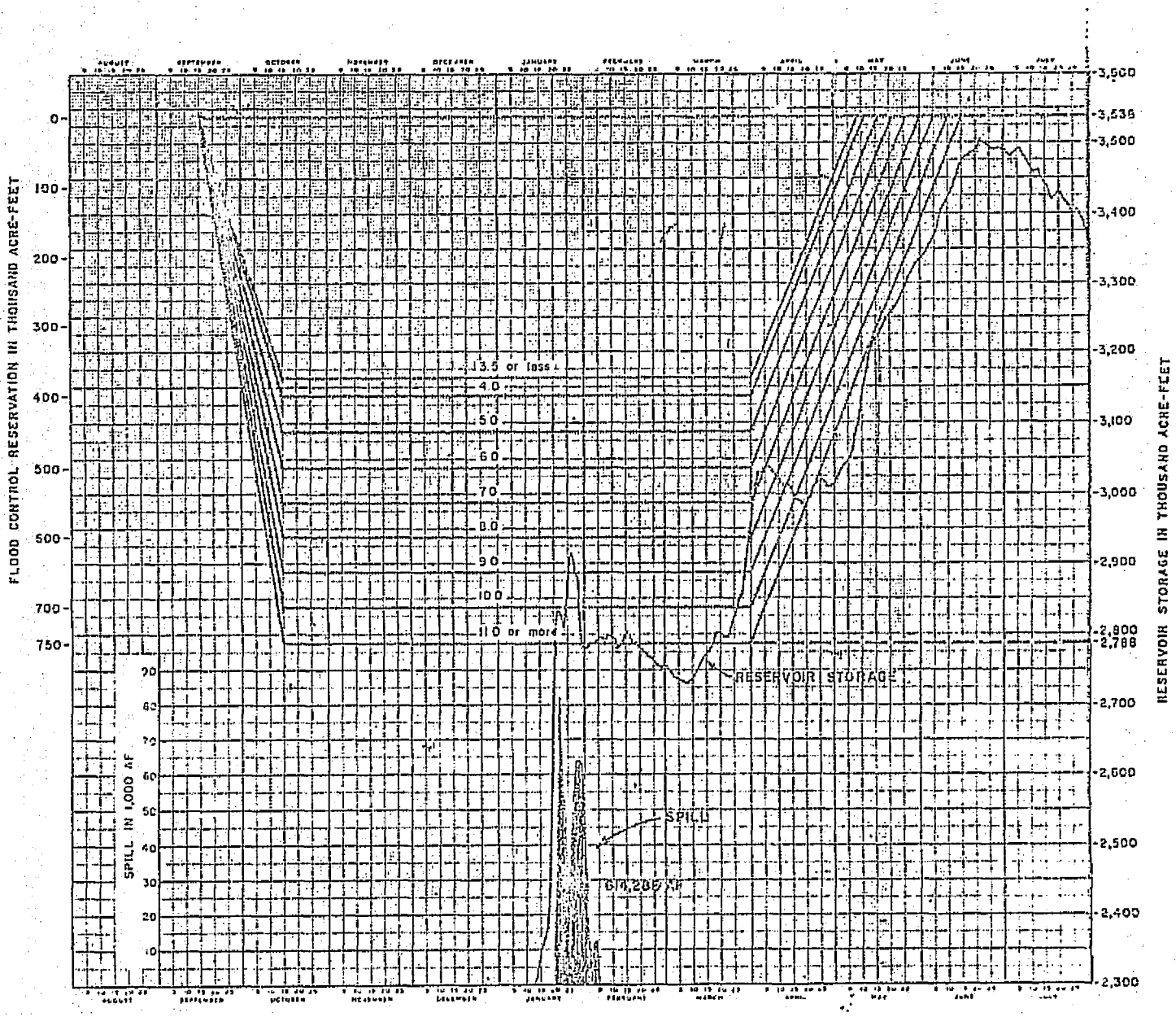

Figure G.6 Oroville Flood Control Diagram, 1968-1969

APPENDIX H: THE APPLICABILITY OF SATELLITE-DERIVED INFORMATION TO MAJOR RESERVOIRS IN THE UNITED STATES

H.1 Description of Background, Findings and Necessary Conditions for the Applicability of Remote Sensing

H.1.1. Introduction

Broadly speaking, two general approaches may be taken to the evaluation of the applicability of remote sensing to runoff forecasting and reservoir management. One is the intensive investigation of the sources of error in a single reservoir-management model, or in a few such models, by means of a computer simulation of reservoir operations or similar methods. This is the approach that has been followed in the main body of this report. Another is the extensive investigation of the general characteristics of a large number of reservoir systems, with the object of setting upper and lower bounds to the possible benefits of widely distributed information derived from remote sensing.

Though this appendix can be classified in the second category, it should not be viewed as independent of the case study to which it is attached. Rather, the Feather River case study suggests a number of necessary conditions which a reservoir system must satisfy if remote sensing is to be applicable to its management. Other such conditions are set by the technical capabilities of applications satellites (e.g., their capability for long-range weather forecasting) and by the information requirements which follow from certain physical parameters of reservoir systems (e.g., the ratio between the capacity of a reservoir and the mean annual streamflow of the river at that point). This appendix reports the results of a survey of all the major reservoir systems in the United States

with respect to the extent to which each system satisfies a half-dozen such generally necessary conditions for the applicability of applications satellites. No attempt is made to determine if any such system meets sufficient conditions for such applicability. That determination can be made only by further case studies of the scope of this report. It is hoped, however, that this appendix succeeds in showing where such studies might (and might not) prove fruitful.

The discussion which follows is restricted to major U.S. reservoir systems. For the purposes of this appendix, a "major" reservoir is regarded as one which either (a) has a gross storage capacity of 1 billion cubic meters (810,700 acre-feet) or more, or (b) has an installed hydroelectric capacity of 200 megawatts or more, or (c) produces an average of 1,000,000 megawatt-hours or more annually, or has some combination of these characteristics.

The most promising area for the application of remote sensing to reservoir operation is the forecasting of inflows into reservoir systems. Because LANDSAT-type satellites are inappropriate to weather forecasting, their usefulness for inflow forecasting is limited in practice to those regions where snowmelt contributes significantly to such inflows. Together with the conditions on size, mentioned previously, this condition restricts the discussion which follows to reservoirs in six major Western regions: the Upper Missouri Basin, the Colorado River Basin, the Snake River Basin, and the Southern, Middle and Northern Pacific Slope Basins (see Figure H.1.1).

H.1.2 Findings

Of the 57 major reservoirs in the six Western regions considered, only 8 ("Category I") clearly meet certain fundamental necessary conditions for the applicability of remote

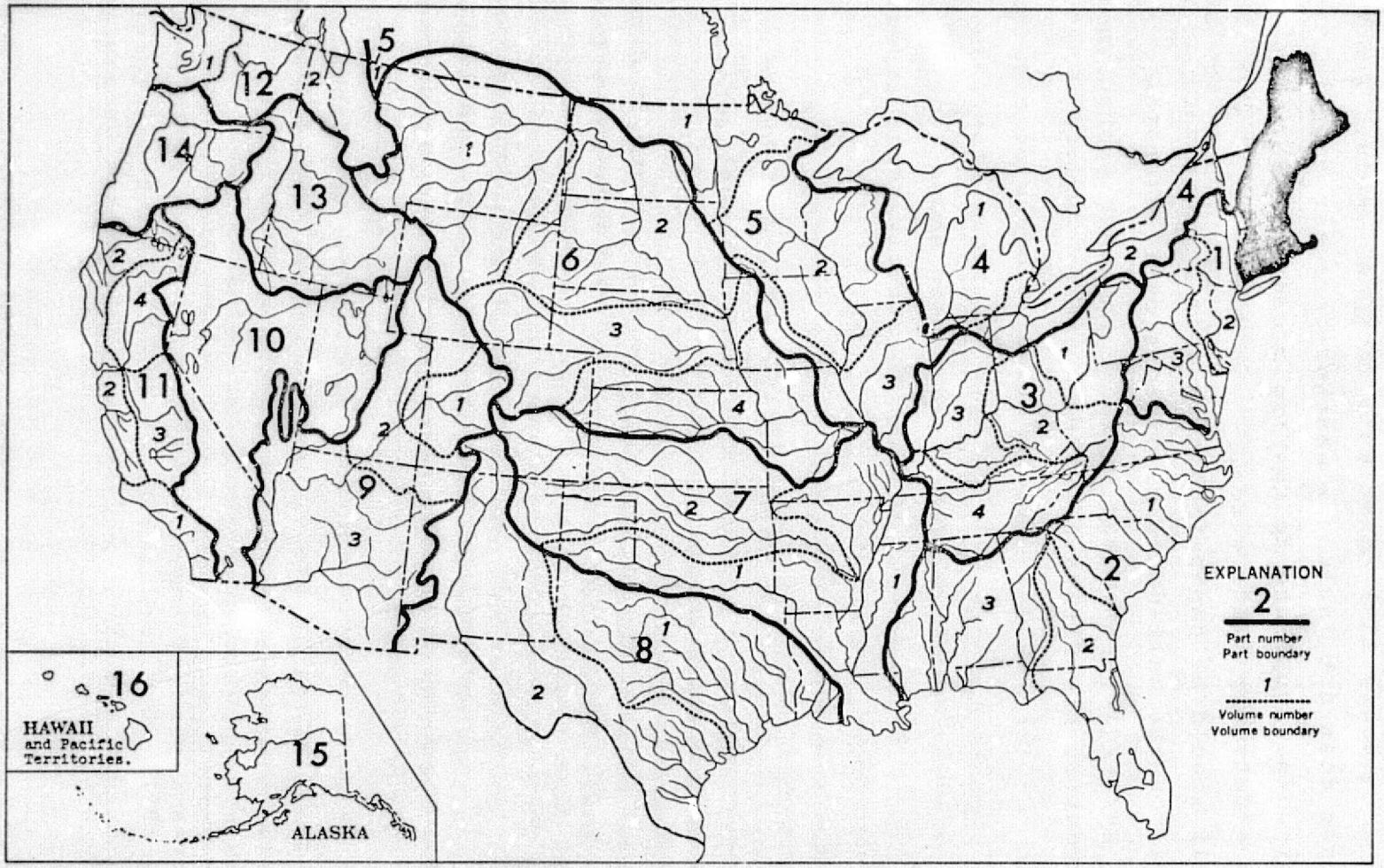

Figure H.1.1 Map of Major American Basins, Showing U.S. Geological Survey Regional Designations.

Note: Reservoirs discussed in Appendix H are Located in Regions 6,9,11,12,13 and 14.

Source: U.S. Geological Survey, Surface Water Supply in the United States, Part 1, Volume 1, Geological Survey Water-Supply Paper 1901, Washington, 1969, p.8.

sensing (not including meteorological capabilities) while another 14 ("Category II") constitute marginal cases. Remote sensing which does not include a weather-forecast capability is considered inappropriate to reservoir management in the remaining 35 ("Category III") cases.

It should be emphasized that this categorization is based solely on the half-dozen conditions outlined below. A Category I reservoir system may be shown on other grounds not to have potential benefits derived from remote sensing, and conversely, special factors may occasionally override a classification in Category III. The Oroville Reservoir, for example, though it is included in Category I, has been shown (for reasons given in this report) to have relatively small expected benefits from remote sensing.

The 21 members of Categories I & II other than Oroville produce an average of 27,754,000 MWH/yr of hydroelectric power, which is 10.8% of the average annual generation of all U.S. hydroelectric installations.[1] However, most of this power is produced by the 14 "marginal" plants in Category II. The average annual generation of the 7 Category I plants other than Oroville is 5,453 MWH/yr, or 2.1% of nationwide hydroelectric generation and 6.4% of the hydroelectric capacity of the 57 reservoir systems examined here. While it is not possible on this basis to make specific benefit projections, it follows from these results that at most a small fraction of American hydroelectric installations would be significantly affected by the widespread use of data derived from remote sensing (not including a meterological capability).

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[1] These figures represent average annual generation as of January 1, 1972. U.S. Federal Power Commission, Hydroelectric Power Resources of the United States, Developed and Undeveloped, Washington, D.C., 1972, pp. 1, 80-97.

The data on which these conclusions are based are summarized in Tables H.1.1, H.1.2, and H.1.3. Details on reservoir management parameters, streamflow patterns and climatic conditions of the 22 Category I and Category II reservoirs are provided in Section H.2.

H.1.3 Necessary Conditions for the Applicability of Remote Sensing

The use of LANDSAT-type remote sensing for reservoir management can be expected to produce significant benefits only when the following conditions (among others) are met: (1) relatively high ratio of annual snowfall to Spring precipitation; (2) relatively high variability of inflows; (3) the existence of tradeoffs between competing reservoir functions; (4) reservoir storage capacity which is more than a small fraction of mean annual runoff. These conditions, and the variables used here to measure them, are discussed below.

H.1.3.1 Precipitation Patterns

As the Oroville case study indicates, the usefulness of improved snow-survey information to reservoir management decreases as the magnitude and variability of Spring precipitation increases. The ideal climatological pattern for remote-sensing applicability is one in which much more precipitation occurs as snow between October and March than occurs as rain between April and July. (This seasonal division follows that employed by the California Seasonal Forecast Model). Because survey data on monthly snowfall were not available in the appropriate form for most of the basins examined here, this study has used the ratio

$$\frac{\text{total Winter precipitation (October - March)}}{\text{total Spring precipitation (April - July)}}$$

(hereafter W/S) as an approximation. Since not all Winter precipitation occurs as snow in the Western basins, this ratio will consistently overstate the ratio of snowmelt runoff to Spring precipitation. A low value of W/S will therefore be a strong indication that improved snow surveys would probably be of limited usefulness to reservoir management in the basin in question.

This parameter varies widely from one basin to another. In the Northwest Missouri basin, for example, W/S averages about .6. Since W/S is based on precipitation for six Winter months and four Spring months, this value is only 40% of that expected for a region with a "flat" precipitation pattern (see Figure H.1.2). In most California basins, on the other hand, W/S averages about 6.0, or four times that expected for a region with no seasonal differences in precipitation. It is significant that, despite the relatively high W/S (5.76) of the Sacramento basin, in which Oroville is located, it is from improved forecasts of Spring precipitation, rather than from more accurate snow surveys, that a decrease in runoff forecast error early in the season is to be expected. Since reservoir systems vary regarding the present accuracy of snow-cover measurement, this result cannot simply be extended to all other basins with W/S equal to or less than Oroville's. However, the probability that improved snow-cover measurements will result in significant benefits decreases as W/S decreases. It is assumed that a value of W/S of less than half of Oroville's (that is, about 2.9) is prima facie grounds for classifying a reservoir in Category II. When $W/S < 1.5$, which implies relatively dry Winter and wet Spring weather, probable benefits from remote sensing are considered to be negligible. $W/S < 1.5$ is therefore interpreted as prima facie grounds for classification in Category III.

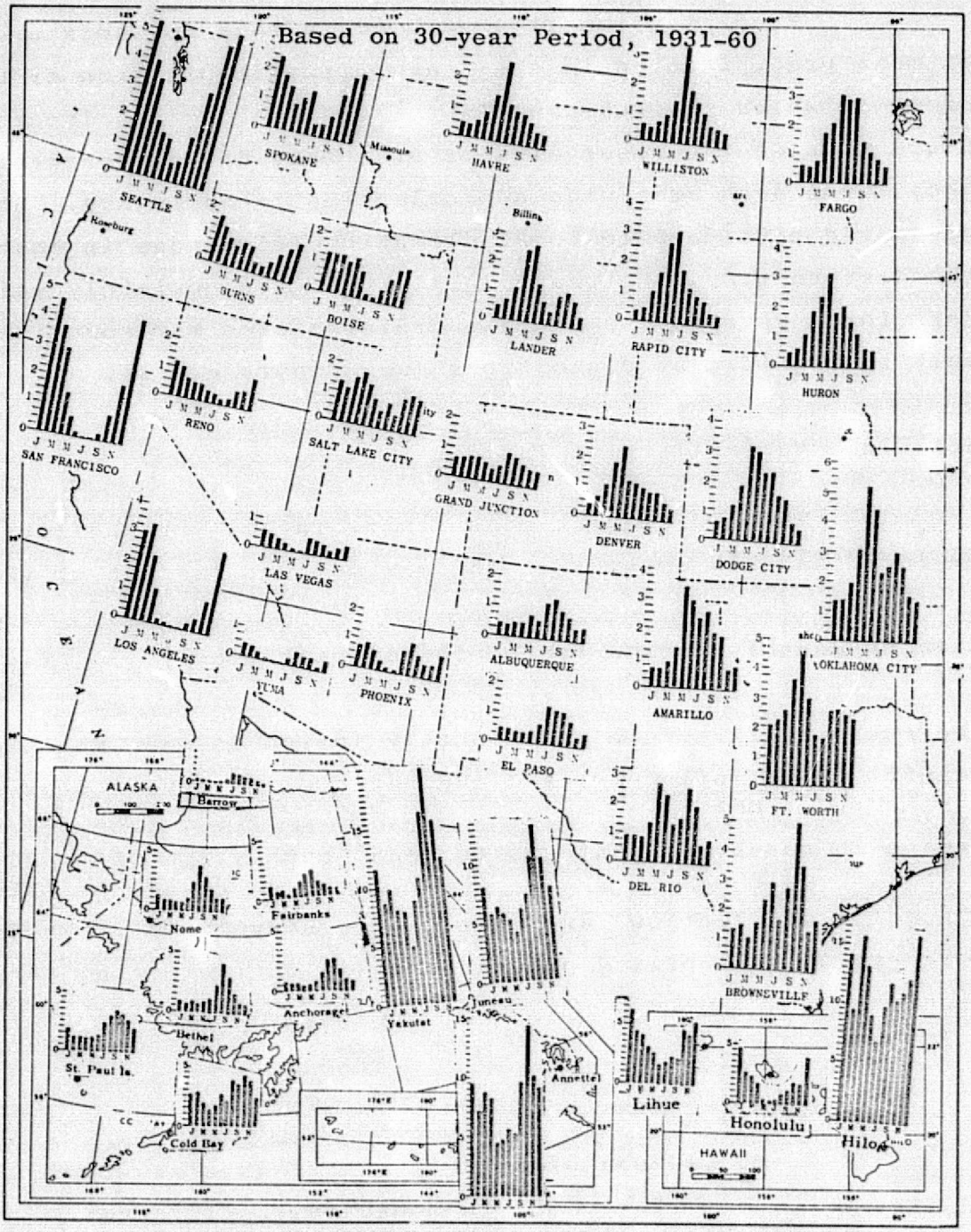

Figure H.1.2 Normal Monthly Total Precipitation (Inches), Western United States.

Source: John L. Baldwin, Climates of the United State, Washington, 1973, p.72.

Precipitation figures used in this appendix are based on mean precipitation in the State Climatic Division or Divisions in which the reservoir's primary drainage is located. Since most of the reservoirs treated here have extensive drainages, some such area-wide approximation is necessary. However, given the considerable local climatic differences in most of the Western U.S., the unavailability of appropriately weighted data for a reservoir's precise drainage area may sometimes result in significant distortions (see Figure H.1.3).

H.1.3.2 Variability of Inflows

Three different measures of inflow variability are employed in this appendix: the maximum coefficient of variation of monthly inflow for months of peak flow $\left(\frac{\sigma_i}{M_i} \quad \max\right)$; the ratio of five-year peak monthly inflow to mean monthly runoff $\left(\frac{\text{Max. inflow}}{\text{MMR}}\right)$; and the ratio of five-year peak increase in reservoir contents to mean monthly run-off $\left(\frac{\Delta C}{\text{MMR}}\right)$. ("Runoff" and "inflow" are here used synonymously). These measures of variability are examined in the following three sections.

H.1.3.2.1 $\left[\frac{\sigma_i}{M_i}\right]$ max

M_i = Mean of monthly runoff into reservoir for the i-th month over a five-year period

σ_i = standard deviation (unbiased) of monthly runoff for the i-th month over the same period.

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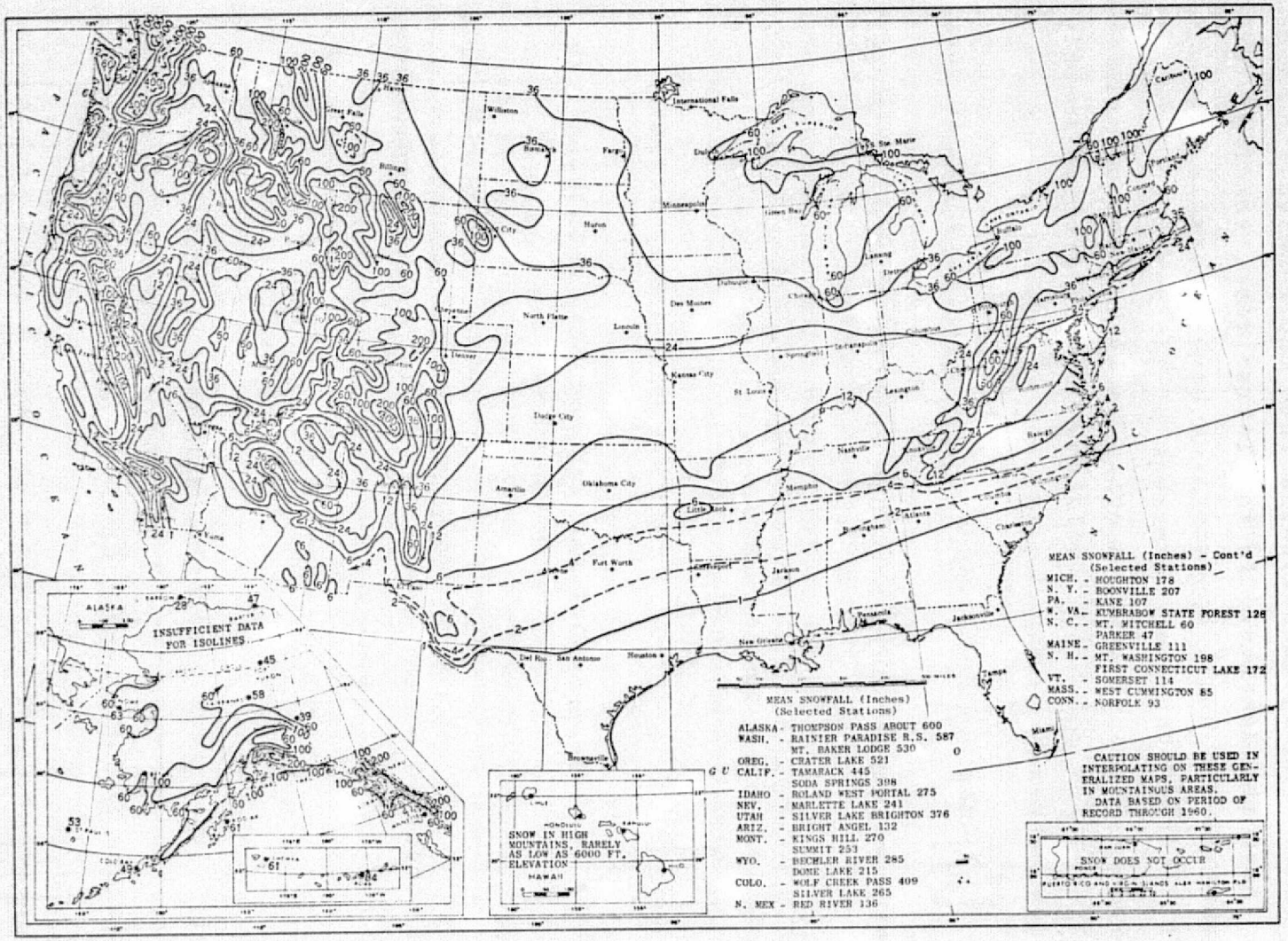

Figure H.1.3 Mean Annual Total Snowfall in the United States (Inches).

Source: U.S. Department of Commerce, Environmental Data Service, Climatic Atlas of the United States, Washington, 1968, p.53.

Data for this parameter are obtained either from USGS gaging stations on streams flowing into the reservoir or from stations near the damsite. In the latter case, readings for years prior to the dam's construction have generally been used. Data from stations downstream of the dam are employed only when the dam's storage capacity is 1% or less of mean annual streamflow and hence could not grossly distort monthly streamflow patterns.

$\left[\frac{\sigma_i}{M_i}\right]_{max}$ is the value of $\left[\frac{\sigma_i}{M_i}\right]$ for the month in which $\left[\frac{\sigma_i}{M_i}\right]$ is at a maximum, subject to the constraint that M_i in this expression must equal or exceed the median value of M_i for all values of i ($1 \leq i \leq 12$).

$\left[\frac{\sigma_i}{M_i}\right]_{max}$ is thus a measure of the year-to-year variability of flow for that part of the year when runoff is heavy and variability is at a (constrained) maximum. $\left[\frac{\sigma_i}{M_i}\right]_{max}$ provides a measure of the unreliability of runoff predictions based solely on historical trends.

Like W/S, $\left[\frac{\sigma_i}{M_i}\right]_{max}$ might be expected to correlate positively with expected benefits (if any) to reservoir management of LANDSAT-type remote sensing. Among the 29 reservoir systems for which this datum is available, the mean value of $\left[\frac{\sigma_i}{M_i}\right]_{max}$ is .57; its σ is .35. A value of $\left[\frac{\sigma_i}{M_i}\right]_{max}$

of .25 or less implies exceptionally low year-to-year variability of streamflow, and is interpreted as prima facie evidence for classification in Category II or III.

H.1.3.2.2 $\frac{\text{Max. inflow}}{\text{MMR}}$

Max inflow = largest recorded 30-day inflow into reservoir or (or unobstructed streamflow at damsite) in a given 5-year period (water years 1961-65 unless otherwise specified)

MMR = mean annual runoff ÷ 12

Unlike $\left[\frac{\sigma_i}{M_i}\right]_{\max}$ which is a measure of year-to-year streamflow variability, this parameter is essentially a measure of the magnitude of peak flows. Other things equal, the greater the value of $\frac{\text{Max. inflow}}{\text{MMR}}$, the greater the flood-control margin a reservoir manager must allow in order to avoid unnecessary spills or excessive discharge rates. However, a large value of $\frac{\text{Max. inflow}}{\text{MMR}}$, in conjunction with a moderate value of $\left[\frac{\sigma_i}{M_i}\right]_{\max}$, indicates large but predictable seasonal variations in flow. For Category I and II reservoirs, Section H.2 provides details on the monthly streamflow patterns on which these parameters are based.

The mean value of $\frac{\text{Max. inflow}}{\text{MMR}}$ for the 29 reservoirs for which this parameter is available is 3.44, with a σ

(unbiased) of 1.26. A value of $\frac{\text{Max. inflow}}{\text{MMR}}$ of 2.18 or less indicates exceptionally small positive deviations from mean streamflow, and correspondingly small expected benefits from improved streamflow forecasting. A value of 2.18 or less for this parameter is therefore grounds for classification in Category II or III.

H.1.3.2.3 $\frac{\Delta C}{\text{MMR}}$

ΔC = Maximum 30-day increase in reservoir contents in a given 5-year period (WY 1961-65 unless otherwise specified)

MMR = mean annual runoff ÷ 12

This parameter is given in place of $\frac{\text{Max. inflow}}{\text{MMR}}$ in cases where the availability of data dictated this. In general, though a large value of $\frac{\Delta C}{\text{MMR}}$ implies large peak inflows, the converse is not the case. A standing reservoir-management policy of avoiding large fluctuations in reservoir level would result in low values of $\frac{\Delta C}{\text{MMR}}$ whatever the variations in inflow. Hence the significance of small values of $\frac{\Delta C}{\text{MMR}}$ can only be evaluated in conjunction with other information on reservoir operation. For this reason, no threshold values for reservoir classification have been established for this parameter.

H.1.3.3 Tradeoffs Among Reservoir Functions

Other things being equal, improved information is of much greater value to the management of a reservoir system with tradeoffs among competing functions than to that of a single-purpose reservoir or a reservoir whose functions are complementary. The existence of significant tradoffs therefore constitutes one criterion for possible remote-sensing benefits to reservoir management.

With a few exceptions, every major Western reservoir has as its primary function either hydroelectric power generation, flood control, irrigation, or some combination of these. Other functions, such as navigation, water supply, and recreation, tend to be secondary and noncompeting. Among the primary functions, hydroelectric power competes directly with flood control, for reasons explored in this report, whereas irrigation and hydroelectric power are often, though not always, noncompetitive. Since the flood control season largely overlaps the planting season in most Western basins, irrigation and flood control also tend to be noncompetitive functions. For these reasons only reservoirs with both hydroelectric and flood control capability are considered *prima facie* candidates for Category I.

H.1.3.4 Storage Ratio (SR)

The storage ratio is defined as the reservoir storage capacity divided by the mean annual runoff. A reservoir with a storage ratio of .1 thus has a capacity approximately equal to the average runoff in a five-week period. The storage ratio sets limits both on the range of possible reservoir functions and on the options available to reservoir managers. In extreme cases, such as Rocky Reach Dam and reservoir on the Columbia River (SR = .001), the daily flow through the dam exceeds the

reservoir's storage capacity. Dams with storage ratios of this magnitude can serve as hydroelectric generating stations or as diversion dams for irrigation, but have negligible flood control reservation space or storage for irrigation. Significant seasonal displacement of hydroelectric generation from periods of peak inflow to periods of peak demand is impossible for the same reason. The benefits to reservoir management of improved runoff information are correspondingly small. For the purposes of this survey, a storage ratio of .05, which represents the equivalent of a total change of reservoir contents every 18 days, is considered to be the minimum value at which significant remote sensing benefits might be expected.

H.1.3.5 Peak Storage as a Fraction of Reservoir Capacity

$\frac{M(maxima)}{Capacity}$ measures the average maximum fraction of total storage capacity attained in five consecutive water years (1961-65 unless otherwise stated). Its value sometimes exceeds unity because reservoir storage capacities are generally stated in terms of a "normal maximum" level, e.g., to the top of spillway gates. When $\frac{M(maxima)}{Capacity} \leq .8$, there are grounds for holding that either (1) the reservoir's capacity exceeds reservoir-management requirements to such an extent that there are no operative tradeoffs between flood-control objectives and other reservoir functions, or (2) flood control takes a clear priority over all other reservoir-management objectives. These hypotheses may be tested by reference to measures of streamflow variability and hydroelectric capacity, which provide evidence of risks of flooding and of the extent of competing demands on reservoir management, respectively. In the absence of evidence to the contrary from these sources, a value of less than .8 for this variable is taken as evidence that

the reservoir's capacity permits joint maximization of hydropower and flood-control objectives, and hence that one of the *prima facie* conditions for classification in Category I is not satisfied.

H.1.3.6 Summary of Reservoir Parameters

Tables H.1.1, H.1.2 and H.1.3 summarize major U.S. reservoirs in terms of the above parameters.

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Table H.1.1 Reservoirs Meeting Certain Necessary Conditions for the Applicability of Remote Sensing (Category I)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_i}{M_i}\right]_{max}$ (c)	$\frac{\Delta C}{MMR}$ or $\frac{\text{max inflow}}{MMR}$ (d) (e)	Storage Ratio (f)	$\frac{M(\text{maxima})}{\text{Capacity}}$ (g)	Mean Annual Precipitation, Inches	$\frac{W}{S}$ (h)
CALIFORNIA BASINS (Region 11)									
Clair Engle Lake Trinity River Lewiston, Cal.	IHF	2448	409	NA	5.09(d)	2.1	.99	41.48	6.26
Folsom American River Folsom, Cal.	IHF R	1010	702.7	NA	1.45(d)	.4	.97	39.52	5.76
New Exchequer (Lake McClure) Merced River Snelling Cal.	IHF	1026	363	.83	3.37(e)	1.1	NA	20.56	6.37
New Bullards Bar (New Colgate Gen. Sta.) Marysville, Cal.	HF R	930	500	1.48	6.11(e)	.8	NA	39.52	5.76
Oroville Feather River Oroville, Cal.	IHF SR	3485	2858	1.29	3.84(e)	.8	NA	39.52	5.76
Shasta Sacramento River Redding, Cal.	IHF N	4493	1727.8	NA	3.41(d)	.7	.91	39.52	5.76
NORTHERN PACIFIC SLOPE									
Ross Skagit River Newhalem, Wash.	HF R	1405	700	NA	2.23(d)	.5	1.000	90.54	4.44
Mossyrock (Davisson Lake) Cowlitz River Morton, Wash.	HF R	NA	1050	.72	2.27(e)	7.35	NA	63.15	4.26

(a) Region numbers refer to USGS designations (see Fig. H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See section H.1.3.2.1
(d) See section H.1.3.2.3
(e) See section H.1.3.2.2
(f) See section H.1.3.4
(g) See section H.1.3.5
(h) See section H.1.3.1
NA = Not available

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Table H.1.2 Reservoirs Having a Marginal Probability of Significant Benefits From Remote Sensing (Category II)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_i}{M_i}\right]_{max}$ (c)	$\frac{\Delta C}{\Delta M}$ (d) or max inflow / MWR (e)	Storage Ratio (f)	M(maxima) / Capacity (g)	Mean Annual Precipitation, inches	$\frac{W}{S}$ (h)
COLORADO BASIN (Region 4) Blue Mesa Gunnison River Gunnison, Colo	IHF	941	280	.77	4.92(d)	.9	NA	16.9	1.55
CALIFORNIA BASINS (Region 11) Almanor N.F. Feather Oroville, Cal.	IH	1036	355.9	NA	1.60(d)	1.0	.72	39.52	5.76
Monticello (Lake Berryessea) Putah Creek Sacramento, Cal.	IF S	1602	0	NA	7.45(d)	4.7	.90	39.52	5.76
New Don Pedro Tuolumne River LaGrange, Cal.	IH	2030	598.4	.91	2.16(e)	1.1	NA	20.56	6.37
Pine Flat Kings River Fesno, Cal.	IF	1013	0	NA	1.43(d)	.6	.67	20.56	6.37
NORTHERN PACIFIC SLOPE (Region 12) Grand Coulee Columbia River Coulee City, Wash.	IHF	9401	16330	NA	.12(d)	.06	1.001	20.53	2.23
Hungry Horse Flathead River Coram Montana	IHF	3468	843	NA	.41(d)	1.5	1.004	19.04	1.62

(a) Region numbers refer to USGS designations (see Figure H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See Section H.1.3.2.1
(d) See Section H.1.3.2.3
(e) See Section H.1.3.2.2
(f) See Section H.1.3.4
(g) See Section H.1.3.5
(h) See Section H.1.3.1
NA = Not available

Table H.1.2 Reservoirs Having a Marginal Probability of Significant Benefits From Remote Sensing (Category II)/(Continued)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_1}{\bar{x}_1}\right]_{max}$ (c)	$\frac{\Delta S}{MAR}$ (d) or $\frac{\text{min inflow}}{MAR}$ (e)	Storage Ratio (f)	M(maxima) Capacity (g)	Mean Annual Precipitation, Inches	$\frac{W}{S}$ (h)
NORTHERN PACIFIC SLOPE (Region 12) (con't)									
Kerr Flathead River Polson, Montana	IHF R	1791	1100	NA	1.54(d)	.2	1.03	19.04	1.62
Albeni Falls (Pend Oreille Lake) Pend Oreille River Hope, Idaho	HF NR	2462	230	NA	.23(d)	.06	1.04	19.04	1.62
SNAKE RIVER BASIN (Region 13)									
Jackson Lake Snake River Main Stem Moran, Wyo	IF	847	0	NA	3.65(d)	.8	.93	24.38	1.95
American Falls Snake River Main Stem American Falls, Idaho	IF S	1700	0	NA	.76(d)	.3	1.003	24.38	1.95
Lake Owyhee Owyhee River Adrian, Oregon	IF	1122	0	NA	2.98(d)	1.0	.83	9.26	1.89
Brownlee Snake River Cambridge, Idaho	HF R	1427	2235	NA	.58(d)	.12	1.012	16.62	2.34

(a) Region numbers refer to USGS designations (see Figure H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See Section H.1.3.2.1
(d) See Section H.1.3.2.3
(e) See Section H.1.3.2.2
(f) See Section H.1.3.4
(g) See Section H.1.3.5
(h) See Section H.1.3.1
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Table H.1.2 Reservoirs Having a Marginal Probability of Significant Benefits From Remote Sensing (Category II)/(Continued)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_I}{M_i}\right]_{max}$ (c)	$\frac{\Delta C}{MMR}$ (d) or $\frac{\text{max inflow}}{MMR}$ (e)	Storage Ratio (f)	$\frac{M(\text{maxima})}{\text{Capacity}}$ (g)	Mean Annual Precipitation, Inches	$\frac{W}{S}$ (h)
Palisades Snake River Irwin, Idaho	IHF S	1400	610	NA	1.52(d)	.3	.925	24.38	1.95

(a) Region numbers refer to USGS designations (see Figure H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See Section H.1.3.2.1
(d) See Section H.1.3.2.3
(e) See Section H.1.3.2.2
(f) See Section H.1.3.4
(g) See Section H.1.3.5
(h) See Section H.1.3.1
NA = Not available

Table H.1.3 Reservoirs Failing to Meet Certain Necessary Conditions for the Applicability of Remote Sensing (Category III)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_i}{\mu_i}\right]_{max}$ (c)	$\frac{\Delta C}{MMR}$ (d) or $\frac{\max \text{ inflow}}{MMR}$ (e)	Storage Ratio (f)	M(maxima)/Capacity (g)	Mean Annual Precipitation, Inches	W/S (h)
MISSOURI RIVER BASIN (Region 6)									
Bighorn Lake (Yellowtail Dam) Bighorn River Hardin, Montana	IHF	1375	910	.69	3.94(e)	.5	NA	9.66	.57
Boysen Reservoir Wind River Thermopolis, Wyo	IHF	820	81	.68	7.02(e)	.8	.96	9.66	.57
Canyon Ferry Missouri River Townsend, Montana	IHF SR	2051	330	NA	1.42(d)	.6	.96	14.28	.78
Fort Peck Missouri River Fort Peck, Montana	IHF NR	19140	960	NA	3.02(d)	2.0	.71	14.13	.54
Fort Randall (Lake Francis Case) Missouri River Yankton, S.D	IHF NR	5108	1503	NA	.70(d)	.3	.89	16.41	.43
Kingsley (Lake McConaughy) N. Platte River Keystone, Neb.	I*	1948	0	NA	1.74(d)	1.8	.85	13.33	.59

(a) Region numbers refer to USGS designations (see Figure H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See Section H.1.3.2.1
(d) See Section H.1.3.2.3
(e) See Section H.1.3.2.2
(f) See Section H.1.3.4
(g) See Section H.1.3.5
(h) See Section H.1.3.1
NA = Not available

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Table H.1.3 Reservoirs Failing to Meet Certain Necessary Conditions for the Applicability of Remote Sensing (Category III)(Continued)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_i}{M_i}\right]_{max}$ (c)	$\frac{\Delta C}{MMR}$ (d) or $\frac{\text{max inflow}}{MMR}$ (e)	Storage Ratio (f)	M(maxima) / Capacity (g)	Mean Annual Precipitation, Inches	W/S (h)
Oahe Missouri River Pierre, S.D.	IHF NR	22530	2027	.38	1.50(c)	1.4	NA	14.13	.54
Pathfinder (Fremont Canyon Powerplant) N. Platte River Casper, Wyo	IH	1016	232	NA	1.25(d)	1.2	.34	13.33	.59
Garrison (Lake Sakakawea) Missouri River Riverdale, N.D.	IHF NR	23210	1886	NA	.16(d)	1.5	.68	14.13	.54
Seminoe N. Platte River Rawlins, Wyo.	IH	1011	131	NA	3.37(d)	1.1	.61	13.33	.59
Big Bend Missouri River Chamberlain, S.D.	HF R	1725	871	.44	1.40(e)	.1	NA	14.13+	.54+
Tiber Marias River Chester, Montana	IF R	1368	0	NA	2.64(d)	1.2	.67	13.07	.40
COLORADO RIVER BASIN (Region 9) Flaming Gorge Green River Vernal, Utah	IH	3789	600	1.34	5.45(d)	2.3	NA	10.29	1.14

(a) Region numbers refer to USGS designations (see Figure H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See Section H.1.3.2.1
(d) See Section H.1.3.2.3
(e) See Section H.1.3.2.2
(f) See Section H.1.3.4
(g) See Section H.1.3.5
(h) See Section H.1.3.1
NA = Not available

Table H.1.3 Reservoirs Failing to Meet Certain Necessary Conditions for the Applicability of Remote Sensing (Category III)(Continued)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_i}{M_i}\right]_{max}$ (c)	$\frac{\Delta C}{MMR}$ (d) or $\frac{\text{max inflow}}{MMR}$ (e)	Storage Ratio (f)	$\frac{M(\text{maxima})}{\text{Capacity}}$ (g)	Mean Annual Precipitation, Inches	$\frac{W}{S}$ (h)
Glen Canyon Colorado River Page, Ariz	IHF R	27000	3100	.86	2.38(d)	1.6	NA	8.32	1.18
Hoover (Lake Mead) Colorado River Boulder City, Ariz-Nev.	IHF NS	29827	4111	NA	1.05(e)	2.2	.67	8.32	1.18
Davis (Lake Mohave) Colorado River Kingman, Ariz	IH	1818	1178	NA	.26(e)	.2	.99	8.32	1.18
NORTH PACIFIC SLOPE (Region 12)									
Boundary Pend Oreille River Metaline, Wash	H R	94	3575	.31	3.68	.005	NA	19.04	1.62
Cabinet Gorge Clark Fork Clark Fork, Idaho	H	NA	1090	.30 March	4.28(e)	.003	NA	19.04	1.62
Chief Joseph Columbia Bridgeport, Wash	HIF	516	8550	NA	.01(d)	.006	1.004	20.53	2.23

(a) Region numbers refer to USGS designations (see Figure H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See Section H.1.3.2.1
(d) See Section H.1.3.2.3
(e) See Section H.1.3.2.2
(f) See Section H.1.3.4
(g) See Section H.1.3.5
(h) See Section H.1.3.1
NA = Not available

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Table H.1.3 Reservoirs Failing to Meet Certain Necessary Conditions for the Applicability of Remote Sensing (Category III)(Continued)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_i}{M_i}\right]_{max}$ (c)	$\frac{\Delta C}{MMR}$ (d) or $\frac{\text{max inflow}}{MMR}$ (e)	Storage Ratio (f)	M(maxima) / Capacity (g)	Mean Annual Precipitation, Inches	W/S (h)
Noxon Rapids Clark Fork Noxon, Montana	H	496	1776	NA	.125(d)	.03	.999	19.04	1.62
Priest Rapids Columbia River Beverly, Wash	HF	199	5256	.24	3.43(e)	.002	NA	20.53	2.23
Rock Island Columbia River Wenatchee, Wash	H	9	1345	.24	3.76(e)	<.001	NA	20.53	2.23
Rocky Reach Columbia Wenatchee, Wash	H	101	5797	.25	3.76(e)	.001	NA	20.53	2.23
Wanapum Columbia River Beverly, Wash.	HF N	669	5580	.24	3.43(e)	.008	NA	20.53	2.23
Wells Columbia River Chelan, Wash.	H	300	5870	.25	3.76(e)	.003	NA	20.53	2.23
Hells Canyon Snake River Homestead, Ore.	H	170	1973	.67	3.05(e)	.013	NA	16.62	2.34
Ice Harbor Snake River Pasco, Wash.	IH NR	406	2050	.55	3.13(e)	.01	NA	27.6	2.92
Little Goose (Lake Bryan) Snake River Walla Walla, Wash	IH NR	565	2360	.48	3.34(e)	.015	NA	27.6	2.92

(a) Region numbers refer to USGS designations (see Figure H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See Section H.1.3.2.1
(d) See Section H.1.3.2.3
(e) See Section H.1.3.2.2
(f) See Section H.1.3.4
(g) See Section H.1.3.5
(h) See Section H.1.3.1
NA = Not available

Table H.1.3 Reservoirs Failing to Meet Certain Necessary Conditions for the Applicability of Remote Sensing (Category III)(Continued)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_i}{M_i}\right]_{max}$ (c)	$\frac{A_i}{MMR}$ (d) or $\frac{\text{max inflow}}{MMR}$ (e)	Storage Ratio (f)	$\frac{M(\text{maxima})}{\text{Capacity}}$ (g)	Mean Annual Precipitation, Inches	$\frac{w}{s}$ (h)
Lower Monumental Snake River Walla Walla, Wash	IHF N	376	2410	.48	3.34(e)	.01	NA	27.6	2.92
Oxbow Snake River Cambridge, Idaho	H	53	1033	.67	3.05(e)	.004	NA	16.62	2.34
MIDDLE PACIFIC SLOPE (Region 14)									
Bonneville Columbia River Portland, Ore	H N	719	4780	.29	2.99(e)	.005	NA	12.78*	2.05*
The Dalles (Lake Celilo) Columbia River The Dalles, Ore	H NR	333	8080	.29	2.99(e)	.002	NA	12.78	2.05
John Day (Lake Umatilla) Columbia River The Dalles, Ore	IFH NR	2640	10400	.29	2.99(e)	.028	NA	12.78	2.09
McNary Columbia River Umatilla, Ore	IFH NR	1350	6720	.27	2.46(e)	.01	NA	12.78	2.05
Round Butte (Lake Billy Chinook) Deschutes River Madras, Ore	H	535	946	.31	1.89(e)	.17	NA	64.17	3.88

(a) Region numbers refer to USGS designations (see Figure H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See Section H.1.3.2.1
(d) See Section H.1.3.2.3
(e) See Section H.1.3.2.2
(f) See Section H.1.3.4
(g) See Section H.1.3.5
(h) See Section H.1.3.1
NA = Not available

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Table H.1.3 Reservoirs Failing to Meet Certain Necessary Conditions for the Applicability of Remote Sensing (Category III) (Continued)

Reservoir Name and Location (a)	Purposes (b)	Capacity, acre-ft x 1000	Average Annual Generation, MWH x1000	$\left[\frac{\sigma_i}{\bar{H}_i}\right]_{max}$ (c)	$\frac{\Delta C}{MMR}$ (d) or $\frac{\text{max inflow}}{MMR}$ (e)	Storage Ratio (f)	$\frac{M(\text{maxima})}{\text{Capacity}}$ (g)	Mean Annual Precipitation, Inches	$\frac{H}{S}$ (h)
Swift No. 1 Lewis Cougar, Wash.	H	755	642	NA	.12(d)	.4	1.00	63.15	4.26

(a) Region numbers refer to USGS designations (see Figure H.1.1)
(b) I = irrigation; H = hydroelectric; F = flood control; R = recreation; S = nonagricultural water supply; N = navigation
(c) See Section H.1.3.2.1
(d) See Section H.1.3.2.3
(e) See Section H.1.3.2.2
(f) See Section H.1.3.4
(g) See Section H.1.3.5
(h) See Section H.1.3.1
NA = Not available

H.2 Parameters of Category I & II Reservoirs

H.2.1 Introductory Note

This section presents details on stream flow and/or reservoir operations for the 22 American reservoirs which have been classified in Categories I & II. Category I includes those reservoirs which clearly meet each of a half-dozen necessary conditions for remote-sensing applicability described in Section H.1; the members of Category II are marginal cases.

Unless otherwise noted, the information in this section is based on data presented in the following sources:

U.S. Geological Survey, Surface Water Supply in the United States 1961-65, 37 vols., Geological Survey Water-Supply Papers 1901-1937, Washington, 1969-71 (WSP)

U.S. Federal Power Commission, Hydroelectric Power Resources of the United States, Developed and Undeveloped, January 1, 1972, Washington, 1972 (FPC)

International Commission on Large Dams, World Register of Dams, Paris, 1973 (WRD)

Martin, R.O.R., and Hanson, R.L., Reservoirs in the United States, Geological Survey Water Supply Paper 1838, Washington, 1966 (RUS)

U.S. Department of Commerce, Environmental Data Service, Climatic Atlas of the United States, Washington, 1968.

These sources are cited in the text by the abbreviations given above. The citation WSP 1925: 205-207 refers to pages 205-207 of Water Supply Paper 1925, which is volume 25 in the Geological Survey Series cited above. Where data from USGS streamflow gaging stations is included in the text, these are cited by USGS gaging station numbers, e.g., USGS 12-0431.

This appendix also follows the USGS division of the United States into 16 drainage regions; where regions are referred to by number, the USGS regional designation is understood. Figure H.1.1. shows the borders of these regions. When different figures for reservoir capacity or other parameters are given in different texts, data from the WSP series have generally been preferred.

H.2.2.1 General Information

(a) Dam or Reservoir Name: Trinity (Clair Engle Lake)

(b) Region: 11

(c) River basin: Trinity

(d) Location: Lewiston, CA. 40°48' x 122°46'

(e) Purposes: irrigation, hydroelectric, flood control

(f) Drainage area, mi^2: 688

(g) Total storage capacity, acre-ft.: 2,447,700
Effective hydroelectric storage, acre-ft.: 2,135,000

(h) Storage ratio: 2.1

(i) Mean annual runoff, acre-ft.: 1,165,000

(j) Installed hydroelectric capacity, kw: 105,556

(k) Average annual generation, 10^3kwh: 409,000

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 447, RUS 31, FPC 94, WSP 1929: 590-92.

H.2.2.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 41.48

Dam or Reservoir Name: Trinity Region: 11

(b) (1) Mean water content of precipitation, Oct.-March, in.: 35.20

(2) As fraction of annual precipitation.: .85

(c) (1) Mean water content of precipitation, Apr.-July, in.: 5.62

(2) As fraction of annual precipitation.: .14

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 6.26$.

H.2.2.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 2,447,700

(b) 5-year range of reservoir contents (WY1963-1965) (acre-ft.) 1,436,000 - 2,548,000

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1963-1965). 494,200

(2) Date: December, 1964

(d) $\frac{\Delta c \text{ (3-year)}}{\text{Reservoir capacity}} = .2$

(e) $\frac{\Delta c \text{ (3-year)}}{\text{Mean monthly runoff}} = 5.09$

(f) Reservoir exceeded listed capacity in 2 of 3 years (WY1963-1965).

(g) Annual maximum contents (WY1963-65) (acre-ft.)

(1) Mean = 2,418,000

(2) Median = 2,454,000

(3) σ = 153,000

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = .99$

(5) $\frac{\text{Mean of annual maxima} + 1\sigma}{\text{Reservoir capacity}} = 1.05$.

H.2.2.4 Category: I

H.2.3.1 General Information

(a) Dam or Reservoir Name: Folsom Lake

(b) Region: 11

(c) River basin: American

(d) Location: Folsom, CA 38°42' x 121°09'

(e) Purposes: irrigation, hydroelectric, flood control, recreation

(f) Drainage area, mi^2: 1863

(g) Total storage capacity, acre-ft.: 1,010,300

Effective hydroelectric storage, acre-ft.: 920,000

(h) Storage ratio: .4

(i) Mean annual runoff, acre-ft.: 2,500,000

(j) Installed hydroelectric capacity, kw: 186,480

(k) Average annual generation, 10^3kwh: 702,700

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 407, 411; FPC 94; RUS 24; WSP 1931: 525-27.

H.2.3.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 39.52

(b) (1) Mean water content of precipitation, Oct.-March, in.: 33.31

(2) As fraction of annual precipitation.: .84

(c) (1) Mean water content of precipitation, Apr.-July, in.: 5.78

(2) As fraction of annual precipitation.: .15

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 5.76$.

Dam or Reservoir Name: Folsom Lake Region 11

H.2.3.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,010,300

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 338,000 - 1,024,400

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965). 305,800

(2) Date April, 1965

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .30$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 1.45$

(f) Reservoir exceeded listed capacity in 2 of 5 years (WY1961-1965).

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 982,700

(2) Median = 994,000

(3) σ = 40,700

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = .97$

(5) $\frac{\text{Mean of annual maxima} + \sigma}{\text{Reservoir capacity}} = 1.01$.

H.2.3.4 Category: I

H.2.4.1 General Information

(a) Dam or Reservoir Name: New Exchequer (Lake McClure)

(b) Region: 11

(c) River basin: Merced

(d) Location: Snelling, Cal., 37°35' x 120°16'

(e) Purposes: irrigation, hydroelectric, flood control, recreation

(f) Drainage area, mi^2: 1037

Dam or Reservoir Name: New Exchequer Region: 11

(g) Total storage capacity, acre-ft.: 1,026,000
Effective hydroelectric storage, acre-ft.: 820,000

(h) Storage ratio: 1.1

(i) Mean annual runoff, acre-ft.: 950,000

(j) Installed hydroelectric capacity, kw: 80,100

(k) Average annual generation, 10^3kwh: 363,000

(l) Ownership of dam or reservoir: Merced Irrigation District

(m) References: WRD 478, FPC 96, RUS 26, WSP 1930: 370-75. (RUS data refers to the Old Exchequer dam, built on the same site as the New Exchequer.)

H.2.4.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 20.56

(b) (1) Mean water content of precipitation, Oct.-March, in.: 17.64

(2) As fraction of annual precipitation.: .86

(c) (1) Mean water content of precipitation, Apr.-July, in.: 2.77

(2) As fraction of annual precipitation: .13

(d) $\frac{\text{Oct.-March precipitation}}{\text{April-July precipitation}} = 6.37$.

H.2.4.3 Streamflow Measurement

(a) Location of gauge: USGS 11-2695: at Old Exchequer Dam
USGS 11-2700: .65 mile downstream from 11-2695
(See Remarks)

C.3

Dam or Reservoir Name: New Exchequer Region: 11

(b) Mean monthly discharge, acre-ft. (WY1961-64)

(1) October

(aa) Mean = 3600

(bb) σ (unbiased) = 4400

(2) November

(aa) Mean = 13,200

(bb) σ = 15,900

(3) December

(aa) Mean = 13,600

(bb) σ = 5,900

(4) January

(aa) Mean = 20,500

(bb) σ = 15,700

(5) February

(aa) Mean = 92,000

(bb) σ = 58,800

(6) March

(aa) Mean = 48,200

(bb) σ = 23,200

(7) April

(aa) Mean =121,700

(bb) σ = 53,100

(8) May

(aa) Mean =176,000

(bb) σ = 91,300

(9) June

(aa) Mean =133,900

(bb) σ = 71,600

(10) July

(aa) Mean = 33,500

(bb) σ = 28,100

Dam or Reservoir Name: New Exchequer Region: 11

(11) August (See Remarks)

(aa) Mean = 4 [illegible]

(bb) σ = 11,300

(12) September (See Remarks)

(aa) Mean = 0

(bb) σ = 2,200

(c) (1) 4-year maximum monthly discharge, acre-ft.: 266,400

(2) Month of maximum: May, 1963

(d) $\left[\frac{\sigma_i}{M_i}\right]_{max}$ = .83 (July)

(e) $\frac{\text{Maximum monthly discharge}}{\text{Mean monthly runoff (adjusted)}}$ = 3.37.

H.2.4.4 Category: I

H.2.4.5 Remarks: Streamflow readings, which were taken prior to the construction of New Exchequer Dam, represent the arithmetic summation of monthly streamflows below Old Exchequer and net monthly changes in reservoir levels. Records cover 4-year period from October, 1960, to September, 1964, when station 11-2700 was discontinued. Negative apparent flows from September and low mean August flow are evidently the result of small inflows and large evaporation from Lake McClure. (cf. WSP 1930:376)

H.2.5.1 General Information

(a) Dam or Reservoir Name: New Bullards Bar (New Colgate generating station)

(b) Region: 11

(c) River basin: N. Yuba

(d) Location: Marysville, Cal., 39°24'x121°09'

(e) Purposes: Hydroelectric, flood control, recreation

(f) Drainage area, mi^2: 487

(g) Total storage capacity, acre-ft.: 930,000

Effective hydroelectric storage, acre-ft.: 679,000

(h) Storage ratio: .84

(i) Mean annual runoff, acre-ft.: 1,102,000

(j) Installed hydroelectric capacity, kw: 284,400

(k) Average annual generation, 10^3kwh: 500,000

(l) Ownership of dam or reservoir: Yuba County Water Agency

(m) References: WRD 498, FPC 95, WSP 1931: 337-39.

H.2.5.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 39.52

(b) (1) Mean water content of precipitation, Oct.-March, in.: 33.31

(2) As fraction of annual precipitation.: .84

(c) (1) Mean water content of precipitation, Apr.-July, in.: 5.78

(2) As fraction of annual precipitation: .15

(d) $\frac{\text{Oct.-March precipitation}}{\text{April-July precipitation}} = 5.76$.

Dam or Reservoir Name: New Bullards Bar Region: 11

H.2.5.3 Streamflow Measurement

(a) Location of gauge: USGS 11-4135: 2000 ft. downstream from Old Bullards Bar Dam. (See Remarks)

(b) Mean monthly discharge, acre-ft. (WY1961-1965)

(1) October

(aa) Mean = 41,100

(bb) σ (unbiased) = 72,400

(2) November

(aa) Mean = 33,700

(bb) σ = 21,700

(3) December

(aa) Mean = 155,700

(bb) σ = 229,700

(4) January

(aa) Mean = 111,200

(bb) σ = 135,400

(5) February

(aa) Mean = 132,400

(bb) σ = 87,200

(6) March

(aa) Mean = 77,300

(bb) σ = 16,800

(7) April

(aa) Mean = 176,100

(bb) σ = 74,700

(8) May

(aa) Mean = 166,400

(bb) σ = 62,200

(9) June

(aa) Mean = 80,200

(bb) σ = 23,700

(10) July

(aa) Mean = 29,300

(bb) σ = 8,700

(11) August

(aa) Mean = 21,900

(bb) σ = 6,500

(12) September

(aa) Mean = 15,100

(bb) σ = 3,800

(c) (1) 5-year maximum monthly discharge, acre-ft.: 561,200

(2) Month of maximum: Dec., 1964

(d) $\left[\frac{\sigma_i}{M_i}\right]_{max}$ = 1.48 (December)

(e) $\frac{\text{Maximum monthly discharge}}{\text{Mean monthly runoff (adjusted)}}$ = 6.11.

H.2.5.4 Category: I

H.2.5.5 Remarks: Readings taken prior to construction of New Bullards Bar Dam, a short distance downstream from an older dam at the same site. The exceptionally low storage ratio of Old Bullards Bar Dam (.001) implies that reservoir did not significantly distort readings of peak flows.

H.2.6.1. General Information

(a) Dam or Reservoir Name: Oroville (Thermalito and Hyatt generating stations)

(b) Region: 11

(c) River basin: Feather

(d) Location: Oroville, Cal., 39°31' x 121°38'

(e) Purposes: irrigation, hydroelectric, flood control, municipal water supply, recreation

(f) Drainage area, mi^2: 3624

(g) Total storage capacity, acre-ft.: 3,485,000

Effective hydroelectric storage, acre-ft.: 1,977,000

(h) Storage ratio: .8

(i) Mean annual runoff, acre-ft.: 4,500,000

(j) Installed hydroelectric capacity,

kw: { Thermalito: 115,100
Hyatt: 644,250
Combined: 759,350

(k) Average annual generation,

10^3kwh: { Thermalito: 383,000
Hyatt: 2,475,000
Combined: 2,858,000

(l) Ownership of dam or reservoir: State of California

(m) References: WSP 1931:301-303, WRD 498, FPC 95, U.S. Department of the Army, Corps of Engineers, Oroville Dam and Reservoir: Report on Reservoir Regulation for Flood Control.

Dam or Reservoir Name: Oroville Region: 11

H.2.6.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 39.52

(b) (1) Mean water content of precipitation, Oct.-March, in.: 33.31

(2) As fraction of annual precipitation.: .84

(c) (1) Mean water content of precipitation, Apr.-July, in.: 5.78

(2) As fraction of annual precipitation: .15

(d) $\frac{\text{Oct.-March precipitation}}{\text{April-July precipitation}} = 5.76$.

H.2.6.3 Streamflow Measurement

(a) Location of gauge: USGS 11-4070: 4 miles downstream from damsite. (See Remarks)

(b) Mean monthly discharge, acre-ft. (WY 1961-64)

(1) October

(aa) Mean = 259,000

(bb) σ (unbiased) = 335,000

(2) November

(aa) Mean = 182,000

(bb) σ = 84,000

(3) December

(aa) Mean = 266,000

(bb) σ = 147,000

(4) January

(aa) Mean = 203,000

(bb) σ = 108,000

(5) February

(aa) Mean = 508,000

(bb) σ = 355,000

(6) March

(aa) Mean = 294,000

(bb) = 82,000

(7) April

(aa) Mean = 599,000

(bb) = 387,000

(8) May

(aa) Mean = 442,000

(bb) = 213,000

(9) June

(aa) Mean = 221,000

(bb) = 57,000

(10) July

(aa) Mean = 174,000

(bb) σ = 16,000

(11) August

(aa) Mean = 147,000

(bb) σ = 18,000

(12) September

(aa) Mean = 107,000

(bb) σ = 20,000

(c) (1) 4-year maximum monthly discharge, acre-ft.: 1,114,000

(2) Month of maximum: April, 1973

(d) $\left[\frac{\sigma_i}{M_i}\right]_{max}$ = 1.29 (Oct.)

(e) $\frac{\text{Maximum monthly discharge}}{\text{Mean monthly runoff (adjusted)}}$ = 3.84 .

H.2.6.4 Category: I

Dam or Reservoir Name: Oroville Region: 11

H.2.6.5 Remarks: Readings taken prior to dam's construction. Data cover water years 1961-64; WY 1965 omitted because of intermittent disturbances of streamflow arising from construction activities.

H.2.7.1 General Information

(a) Dam or Reservoir Name: Shasta

(b) Region: 11

(c) River basin: Sacramento

(d) Location: Redding, CA 40°43' x 122°25'

(e) Purposes: irrigation, hydroelectric, flood control, navigation

(f) Drainage area, mi^2: 6,421

(g) Total storage capacity, acre-ft.: 4,492,600

Effective hydroelectric storage, acre-ft.: 4,050,000

(h) Storage ratio: .7

(i) Mean annual runoff, acre-ft.: 6,400,000

(j) Installed hydroelectric capacity, kw: 420,310

(k) Average annual generation, 10^3kwh: 1,727,800

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 380, RUS 30, FPC 96, WSP 1931:74-76 .

H.2.7.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 39.52

(b) (1) Mean water content of precipitation, Oct.-March, in.: 33.31

(2) As fraction of annual precipitation.: .84

(c) (1) Mean water content of precipitation, Apr.-July, in.: 5.78

Dam or Reservoir Name: Shasta Region: 11

(2) As fraction of annual precipitation.: .15

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 5.76$.

H.2.7.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 4,492,600

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 2,144,900 - 4,516,100

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965). 904,500

(2) Date: February, 1962

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .20$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 2.41$

(f) Reservoir exceeded listed capacity in 2 of 5 years (WY1961-1965).

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 4,093,000

(2) Median = 4,330,000

(3) σ = 519,000

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = .91$

(5) $\frac{\text{Mean of annual maxima} + \sigma}{\text{Reservoir capacity}} = 1.03$.

H.2.7.4 Category: I

H.2.8.1 General Information

(a) Dam or Reservoir Name: Ross

(b) Region: 12

(c) River basin: Skagit

Dam or Reservoir Name: Ross Region: 12

(d) Location: Newhalem, Wash., 48°44' x 121°04

(e) Purposes: hydroelectric, flood control, recreation

(f) Drainage area, mi^2: 999

(g) Total storage capacity, acre-ft.: 1,405,300

Effective hydroelectric storage, acre-ft.: 1,023,000

(h) Storage ratio: .5

(i) Mean annual runoff, acre-ft.: 2,800,000

(j) Installed hydroelectric capacity, kw: 360,000

(k) Average annual generation, 10^3kwh: 700,000

(l) Ownership of dam or reservoir: City of Seattle

(m) References: WRD 387, FPC 88, RUS 105, WSP 1932:574-76 .

H.2.8.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 90.54

(b) (1) Mean water content of precipitation, Oct.-March, in.: 69.21

(2) As fraction of annual precipitation.: .76

(c) (1) Mean water content of precipitation, Apr.-July, in.: 15.58

(2) As fraction of annual precipitation.: .17

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 4.44$.

H.2.8.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,405,300

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 602,300-1,405,300

Dam or Reservoir Name: Ross Region: 12

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-65): 522,000

(2) Date: June, 1964

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .37$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 2.23$

(f) Reservoir exceeded listed capacity in 5 of 5 years (WY1961-1965)

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 1,405,300

(2) Median = 1,405,300

(3) σ = 0

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = 1.000$.

H.2.8.4 Category: I

H.2.9.1 General Information

(a) Dam or Reservoir Name: Mossyrock (Davisson Lake)

(b) Region: 14

(c) River basin: Cowlitz

(d) Location: Morton, Washington

(e) Purposes: hydroelectric, flood control, recreation

(f) Drainage area, mi^2: 1042

(g) Total storage capacity, acre-ft.: NA

Effective hydroelectric storage, acre-ft.: 1,297,000

(h) Storage ratio: > .35

Dam or Reservoir Name: Mossyrock Region: 14

(i) Mean annual runoff, acre-ft.: 3,700,000

(j) Installed hydroelectric capacity, kw: 300,000

(k) Average annual generation, 10^3kwh: 1,050,000

(l) Ownership of dam or reservoir: Tacoma City Light

(m) References: FPC 89, WRD 497, WSP 1935:651-653 .

H.2.9.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 63.15

(b) (1) Mean water content of precipitation, Oct.-March, in.: 47.84

(2) As fraction of annual precipitation.: .76

(c) (1) Mean water content of precipitation, Apr.-July, in.: 11.23

(2) As fraction of annual precipitation: .18

(d) $\frac{\text{Oct.-March precipitation}}{\text{April-July precipitation}} = 4.26.$

H.2.9.3 Streamflow Measurement

(a) Location of gauge: 14-2335, 4 miles upstream from upstream end of reservoir. Readings taken prior to reservoir's construction.

(b) Mean monthly discharge, acre-ft. (WY1961-1965)

(1) October

(aa) Mean = 117,000

(bb) σ (unbiased) = 31,000

(2) November

(aa) Mean = 303,000

(bb) σ = 137,000

Dam or Reservoir Name: Mossyrock Region: 14

(3) December

(aa) Mean = 390,000

(bb) σ = 149,000

(4) January

(aa) Mean = 376,000

(bb) σ = 120,000

(5) February

(aa) Mean = 304,000

(bb) σ = 218,000

(6) March

(aa) Mean = 235,000

(bb) σ = 218,000

(7) April

(aa) Mean = 357,000

(bb) σ = 69,000

(8) May

(aa) Mean = 419,000

(aa) σ = 65,000

(9) June

(aa) Mean = 442,000

(bb) σ = 171,000

(10) July

(aa) Mean = 236,000

(bb) σ = 104,000

(11) August

(aa) Mean = 123,000

(bb) σ = 35,000

(12) September

(aa) Mean = 82,000

(bb) σ = 18,000

Dam or Reservoir Name: Mossyrock Region: 14

(c) (1) 5-year maximum monthly discharge, acre-ft.: 700,000

(2) Month of maximum: June, 1964

(d) $\left[\frac{\sigma_i}{M_i}\right]_{max}$ = .72 (February)

(e) $\frac{\text{Maximum monthly discharge}}{\text{Mean monthly runoff (adjusted)}}$ = 2.27 .

H.2.9.4 Category: I

H.2.10.1 General Information

(a) Dam or Reservoir Name: Blue Mesa

(b) Region: 9

(c) River basin: Gunnison River

(d) Location: Gunnison, Colo., 38°27' x 107°21'

(e) Purposes: irrigation, hydroelectric, flood control

(f) Drainage area, mi^2: 3543

(g) Total storage capacity, acre-ft.: 941,200

Effective hydroelectric storage, acre-ft.: 743,000

(h) Storage ratio: .9

(i) Mean annual runoff, acre-ft.: 1,000,000

(j) Installed hydroelectric capacity, kw: 60,000

(k) Average annual generation, 10^3kwh: 280,000

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 474, FPC 85, WSP 1924: 321-22, 335-37 .

Dam or Reservoir Name: Blue Mesa Region: 9

H.2.10.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 16.9

(b) (1) Mean water content of precipitation, Oct.-March, in.: 8.33

(2) As fraction of annual precipitation.: .49

(c) (1) Mean water content of precipitation, Apr.-July, in.: 5.39

(2) As fraction of annual precipitation: .31

(d) $\frac{\text{Oct.-March precipitation}}{\text{April-July precipitation}} = 1.55$.

H.2.10.3 Streamflow Measurement

(a) Location of gauge: USGS 9-1280: 20 Miles downstream from site of dam.

(b) Mean monthly inflow acre-ft. (WY1961-1965)

(1) October

(aa) Mean = 41,400

(bb) σ (unbiased) = 8,300

(2) November

(aa) Mean = 33,400

(bb) σ = 6,900

(3) December

(aa) Mean = 25,400

(bb) σ = 4,200

(4) January

(aa) Mean = 23,000

(bb) σ = 4,900

(5) February

(aa) Mean = 22,400

(bb) σ = 4,500

(6) March

(aa) Mean = 33,400

(bb) σ = 11,500

(7) April

(aa) Mean = 113,000

(bb) σ = 69,900

(8) May

(aa) Mean = 258,100

(bb) σ = 93,800

(9) June

(aa) Mean = 269,400

(bb) σ = 146,300

(10) July

(aa) Mean = 160,600

(bb) σ = 123,500

(11) August

(aa) Mean = 91,100

(bb) σ = 30,800

(12) September

(aa) Mean = 63,900

(bb) σ = 21,500

(c) (1) 5-year maximum monthly inflow acre-ft.: 465,540

(2) Month of maximum: June, 1965

(d) $\left[\frac{\sigma_i}{M_i}\right]_{max}$ = .77 (July)

(e) $\frac{\text{Maximum monthly discharge}}{\text{Mean monthly runoff (adjusted)}}$ = 4.92.

H.2.10.4 Category: II

Dam or Reservoir Name: Blue Mesa Region: 9

H.2.10.5 Remarks: Streamflow readings taken prior to construction of dam. Readings given here are uncorrected for inflows between damsite and gauging station, which add approximately 13% to mean annual flow.

H.2.11.1 General Information

(a) Dam or Reservoir Name: Lake Almanor

(b) Region: 11

(c) River basin: North Fork Feather River

(d) Location: Oroville, CA, 40°13' x 121°10'

(e) Purposes: hydroelectric, irrigation

(f) Drainage area, mi^2: 491

(g) Total storage capacity, acre-ft.: 1,036,000
Effective hydroelectric storage, acre-ft.: 33,000

(h) Storage ratio: 1.0

(i) Mean annual runoff, acre-ft.: 1,000,000

(j) Installed hydroelectric capacity, kw: 184,800

(k) Average annual generation, 10^3kwh: 355,900

(l) Ownership of dam or reservoir: Pacific Gas & Electric

(m) References: WRD 341, RUS 25, WSP 1931: 261-263, FPC 95 .

H.2.11.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 39.52

(b) (1) Mean water content of precipitation, Oct.-March, in.: 33.31

(2) As fraction of annual precipitation.: .84

Dam or Reservoir Name: Lake Almanor Region: 11

(c) (1) Mean water content of precipitation, Apr.-July, in.: 5.78

(2) As fraction of annual precipitation.: .15

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 5.76$.

H.2.11.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,036,000

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.)

(c) (1) Maximum 30-day increase in contents Δc) (acre-ft.) (WY1961-1965) 133,600

(2) Date: December, 1964

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .13$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 1.60$

(f) Reservoir exceeded listed capacity in 1 of 5 years (WY1961-1965).

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 745,000

(2) Median = 723,100

(3) σ = 203,000

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = .72$

(5) $\frac{\text{Mean of annual maxima} + \sigma}{\text{Reservoir capacity}} = .89$.

H.2.11.4 Category: II

H.2.12.1 General Information

(a) Dam or Reservoir Name: Monticello (Lake Berryessa)

(b) Region: 11

(c) River basin: Putah Creek

(d) Location: Sacramento CA, 38°31' x 122°06'

(e) Purposes: irrigation, flood control, municipal and industrial water supply

(f) Drainage area, mi^2: 574

(g) Total storage capacity, acre-ft.: 1,602,300

Effective hydroelectric storage, acre-ft.: 0

(h) Storage ratio: 4.7

(i) Mean annual runoff, acre-ft.: 340,900

(j) Installed hydroelectric capacity, kw: 0

(k) Average annual generation, 10^3kwh: 0

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 416, RUS 25, WSP 1931: 591-96 .

H.2.12.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 39:52

(b) (1) Mean water content of precipitation, Oct.-March, in.: 33.31

(2) As fraction of annual precipitation.: .84

(c) (1) Mean water content of precipitation, Apr.-July, in.: 5.78

(2) As fraction of annual precipitation.: .15

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 5.76$.

Dam or Reservoir Name: Monticello Region: 11

H.2.12.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,602,300

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 974,000-1,686,000

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965) 211,700

(2) Date: December, 1964

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .13$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 7.45$

(f) Reservoir exceeded listed capacity in 2 of 5 years (WY1961-1965)

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 1,449,000

(2) Median = 1,561,000

(3) σ = 245,000

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = .90$

(5) $\frac{\text{Mean of annual maxima} + \sigma}{\text{Reservoir capacity}} = 1.06$.

H.2.12.4 Category: II

H.2.13.1 General Information

(a) Dam or Reservoir Name: New Don Pedro

(b) Region: 11

(c) River basin: Tuolumne

(d) Location: La Grange, Cal., 37°43' x 120°24'

(e) Purposes: irrigation and hydroelectric

(f) Drainage area, mi^2: 1530

Dam or Reservoir Name: New Don Pedro Region: 11

(g) Total storage capacity, acre-ft.: 2,030,000
Effective hydroelectric storage, acre-ft.: 1,721,000

(h) Storage ratio: 1.1

(i) Mean annual runoff, acre-ft.: 1,800,000

(j) Installed hydroelectric capacity, kw: 136,515

(k) Average annual generation, 10^3kwh: 598,400

(l) Ownership of dam or reservoir: Turlock and Modesto irrigation districts

(m) References: WRD 516, FPC 96, WSP 1930: 440-45 .

H.2.13.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 20.56

(b) (1) Mean water content of precipitation, Oct.-March, in.: 17.64

(2) As fraction of annual precipitation.: .86

(c) (1) Mean water content of precipitation, Apr.-July, in.: 2.77

(2) As fraction of annual precipitation: .13

(d) $\frac{\text{Oct.-March precipitation}}{\text{April-July precipitation}} = 6.37$.

H.2.13.3 Streamflow Measurement

(a) Location of gauge: USGS 11-2875, at Old Don Pedro Reservoir; USGS 11-2880, .5 mi. downstream from dam. (See Remarks.)

(b) Mean monthly discharge, acre-ft. (WY1961-1965)

(1) October

(aa) Mean = 53,000

(bb) σ = 30,000

Dam or Reservoir Name: New Don Pedro Region: 11

(2) November
- (aa) Mean = 62,000
- (bb) σ = 38,000

(3) December
- (aa) Mean = 107,000
- (bb) σ = 103,000

(4) January
- (aa) Mean = 120,000
- (bb) σ = 109,000

(5) February
- (aa) Mean = 156,000
- (bb) σ = 84,000

(6) March
- (aa) Mean = 115,000
- (bb) σ = 48,000

(7) April
- (aa) Mean = 176,000
- (bb) σ = 87,000

(8) May
- (aa) Mean = 200,000
- (bb) σ = 108,000

(9) June
- (aa) Mean = 212,000
- (bb) σ = 107,000

(10) July
- (aa) Mean = 120,000
- (bb) σ = 46,000

(11) August
- (aa) Mean = 78,000
- (bb) σ = 21,000

Dam or Reservoir Name: New Don Pedro Region: 11

(12) September

(aa) Mean = 60,000

(bb) σ = 29,000

(c) (1) 5-year maximum monthly discharge, acre-ft.: 393,900

(2) Month of maximum: June, 1962

(d) $\left[\frac{\sigma_i}{M_i}\right]_{max}$ = .91 (January)

(e) $\frac{\text{Maximum monthly discharge}}{\text{Mean monthly runoff (adjusted)}}$ = 2.16 .

H.2.13.4 Category: II

H.2.13.5 Remarks: Streamflow data given represent the arithmetic summation of streamflow downstream of reservoir and net monthly change in reservoir contents. No significant diversions between gauging stations.

The relatively low variability of streamflow at this site may be the result of regulation by the numerous reservoirs upstream. A complete evaluation of the possible benefits of remote sensing to this reservoir would have to consider this installation in the context of the system of reservoirs of which it forms a part.

H.2.14.1 General Information

(a) Dam or Reservoir Name: Pine Flat

(b) Region: 11

(c) River basin: Kings

(d) Location: Fresno, CA, 36°50' x 119°19'

Dam or Reservoir Name: Pine Flat Region: 11

(e) Purposes: irrigation, flood control, recreation

(f) Drainage area, mi^2: 1,542

(g) Total storage capacity, acre-ft.: 1,013,400

Effective hydroelectric storage, acre-ft.: 904,000

(h) Storage ratio: .6

(i) Mean annual runoff, acre-ft.: 1,700,000

(j) Installed hydroelectric capacity, kw: 0

(k) Average annual generation, 10^3kwh: 0

(l) Ownership of dam or reservoir: Corps of Engineers

(m) References: WRD 405, FPC 97, RUS 29, WSP 1930:206-208 .

H.2.14.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 20.56

(b) (1) Mean water content of precipitation, Oct.-March, in.: 17.64

(2) As fraction of annual precipitation.: .86

(c) (1) Mean water content of precipitation, Apr.-July, in.: 2.77

(2) As fraction of annual precipitation.: .13

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 6.37$.

H.2.14.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,013,400

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 109,100-942,000

Dam or Reservoir Name: Pine Flat Region: 11

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965) 202,000

(2) Date: May, 1963

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .20$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 1.43$

(f) Reservoir exceeded listed capacity in 0 of 5 years (WY1961-1965).

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 690,000

(2) Median = 694,400

(3) σ = 190,000

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = .68$

(5) $\frac{\text{Mean of annual maxima} + \sigma}{\text{Reservoir capacity}} = .87$.

H.2.14.4 Category: II

H.2.15.1 General Information

(a) Dam or Reservoir Name: Grand Coulee

(b) Region: 12

(c) River basin: Columbia

(d) Location: Coulee City, Wash., 47°57' x 118°59'

(e) Purposes: irrigation, hydroelectric, flood control, navigation

(f) Drainage area, mi^2: 74,700

(g) Total storage capacity, acre-ft.: 9,562,000 (with flashboards)

Effective hydroelectric storage, acre-ft.: 5,232,000

Dam or Reservoir Name: Grand Coulee Region: 12

(h) Storage ratio: .06

(i) Mean annual runoff, acre-ft.: 160,000,000

(j) Installed hydroelectric capacity, kw: 2,100,000

(k) Average annual generation, 10^3kwh: 16,300,000

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 375, FPC 91, RUS 103, WSP 1933:419-421, U.S. Geological Survey, Water Resources Data for Washington, 1973, Part I: Surface Water Records, Tacoma, Wash., 1973, p.209.

H.2.15.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 20.53

(b) (1) Mean water content of precipitation, Oct.-March, in.: 12.88

(2) As fraction of annual precipitation.: .63

(c) (1) Mean water content of precipitation, Apr.-July, in.: 5.77

(2) As fraction of annual precipitation.: .28

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 2.23$.

H.2.15.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 9,562,000

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 6,748,000-9,564,000

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965): 1,612,400

(2) Date: June, 1965

Dam or Reservoir Name: Grand Coulee Region: 12

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .17$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = .12$

(f) Reservoir exceeded listed capacity in 5 of 5 years (WY1961-1965).

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 9,573,000

(2) Median = 9,575,000

(3) σ = 6,900

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = 1.001$

(5) $\frac{\text{Mean of annual maxima} + \sigma}{\text{Reservoir capacity}} = 1.001$.

H.2.15.4 Category: II

H.2.16.1 General Information

(a) Dam or Reservoir Name: Hungry Horse

(b) Region: 12

(c) River basin: Flathead (S. Fork)

(d) Location: Coram, Montana, 48°21' x 114°01'

(e) Purposes: hydroelectric, flood control, irrigation

(f) Drainage area, mi^2: 1654

(g) Total storage capacity, acre-ft.: 3,468,140

Effective hydroelectric storage, acre-ft.: 2,982,000

(h) Storage ratio: 1.5

(i) Mean annual runoff, acre-ft.: 2,300,000

Dam or Reservoir Name: Hungry Horse Region: 12

(j) Installed hydroelectric capacity, kw: 285,000

(k) Average annual generation, 10^3kwh: 843,000

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 400, RUS 62, FPC 80, WSP 1933, 200-202 .

H.2.16.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 19.04

(b) (1) Mean water content of precipitation, Oct.-March, in.: 10.36

(2) As fraction of annual precipitation.: .54

(c) (1) Mean water content of precipitation, Apr.-July, in.: 6.41

(2) As fraction of annual precipitation.: .34

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 1.62$.

H.2.16.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 3,468,140

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.): 1,521,000 - 3,400,000

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY 1961-1965). 1,043,000

(2) Date: June, 1965

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .30$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 5.41$

(f) Reservoir exceeded listed capacity in 5 of 5 years (WY 1961-1965)

Dam or Reservoir Name: Hungry Horse Region: 12

(g) Annual maximum contents (WY 1961-1965) (acre-ft.)

(1) Mean = 3,481,000

(2) Median = 3,482,000

(3) σ = 1,100

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = 1.004$

(5) $\frac{\text{Mean of annual maxima} + 1\ \sigma}{\text{Reservoir capacity}} = 1.004$.

H.2.16.4 Category: II

H.2.17.1 General Information

(a) Dam or Reservoir Name: Kerr (Flathead Lake)

(b) Region: 12

(c) River basin: Flathead

(d) Location: Polson, Montana, 48°04' x 114°14'

(e) Purposes: hydroelectric, flood control, irrigation, recreation

(f) Drainage area, mi^2: 7086

(g) Total storage capacity, acre-ft.: 1,791,000 (usable storage)

Effective hydroelectric storage, acre-ft.: 1,217,000

(h) Storage ratio: .2

(i) Mean annual runoff, acre-ft.: 6,100,000

(j) Installed hydroelectric capacity, kw: 168,000

(k) Average annual generation, 10^3kwh: 1,100,000

(l) Ownership of dam or reservoir: Montana Power Company

(m) References: WRD 420, FPC 80, RUS 62, WSP 1933:216-218 .

Dam or Reservoir Name: Kerr Region: 12

H.2.17.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 19.04

(b) (1) Mean water content of precipitation, Oct.-March, in.: 10.36

(2) As fraction of annual precipitation: .54

(c) (1) Mean water content of precipitation, Apr.-July, in.: 6.41

(2) As fraction of annual precipitation: .34

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 1.62$.

H.2.17.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,791,000 (usable)

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.): 1,952,000

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft) (WY 1961-1965). 785,300

(2) Date: May, 1964

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .44$ (See Remarks)

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 1.54$

(f) Reservoir exceeded listed capacity in 5 of 5 years (WY 1961-1965).

(g) Annual maximum contents (WY 1961-1965) (acre-ft.)

(1) Mean = 1,843,000

(2) Median = 1,819,000

(3) σ = 63,000

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = 1.03$

(5) $\frac{\text{Mean of annual maxima} + 1\sigma}{\text{Reservoir capacity}} = 1.06$.

Dam or Reservoir Name: Kerr Region: 12

H.2.17.4 Category: II

H.2.17.5 Remarks: The value given here for $\frac{\Delta C}{\text{capacity}}$ is not comparable with values given for other reservoirs since "capacity" here refers to usable, rather than total, reservoir contents. The total capacity of this reservoir is listed as "unknown" in WSP 1933.

H.2.18.1 General Information

(a) Dam or Reservoir Name: Albeni Falls (Pend Oreille Lake)

(b) Region: 12

(c) River basin: Pend Oreille

(d) Location: Hope, Idaho, 48°11' x 117°00'

(e) Purposes: hydroelectric, flood control, navigation, recreation

(f) Drainage area, mi^2: 22,900

(g) Total storage capacity, acre-ft.: 1,561,000 (See Remarks)

Effective hydroelectric storage, acre-ft.: 1,153,000

(h) Storage ratio: .06

(i) Mean annual runoff, acre-ft.: 26,000,000

(j) Installed hydroelectric capacity, kw: 42,600

(k) Average annual generation, 10^3kwh: 230,000

(l) Ownership of dam or reservoir: Corps of Engineers

(m) References: WRD 406, FPC 83, RUS 43, WSP 1933: 251-253.

Dam or Reservoir Name: Albeni Falls Region: 12

H.2.18.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 19.04

(b) (1) Mean water content of precipitation, Oct.-March, in.: 10.36

(2) As fraction of annual precipitation.: .54

(c) (1) Mean water content of precipitation, Apr.-July, in.: 6.41

(2) As fraction of annual precipitation.: .34

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 1.62$.

H.2.18.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,561,000

(b) 5-year range of reservoir contents (WY 1961-1965) (acre-ft.) 629,600 - 1,738,000

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY 1961-1965). 508,000

(2) Date: May, 1961

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .33$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = .23$

(f) Reservoir exceeded listed capacity in 5 of 5 years (WY 1961-1965).

(g) Annual maximum contents (WY 1961-1965) (acre-ft.)

(1) Mean = 1,624,000

(2) Median = 1,578,000

(3) σ = 75,000

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = 1.04$

Dam or Reservoir Name: Albeni Falls Region: 12

(5) $\frac{\text{Mean of annual maxima} + {}^{1}\sigma}{\text{Reservoir capacity}} = 1.09.$

H.2.18.4 Category: II

H.2.19.1 General Information

(a) Dam or Reservoir Name: Jackson Lake

(b) Region: 13

(c) River basin: Snake River Main Stem

(d) Location: Moran, Wyoming, 43°51' x 110°35'

(e) Purposes: irrigation and flood control

(f) Drainage area, mi^2: 824

(g) Total storage capacity, acre-ft.: 847,000
Effective hydroelectric storage, acre-ft.: 0

(h) Storage ratio: .8

(i) Mean annual runoff, acre-ft.: 1,100,000

(j) Installed hydroelectric capacity, kw: 0

(k) Average annual generation, 10^3kwh: 0

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 313, RUS 111, WSP 1934:13-15 .

H.2.19.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 24.38

(b) (1) Mean water content of precipitation, Oct.-March, in.: 14.32

(2) As fraction of annual precipitation.: .59

(c) (1) Mean water content of precipitation, Apr.-July, in.: 7.33

(2) As fraction of annual precipitation.: .30

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 1.95$.

H.2.19.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 847,000

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 1,720-859,530

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965). 322,130

(2) Date: June, 1965

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .38$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 3.65$

(f) Reservoir exceeded listed capacity in 4 of 5 years (WY 1961-1965).

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 789,000

(2) Median = 857,000

(3) σ = 147,000

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = .93$

(5) $\frac{\text{Median of annual maxima}}{\text{Reservoir capacity}} = 1.01$.

H.2.19.4 Category: II

H.2.20.1 General Information

(a) Dam or Reservoir Name: American Falls

(b) Region: 13

(c) River basin: Snake River Main Stem

Dam or Reservoir Name: American Falls Region: 13

(d) Location: American Falls, Idaho, 42°47' x 112°53'

(e) Purposes: irrigation, flood control, water supply

(f) Drainage area mi^2: 13,580

(g) Total storage capacity, acre-ft.: 1,700,000

Effective hydroelectric storage, acre-ft.: 0

(h) Storage ratio: .3

(i) Mean annual runoff, acre-ft.: 5,700,000

(j) Installed hydroelectric capacity, kw: 0

(k) Average annual generation, 10^3kwh: 0

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 340, RUS 41, FPC 83, WSP 1934: 136-38 .

H.2.20.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 24.38

(b) (1) Mean water content of precipitation, Oct.-March, in.: 14.32

(2) As fraction of annual precipitation.: .59

(c) (1) Mean water content of precipitation, Apr.-July, in.: 7.33

(2) As fraction of annual precipitation.: .30

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 1.95.$

H.2.20.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,700,000

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 2,000-1,748,000

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965). 362,000

(2) Date: February, 1962

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .21$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = .76$

(f) Reservoir exceeded listed capacity in 4 of 5 years (WY1961-1965).

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 1,705,000

(2) Median = 1,745,000

(3) σ = 73,700

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = 1.003$

(5) $\frac{\text{Mean of annual maxima} + 1^{\sigma}}{\text{Reservoir capacity}} = 1.04$.

H.2.20.4 Category: II

H.2.21.1 General Information

(a) Dam or Reservoir Name: Owyhee

(b) Region: 13

(c) River basin: Owyhee

(d) Location: Adrian, Oregon, 43°39' x 117°15'

(e) Purposes: Irrigation and flood control

(f) Drainage area, mi^2: 11,160

(g) Total storage capacity, acre-ft.: 1,122,000
Effective hydroelectric storage, acre-ft.: 0

(h) Storage ratio: 1.0

Dam or Reservoir Name: Owyhee Region: 13

(i) Mean annual runoff, acre-ft.: 1,100,000

(j) Installed hydroelectric capacity, kw: 0

(k) Average annual generation, 10^3kwh: 0

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WRD 352, RUS 85, WSP 1934:382 .

H.2.21.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 9.26

(b) (1) Mean water content of precipitation, Oct.-March, in.: 5.70

(2) As fraction of annual precipitation.: .61

(c) (1) Mean water content of precipitation, Apr.-July, in.: 3.01

(2) As fraction of annual precipitation.: .32

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 1.89$.

H.2.21.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,122,000

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 437,000 - 1,128,000

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965). 273,000

(2) Date: April, 1964

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .24$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 2.98$

(f) Reservoir exceeded listed capacity in 1 of 5 years (WY1961-1965).

Dam or Reservoir Name: Owyhee Region: 13

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 926,200

(2) Median = 831,000

(3) σ = 164,200

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = .83$

(5) $\frac{\text{Mean of annual maxima} + 1\sigma}{\text{Reservoir capacity}} = .97$.

H.2.21.4 Category: II

H.2.22.1 General Information

(a) Dam or Reservoir Name: Brownlee

(b) Region: 13

(c) River basin: Snake

(d) Location: Cambridge, Idaho, 44°50' x 116°54'

(e) Purposes: hydroelectric, flood control, recreation

(f) Drainage area, mi^2: 72,590

(g) Total storage capacity, acre-ft.: 1,426,700

Effective hydroelectric storage, acre-ft.: 980,000

(h) Storage ratio: .12

(i) Mean annual runoff, acre-ft.: 12,300,000

(j) Installed hydroelectric capacity, kw: 360,400

(k) Average annual generation, 10^3kwh: 2,235,000

(l) Ownership of dam or reservoir: Idaho Power Company

(m) References: WRD 423, RUS 41, FPC 82, WSP 1934: 577-79 .

Dam or Reservoir Name: Brownlee Region: 13

H.2.22.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 16.62

(b) (1) Mean water content of precipitation, Oct.-March, in.: 10.85

(2) As fraction of annual precipitation.: .65

(c) (1) Mean water content of precipitation, Apr.-July, in.: 4.64

(2) As fraction of annual precipitation.: .28

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 2.34$.

H.2.22.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,426,700

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.): 446,300 - 1,453,500

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965). 594,800

(2) Date: June, 1965

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .42$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = .58$

(f) Reservoir exceeded listed capacity in 5 of 5 years (WY1961-1965)

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 1,443,200

(2) Median = 1,440,800

(3) σ = 5,900

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = 1.012$

(5) $\frac{\text{M(maxima)} + 1\sigma}{\text{capacity}} = 1.016$.

Dam or Reservoir Name: Brownlee Region: 13

H.2.22.4 Category: II

H.2.23.1 General Information

(a) Dam or Reservoir Name: Palisades

(b) Region: 13

(c) River basin: Snake

(d) Location: Irwin, Idaho, 43°20' x 111°12'

(e) Purposes: irrigation, hydroelectric, flood control, conservation, municipal water-supply

(f) Drainage area, mi^2: 5208

(g) Total storage capacity, acre-ft.: 1,400,000

Effective hydroelectric storage, acre-ft.: 1,200,000

(h) Storage ratio: .3

(i) Mean annual runoff, acre-ft.: 4,700,000

(j) Installed hydroelectric capacity, kw: 118,750

(k) Average annual generation, 10^3kwh: 610,000

(l) Ownership of dam or reservoir: Bureau of Reclamation

(m) References: WSP 1934:48-50, WRD 416, RUS 43, FPC 83 .

H.2.23.2 Precipitation

(a) Mean annual water content of precipitation in drainage area, in.: 24.38

(b) (1) Mean water content of precipitation, Oct.-March, in.: 14.32

(2) As fraction of annual precipitation.: .59

(c) (1) Mean water content of precipitation, Apr.-July, in.: 7.33

Dam or Reservoir Name: Palisades Region: 13

(2) As fraction of annual precipitation.: .30

(d) $\frac{\text{Oct.-Mar. precipitation}}{\text{Apr.-July precipitation}} = 1.95$.

H.2.23.3 Reservoir Management Parameters

(a) Capacity (acre-ft.): 1,400,000

(b) 5-year range of reservoir contents (WY1961-1965) (acre-ft.) 240,000 - 1,421,000

(c) (1) Maximum 30-day increase in contents (Δc) (acre-ft.) (WY1961-1965). 591,000

(2) Date: June, 1965

(d) $\frac{\Delta c \text{ (5-year)}}{\text{Reservoir capacity}} = .42$

(e) $\frac{\Delta c \text{ (5-year)}}{\text{Mean monthly runoff}} = 1.52$

(f) Reservoir exceeded listed capacity in 3 of 5 years (WY1961-1965).

(g) Annual maximum contents (WY1961-1965) (acre-ft.)

(1) Mean = 1,295,400

(2) Median = 1,405,000

(3) σ = 219,600

(4) $\frac{\text{Mean of annual maxima}}{\text{Reservoir capacity}} = .93$

(5) $\frac{\text{M(maxima)} + 1\sigma}{\text{Capacity}} = 1.08$.

H.2.23.4 Category: II

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APPENDIX I: VARIABLE IDENTIFICATION AND LISTING OF THE OROSIM PROGRAM

OROSIM - Variable and array identification

MAILINE

KK	Incremental value determined by April-July predicted inflow used in computing winter and spring release.
POWRS	Summing variable for yearly spill as of wk. 24.
POWR24	Summing variable for onpeak power as of wk. 24.
POWR25	Summing variable for offpeak power as of wk. 24.
SUMSP	Summing variable for yearly spill as of wk. 43.
QSPILL	Total spill for week j.
PSUM11	Summing variable for total onpeak power.
PSUM22	Summing variable for total offpeak power.
SUMSPT	Summing variable for total spill.
PSUM1	Summing variable for wk. 43 onpeak power.
PSUM2	Summing variable for wk. 43 offpeak power.
AZ	Control variable for WIF in mainline. AZ was set equal to zero for all cases presented in this report.
WIFI-4	With improved information variable. When WIF=1, perfect information, WIF=0.0, present forecasting skill.
PAR	Flood control parameter.
PCP(I,J)	Matrix of weekly precipitation values at the eight index stations.
T1,T2,T3	Hourly values used in time check during iterative spill.
PLIM1-4	Upper bounds on the predicted April-July inflows which influence reservoir constrainment.
TOTIN	Summing variable for yearly inflow as of wk. 43.
TOTIN1	Summing variable for total inflow of the 26 years.
TOTOUT	Summing variable for yearly outflow as of wk. 43.
TOTOT2	Summing variable for total outflow of the 26 years.

PLIM1-4	Constant upper bounds on the predicted April-July inflows which are checked against yearly predicted inflows to determine length of reservoir constrainment about STOMAX.
N	Number of years to simulate.
IRULE	Predefined rule (rule B was used in all runs).
ISTART	Starting year of simulation.
SORV1	Beginning of week storage.
K	Number of weeks to simulate.
IYEAR	Starting year of simulation.
IYREND	Ending year of simulation.
BORV(I,J)	Coef. for volume, elevation and area calculations.
BASORV(1)	Base elevations that determine correct set of Borv coef.
BARQ(I)	Mean weekly inflow (historical).
CORRE(I)	Lag-1 correlation coef. for weekly inflows.
ELORV1	Beginning elevation.
QOUT	Total weekly outflow.
MAT(I)	Input format specification.
QWEEK(I)	Weekly inflow data in hundreds of acre feet.
PBAR(I)	Mean precipitation at index stations.
J	Week number for year (J=1, 52).
MM1	Integer month number.
MON	MM1+1.
PREDIC(I)	Predicted April-July inflow.
SUMOUT	Summing variable for hourly release during iterative spill.
PRECP	Precipitation for particular year.
SNOCST	Predicted April-July inflow as of month N.
NN	Last week number of which reservoir will be constrained by April-July inflow prediction.
STOMAX	Weekly target reservoir volume.
JK	Weighting factor that is a function of the week number and used in computing STOMAX during November, December and January, when J=44, 4 JK=1,12.

C	Weighting factor determined by the time of year used in computing STOMAX .
X	Month number as a real number at week j.
Z	Exponent of natural log used in computing evaporation.
EVAP	Evaporation of reservoir in inches.
PFAC	Pacfactor.
AREA1	Surface area of reservoir.
QIN	Inflow for week j.
QMIN	Minimum outflow for fish flow plus minimum needed for service area power demand.
QRICE	Monthly power demands to service area.
XK1	Weekly precipitation-evaporation.
SORV2	End of week storage.
QBASE	Lagged inflows for base inflow rate at time t.
QVOL	Pos. change between week t inflow and week t-n inflow.
QBRATE	Hourly base inflow rate.
QPEAK	Peak inflow.
STO1	Beginning storage for iterative spill.
TEMPEL	Present elevation for iterative spill.
DT	Two-hour time value.
Q1	Base inflow rate.
QMXGEN	Maximum outflow in acre feet that the Hyatt generators can take per two-hour period.
TIME	Time counter incremented by two-hour periods.
QSPILL	Summing variable for QDUMP.
QDUMP	Summing variable for DRATE and DSPILL.
IHOUR	Same as TIME.
Q2	Base inflow rate plus change in inflow as function of time.
QINFLOW	Inflow per two-hour period.
DRATE	Spill rate.
DSDT	Change in storage per two-hour period.

QOTFLO	Total outflow per two hour outflow.
ANGEL	Average weekly reservoir elevation.
POWFAC	Megawatt hours generated per one acre-foot of release.
PON	Onpeak energy produced at Hyatt power plant in thousands of megawatts.
POFF	Offpeak energy.

NEW VARIABLES APPEARING IN SUBROUTINE RULE

DELT1	As a function of week 39, DELT1 is used during the nonflood control months to first increase the outflow up to and including week 39, then decrease it until storage is brought down to the November 1st requirement.
SUMBAR	Summing variable for mean precipitation.
SUMPOP	Summing variable for precipitation.
JMI	Lagged week number.
SLOPE	Slope of flood control diagram at week t.
S4	Required flood control reservation space.
S3	Maximum allowable storage.
DELSTO	Change in allowable storage for week t.
QMI	One week lagged inflow.
DELTA	Change in target storage for week t.
CC	Variable controlling affect of DELTA as a function of week number.

ORIGINAL PAGE IS
OF POOR QUALITY


```
      IMPLICIT REAL*8 (A-H,O-Z)
      INTEGER UNIT1,UNIT2,UNIT3,UNIT4                                   OSIM0020
      COMMON/LARGE/WHEEK(2600),QIN,QOUT,QM1,PCP(8,52),S3,SORV2,SORV1,
     1 PAN,WIF,QIN2,QIN3,QIN4,WIF2,WIF3,WIF4,
     1 ISTOR(2600),TEMSTO(2600),SIGMAX,PREDIC(4),QBAR(8),BARQ(52),
     1 QUBBE(52),QRICE(12),BQRV(7,4),BASQRV(7),JWEEK(52),N,J,KWEEK,
     1 UNIT1,UNIT2,MAT(20),NS,KK,IYEAR,JM1
C....UNIT1=CARD READER,UNIT2=PRINTER,UNIT3=PUNCH,UNIT4=TAPE         OSIM0370
      UNIT1= 5                                                          OSIM0380
      UNIT2= 6                                                          OSIM0390
      UNIT3= 7                                                          OSIM0400
      UNIT4=61                                                          OSIM0410
      KK=0
      POWRS=0.D0
      POWR24=0.D0
      POWR25=0.D0
      SUMSP=0.0
      QSPIII=0.0
      PSUM11=0.D0                                                       CHNG0001
      PSUM22=0.D0                                                       CHNG0002
      SUMSP1=0.D0                                                       CHNG0003
      PSUM1=0.D0
      PSUM2=0.D0
C        WIF IS THE 'WITH IMPROVED INFORMATION VARIABLE'
C          THE VAR. AZ MERELY CONTROLS THE EFFECT OF WIF IN THE MAINLINER
      AZ=0.D0
      WIF=0.500
      WIF2=0.500
      WIF3=0.500
      WIF4=0.500
C.....SET INITIAL VALUES ON THE FLOOD CONTROL PARAMETER AND 1ST PRECIP  OSIM0420
      PAR=5.75                                                          OSIM0430
      PCP(1,1)=0.                                                       OSIM0440
      T1=36.                                                            OSIM0450
      T2=60.                                                            OSIM0460
      T3=132.                                                           OSIM0470
C.....SET THE UPPER BOUNDS ON THE PREDICTED APRIL-JULY INFLOW VALUES WHICH
C.....INFLUENCE THE LENGTH OF TIME THE RESERVOIR IS CONSTRAINED ABOUT   OSIM0490
C.....THE VARIABLE FLOMAX                                               OSIM0500
      PLIM1=2200.                                                       OSIM0510
      PLIM2=2500.                                                       OSIM0520
      PLIM3=3000.                                                       OSIM0530
      PLIM4=4000.                                                       OSIM0540
      IOTIN=0.D0
      TOTIN1=0.D0
      IOTOUT=0.D0
      TOTOT2=0.D0
      THSUM=0.D0
      IHSUM1=0.D0
      THERM=0.D0
      THERM1=0.D0
C.....SORV1 IS THE INITIAL STARTING STORAGE IN THE RESERVOIR            OSIM0550
      READ(UNIT1,801) N,IRULE,ISTART,SORV1                              OSIM0560
C.....N=NUMBER OF YEARS TO SIMULATE...IFIRST=FIRST YEAR OF SIMULATION   OSIM0570
C.....ISTART-STARTING YEAR OF SIMULATION                                OSIM0580
      N=N*52                                                            OSIM0590
```

```
0043                IYEAR=ISTART                                                    OSIM0600
0044                IYREND=ISTART+N                                                 OSIM0610
0045                DO 10 I=1,7
0046                WRITE(UNIT2,805 ) (BORV(I,J),J=1,4)
0047          10    CONTINUE                                                        OSIM0640
0048                WRITE(UNIT2,805)BASORV                                          OSIM0650
0049          809   FORMAT(13F6.0)                                                  OSIM0660
0050          810   FORMAT(13F6.5)                                                  OSIM0670
              C     WRITE(UNIT2,805)  (BARQ(I),I=1,52)                              OSIM0680
              C     WRITE(UNIT2,805)  (CORSE(I),I=1,52)                             OSIM0690
0051          800   FORMAT(20A4)                                                    OSIM0700
0052          801   FORMAT(I10,F10.0)                                               OSIM0710
0053          803   FORMAT(1H ,12F10.3)                                             OSIM0720
0054          2000  FORMAT(1H,10D12.6)
0055          805   FORMAT(1H,10F12.4)
0056          806   FORMAT(1H ,3E20.6)                                              OSIM0740
0057          807   FORMAT(1H ,13F10.2)                                             OSIM0750
0058          808   FORMAT(1H ,4I10,9F10.2)                                         OSIM0760
0059          811   FORMAT(9X,4F5.0)                                                OSIM0770
0060                ELORV1=ELEVCN(SORV1)                                            OSIM0780
              C     WRITE(UNIT2,806)SORV1,ELORV1                                    OSIM0790
0061                QOUT=0.                                                         OSIM0800
              C.....READ WEEKLY INFLOW DATA FOR PERIOD OF STUDY IN HUNDREDS OF AC-FT. OSIM0810
0062                READ(UNIT1,800)MAT                                              OSIM0820
0063                READ(UNIT1,MAT)  (QWEEK(I),I=1,K)                               OSIM0830
0064                DO 20 I=1,K                                                     OSIM0840
0065                QWEEK(I)=QWEEK(I)*100.                                          OSIM0850
0066          20    CONTINUE                                                        OSIM0860
              C     WRITE(UNIT2,807)  (QWEEK(I),I=1,K)                              OSIM0870
              C     WRITE(UNIT2,807)  (PEAK(I),I=1,8)                               OSIM0880
0067                DO 500 KWEEK=1,K                                                OSIM0890
0068                J=KWEEK-KWEEK/52*52                                             OSIM0900
0069                IF(J.EQ.0)J=52                                                  OSIM0910
0070          905   MM1=J/4.33
0071                IF(MM1.GT.11)MM1=11                                             OSIM1080
0072                MON=MM1+1                                                       OSIM1090
0073                IF(J.NE.2)GO TO 40                                              OSIM1100
              C.....READ WEEKLY PRECIP FOR A YEAR FOR THE 8 INDEX STATIONS ON THE WATERSHED
              C                                                                     OSIM1120
              C                                                                     OSIM1130
              C...INDEX STA. NO.1...OROVILLE RANGER STA.                            OSIM1140
              C...INDEX STA. NO.2...BRUSH CREEK                                     OSIM1150
              C...INDEX STA. NO.3...DE SALBLA                                       OSIM1160
              C...INDEX STA. NO.4...CONCHONVILLE                                    OSIM1170
              C...INDEX STA. NO.5...DOWNIEVILLE                                     OSIM1180
              C...INDEX STA. NO....CANYON                                           OSIM1190
              C...INDEX STA. NO.6...CANYON DAM                                      OSIM1200
              C...INDEX STA. NO.7...QUINCY RANGER STA                               OSIM1210
              C...INDEX STA. NO.8...SISSRAVILLE                                     OSIM1220
0074                IF(IYEAR.LT.1947)GO TO 40                                       OSIM1230
0075                READ(UNIT1,800)MAT                                              OSIM1240
0076                DO 24 I=1,8                                                     OSIM1250
0077                READ(UNIT1,MAT) (PCP(I,JJ),JJ=1,52)                             OSIM1260
0078          24    CONTINUE                                                        OSIM1270
0079                READ(UNIT1,811) (PREDIC(I),I=1,4)                               OSIM1280
              C     WRITE(UNIT2,803)(PREDIC(I),I=1,4)                               OSIM1290
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0080          40    CONTINUE                                                  OSIM1300
0081                SUMOUT=0.                                                 OSIM1310
0082                OSPILL=0.                                                 OSIM1320
0083                PRECP=PCP(1,J)                                            OSIM1330
0084                IF(IYEAR.LT.1947)GO TO 43                                 OSIM1340
0085                GO TO 44                                                  OSIM1350
0086          43    CONTINUE                                                  OSIM1360
                    C.....IF PRECIP VALUES ARE NOT READ IN , THE MEAN PRECIP AT OROVILLE RANGER
                    C.....STATION IS SIMULATED BY A PARABOLA AND A STRAIGHT LINE.          OSIM1380
0087                PRECP=(NON*NON-12.1*NON+36.4)/3.942                       OSIM1390
0088                PRECP=PRECP/4.33                                          OSIM1400
0089                IF(J.LE.6.OR.J.GT.50)PRECP=1.2                            OSIM1410
0090          44    CONTINUE                                                  OSIM1420
                    C....CONSTRAINMENT OF RESERVOIR IS DEPENDENT UPON SNOWMELT PREDICTION   OSIM1430
                    C.....ON FEB.1,MAR.1,APRIL 1,AND MAY 1                    OSIM1440
0091                IF(J.EQ.1)NN=4                                            OSIM1450
0092                IF(J.EQ.5.AND.PREDIC(1).GE.PLIM1)NN=8                     OSIM1460
0093                IF(J.EQ.9.AND.PREDIC(2).GE.PLIM2)NN=13                    OSIM1470
0094                IF(J.EQ.14.AND.PREDIC(3).GE.PLIM3)NN=17                   OSIM1480
0095                IF(J.EQ.18.AND.PREDIC(4).GE.PLIM4)NN=21                   OSIM1490
0096                IF(J.LE.4.AND.J.GT.NN)SNOCST=2000.                        OSIM1500
0097                IF(J.EQ.5)SNOCST=PREDIC(1)                                OSIM1520
0098                IF(J.EQ.9)SNOCST=PREDIC(2)                                OSIM1530
0099                IF(J.EQ.14)SNOCST=PREDIC(3)                               OSIM1540
0100                IF(J.EQ.18)SNOCST=PREDIC(4)                               OSIM1550
                    C.....THE FOLLOWING STATEMENTS ADJUST THE PROGRAM FOR A PARTICULAR RULE OSIM1560
                    C                                                         OSIM1570
                    C                                                         OSIM1580
0101                GO TO (31,32,33),IRULE                                    OSIM1590
0102          32    CONTINUE                                                  OSIM1600
0103                EN= MAX0( 17-J,1)                                         OSIM1610
0104                IF(SNOCST.GT.3200. ) EN= MAX0(21-J,1)                     OSIM1620
0105                IF(SNOCST.GT.4000. ) EN= MAX0(26-J,1)                     OSIM1630
0106                IF(J.GE.44.OR.J.LE.4) GO TO 35                            OSIM1640
0107                IF(J.GE.5.AND.J.LE.8) GO TO 36                            OSIM1650
0108                IF(J.GE.9.AND.J.LE.13) GO TO 37                           OSIM1660
0109                IF(J.GE.14.AND.J.LE.17) GO TO 38                          OSIM1670
0110                IF(J.GE.18.AND.J.LE.24) GO TO 39                          OSIM1680
0111                STOMAX = 3538000.0                                        OSIM1690
0112                GO TO 31                                                  OSIM1700
0113          35    CONTINUE                                                  OSIM1710
0114                JK=IABS( MIN0(44-J,J+8))                                  OSIM1720
              C  PLEASE NOTE THAT IF WIF=0,STOMAX WILL BE IDENTICAL TO COOK ORIGINAL
0115                STOMAX=2470000.D0+WIF*AZ*318000.D0+(1.D0-WIF*AZ)*16769.23D0
                   1 *DFLOAT(JK)                                              CHNG0008
0116                GO TO 41                                                  OSIM1740
0117          36    CONTINUE                                                  OSIM1750
0118                C=5.056                                                   OSIM1760
0119                STOMAX=(C-(DLOG10(DMAX1(SNOCST,1.D0)))**(0.969D0))
                   1 *10000000.D0                                             CHNG0010
0120                GO TO 41                                                  OSIM1780
0121          37    CONTINUE                                                  OSIM1790
0122                C=C+0.0388                                                OSIM1800
0123                STOMAX=(C-(DLOG10(DMAX1(SNOCST,1.D0)))**(0.969D0))
                   1 *10000000.D0                                             CHNG0012
0124                GO TO 41                                                  OSIM1820
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0125          38    CONTINUE                                                  OSIM1830
0126                C=C+0.100                                                 OSIM1840
0127                STOMAX=(C-(DLOG10(DMAX1(SNOCST,1.D0)))**(0.969D0))
                   1 *1000000.D0                                              CHNG0014
0128                GO TO 41                                                  OSIM1860
0129          39    CONTINUE                                                  OSIM1870
0130                C=C+0.090                                                 OSIM1880
0131                STOMAX=(C-(DLOG10(DMAX1(SNOCST,1.D0)))**(0.969D0))
                   1 *1000000.D0
0132          41    CONTINUE                                                  OSIM1900
0133                IF(IYEAR.LT.1947)STOMAX=2788000.                          OSIM1910
0134                GO TO 34                                                  OSIM1920
0135          31    CONTINUE                                                  OSIM1930
0136                STOMAX=S3                                                 OSIM1940
0137                GO TO 34                                                  OSIM1950
0138          33    CONTINUE                                                  OSIM1960
0139                STOMAX=2470000.D0*(1.D0-WIF*AZ)+WIF*AZ*2788000.D0         CHNG0017
0140                NN=0                                                      OSIM1980
0141          34    CONTINUE                                                  OSIM1990
                C.....THE MEAN MONTHLY PAN EVAP IS ASSUMED TO BE A NORMAL DISTRIBUTION  OSIM2000
                C.....WITH A MEAN=6.5 AND STD. DEV=2                          OSIM2010
0142                X=DFLOAT(J)/4.33D0
0143                Z=(X-6.5D0)*.5D0
0144                Z=-.5D0*Z**2
                C.....THE CONSTANT 2.0684 IS THE QUOTIENT OF THE MEAN YEARLY EVAPORATIONOSIM2050
                C.....(62.26 INCHES PER YEAR ) AND THE SQRT(2 PI)* THE STD. DEV. (2)4.33OSIM2060
                C.....62.26/(SQRT(2*PI)*2*4.33)     THE CONSTANT 4.33 CONVERTS EVAP INTO OSIM2070
                C.....INCHE PER WEEK                                          OSIM2080
0145                EVAP=2.0684*DEXP(Z)
                C.....CALC THE PAN COEFF AS LINEARLY INCREASING FROM .6 IN JAN TO .8 IN AUG.
0146                PFAC=DFLOAT(J)*.00697+.6
0147                IF(J.GT.30)PFAC=.8-.00909*(DFLOAT(J)-30)                  OSIM2120
0148                AREA1=AREA05(ELORV1)                                      OSIM2130
0149                QIN=QWEEK(KWEEK)                                          OSIM2140
0150                JWK = KWEEK + 1
0151                KWK = KWEEK + 2
0152                LWK = KWEEK + 3
0153                IF(KWEEK.EQ.52)GO TO 3602
0154                IF(KWEEK.EQ.51)GO TO 3601
0155                IF(KWEEK.EQ.50)LWK=1
0156                GO TO 3700
0157          3601  CONTINUE
0158                LWK=2
0159                KWK=1
0160                GO TO 3700
0161          3602  CONTINUE
0162                LWK=3
0163                KWK=2
0164                JWK=1
0165          3700  CONTINUE
0166                QIN2 =QWEEK (JWK)
0167                QIN3 =QWEEK (KWK)
0168                QIN4 =QWEEK (LWK)
                C.....THE MINIMUM OUTFLOW IN THE FISH FLOW PLUS THE SERVICE AREA DEMAND OSIM2150
0169                QMIN=23600.+QRICE(MON)*230.77                             OSIM2160
                C.....THE CONSTANT 230.77=1000/4.33                           OSIM2170
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0170            XK1=-.033333*(PRECP-EFAC*EVAP)                                  OSIM2180
0171            IF(SORV1.LT.140000.)QMIN=.8*QMIN                                OSIM2190
0172            IF(SORV2.LT.2400000.)QMIN=DMIN1(QMIN,(QIN-XK1*AREA1))           OSIM2200
                C       WRITE(6,2008)
0173        2008  FORMAT(1X,'PREVIOUS TO ENTERING SUBR RULE,THE VALUES OF N,J,K,
                1 KWEEK,PRECP,EVAP,EFAC,AREA1,QIN, ARE:')
                C       WRITE(6,2012,ERR=808)N,J,K,KWEEK,PRECP,EVAP,EFAC,AREA1,QIN  OSIM2210
0174            CALL RULE                                                       OSIM2220
                C....LIMIT OUTFLOW FOR FISH SPAWN FROM OCT TO NOV 15 TO 3000CFS  OSIM2230
                C....LIMIT MINIMUM OUTFLOW TO 1700 CFS                          OSIM2240
0175            IF(J.GT.39.AND.J.LE.46)QOUT=DMIN1(QOUT,41650.00)
0176            QOUT=DMAX1(QOUT,QMIN)                                           OSIM2260
0177            IF(IRULE.EQ.1)STOMAX=SJ                                         OSIM2270
0178            IF(IRULE.EQ.3.AND.J.GT.NN.AND.J.LT.37)STOMAX=SJ                 OSIM2280
0179            STOMAX=DMIN1(STOMAX,SJ)                                         OSIM2290
0180        45  CONTINUE                                                        OSIM2300
0181            SORV2=QWEEK(KWEEK)-XK1*AREA1-QOUT+SORV1
                C
                C
0182            IF(SORV2-SJ)11,12,12                                            OSIM2320
0183        12  CONTINUE                                                        OSIM2330
0184            IF(QOUT.LT.228500.)QOUT=DMIN1(228500.00,QOUT+(SORV2-SJ))
0185            SORV2=QWEEK(KWEEK)-XK1*AREA1-QOUT+SORV1
                C
                C
0186            IF(SORV2.LE.SJ) GO TO 96                                        OSIM2360
0187            IF(K.EQ.IWEEK+1)GO TO 204                                       OSIM2370
0188            IF(KWEEK-2) 203,203,202                                         OSIM2380
0189        202 CONTINUE                                                        OSIM2390
0190            QBASE=DMIN1(QM1,QWEEK(KWEEK-2))                                 OSIM2400
0191            GO TO 205                                                       OSIM2410
0192        203 CONTINUE                                                        OSIM2420
0193            QBASE=QM1                                                       OSIM2430
0194            GO TO 205                                                       OSIM2440
0195        204 CONTINUE
0196            QBASE=QBASE                                                     OSIM2460
0197        205  CONTINUE                                                       OSIM2470
0198            QVOL=DMAX1(QIN-QBASE,0.00)
0199            QBRATE=QBASE/168.                                               OSIM2490
0200            QPEAK=QVOL*.0208333+QBRATE                                      OSIM2500
0201            SIG1=SORV1                                                      OSIM2510
0202            TEMPEL=SLORV2                                                   OSIM2520
0203            DT=2.                                                           OSIM2530
0204            Q1=QBRATE                                                       OSIM2540
0205            QMAGEN=2721.                                                    OSIM2550
0206            TIME=0.                                                         OSIM2560
0207            QSPILL=0.                                                       OSIM2570
0208            QDUMP=0.                                                        OSIM2580
0209            S1=(QPEAK-QBRATE)*.041667                                       OSIM2590
0210            S2=-S1/3.                                                       OSIM2600
0211        200 CONTINUE                                                        OSIM2610
0212            TIME=TIME+DT                                                    OSIM2620
0213            IHOUR=TIME                                                      OSIM2630
0214            IF(TIME.LE.T1.OR.TIME.GE.T3)Q2=QBRATE                           OSIM2640
0215            IF(TIME.GT.T1.AND.TIME.LE.T2)Q2=QBRATE+S1*(TIME-T1)             OSIM2650
0216            IF(TIME.GT.T2.AND.TIME.LT.T3)Q2=QPEAK+S2*(TIME-T2)              OSIM2660
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0217                QINFLO=(Q1+Q2)*.5*DT                                          OSIM2670
0218                IRATE=0.                                                      OSIM2680
0219                IF(STO1 .GT.S3+5000.)DRATE=QINFLO                             OSIM2690
0220                IF(STO1 .GT.S3+3000?.AND.QINFLO.GE.1240.AND.QINFLO.LT. 9920.) OSIM2700
                   $DRATE=DMIN1(QINFLO,4960.D0)
0221                IF(STO1 .GT.S3+3000).AND.QINFLO.GE. 9920.AND.QINFLO.LT.14460.) OSIM2720
                   $DRATE=DMIN1(QINFLO, 8260.D0)
0222                IF(STO1 .GT.S3+5000.AND.QINFLO.GT.14460.)DRATE=DMIN1(QINFLO,  OSIM2740
                   $12400.D0)
0223                DSOF=SORV2-STO1                                               OSIM2760
0224                IF(DSOI.GT.0..AND.DRATE.LT.1650.)QDUMP=QDUMP+DRATE            OSIM2770
0225                IF(DRATE.GE.1650..AND.DRATE.GT.QDUMP)QDUMP=QDUMP+1650.        OSIM2780
0226                IF(DSOI.LE.0..AND.DRATE.LE.QDUMP)QDUMP=QDUMP-825.             OSIM2790
0227                QDUMP=DMAX1(QDUMP,0.D0)
0228                QOUTFLO=QMAGER+QDUMP                                          OSIM2810
0229                SORV2=QINFLO-QOUTFLO+STO1                                     OSIM2820
0230                ELORV2=ELEVOR(SORV2)                                          OSIM2830
0231                IF(ELORV2.LE.901.)GO TO 201                                   OSIM2840
0232                DSPILL=STORCR(ELORV2)-3553405.                                OSIM2850
0233                SORV2=SORV2-DSPILL                                            OSIM2860
0234                ELORV2=901.                                                   OSIM2870
0235                QDUMP=QDUMP+DSPILL                                            OSIM2880
0236          201   CONTINUE                                                      OSIM2890
                C   WRITE(6,2007)
0237          2007  FORMAT(1X,'THE CURRENT VALUES FOR J,IHOUR,TEMPEL,ELORV2,SORV1,
                   1 SORV2,S3,Q1,Q2,QINFLOW,QOUTFLO,QDUMP,QSPILL ARE:')
                C   WRITE( 6,865)J,IHOUR,TEMPEL,ELORV2,SORV1,SORV2,S3,Q1,Q2,QINFLO, OSIM2900
                C  $QOUTFLO,QDUMP,QSPILL                                          OSIM2910
0238          865   FORMAT(1H ,I2,1X,I3,2F9.2,9F9.0)                              OSIM2920
0239                QSPILL=QSPILL+QDUMP                                           OSIM2930
0240                SUMOUT=SUMOUT+QOTFLO                                          OSIM2940
0241                QOUT=SUMOUT                                                   OSIM2950
0242                IWEEK=KWEEK                                                   OSIM2960
0243                IF(TIME.GE.168.)GO TO 96                                      OSIM2970
0244                STO1=SORV2                                                    OSIM2980
0245                TEMPEL=ELORV1                                                 OSIM2990
0246                Q1=Q2                                                         OSIM3000
0247                IF(TIME.LT.168.)GO TO 200                                     OSIM3010
0248                GO TO 96                                                      OSIM3020
0249          11    CONTINUE                                                      OSIM3030
0250                IF(SORV2-STOMAX)15,15,16                                      OSIM3040
0251          16    CONTINUE                                                      OSIM3050
0252                IF(QOUT.GT.228500.)GO TO 17                                   OSIM3060
0253                QOUT=DMIN1(228500.D0,QOUT+SORV2-STOMAX)
0254                QOUT=DMAX1(QOUT,QMIN)                                         OSIM3080
0255                SORV2=QIN-XK1*AREA1+SORV1-QOUT                                OSIM3090
0256                GO TO 94                                                      OSIM3100
0257          17    CONTINUE                                                      OSIM3110
0258                SORV2=DMIN1(S3,SORV2+(QOUT-228500.))                          OSIM3120
0259                QOUT=QIN-XK1*AREA1-SORV2+SORV1                                OSIM3130
0260                GO TO 94                                                      OSIM3140
0261          15    CONTINUE                                                      OSIM3150
0262                QOUT=DMIN1(QOUT,228500.D0)
0263                SORV2=QIN-XK1*AREA1-QOUT+SORV1                                OSIM3170
0264                IF(SORV2.GT.STOMAX)GO TO 45                                   OSIM3180
0265          94    CONTINUE                                                      OSIM3190
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0266                IF(QOUT.GT.228500.)QSPILL=QOUT-228500.                    OSIM3200
0267                IF(SORV2.GT.3553405.)GO TO 95                             OSIM3210
0268                GO TO 96                                                  OSIM3220
0269          95    CONTINUE                                                  OSIM3230
0270                DSPILL=DMAX1(0.00,(SORV2-3553405.00))
0271                QSPILL=QSPILL+DSPILL                                      OSIM3250
0272                SORV2=SORV2-DSPILL                                        OSIM3260
0273          96    CONTINUE                                                  OSIM3270
0274                SUMSP=SUMSP+QSPILL                                        OSIM3280
0275                POWRS=POWRS+QSPILL
0276                ELORV2=ELEVCH(SORV2)                                      OSIM3290
                C.....QOUT1...ONPEAK RELEASE      QOUT2...OFFPEAK RELEASE     OSIM3300
0277                IF(QOUT-114250) 100,100,101                               OSIM3310
0278          100   QOUT1=QOUT                                                OSIM3320
0279                QOUT2=0.                                                  OSIM3330
0280                GO TO 102                                                 OSIM3340
0281          101   QOUT1=114250.                                             OSIM3350
0282                QOUT2=QOUT-114250.                                        OSIM3360
0283                QOUT2=DMIN1(114250.00,QOUT2)
0284          102   CONTINUE                                                  OSIM3380
                C.....CALC AVERAGE WEEKLY RESERVOIR ELEVATION                 OSIM3390
0285                AVGEL=(ELORV1+ELORV2)*.5                                  OSIM3400
                C.....CALC MEGAWATT HOURS PER AC-FT RELEASE                   OSIM3410
0286                POWFAC=-1.256083146+3.443417349E-3*AVGEL-1.523805837E-6*AVGEL**2
                C.....CALC ONPEAK AND OFFPEAK POWER GENERATED                 OSIM3430
0287                PON=POWFAC*QOUT1*.001
0288                POFF=QOUT2*POWFAC*.001
                C
                C.....ACCUMULATE POWER PRODUCED                               OSIM3460
0302                PSUM1=PSUM1+PON                                           OSIM3470
0303                PSUM2=PSUM2+POFF                                          OSIM3480
0304                PSUM=PSUM1+PSUM2                                          OSIM3490
0305                POWR24=POWR24+PON
0306                POWR25=POWR25+POFF
0307                TOTIN=TOTIN+QWEEK(KWEEK)
0308                TOTOUT=TOTOUT+QCUT
0309                INSUM=INSUM+POWTH
0310                INSUM1=INSUM1+ECPTH
0311                IF(KWEEK.EQ.1)GO TO 103                                   OSIM3500
0312                IF(J.NE.44) GO TO 105
0313                IYEAR=IYEAR+1                                             OSIM3520
0314          103   CONTINUE                                                  OSIM3530
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0315            WRITE(UNIT2,855)IYEAR                                          OSIM3540
0316            WRITE(UNIT2,852)                                               OSIM3550
0317      105   CONTINUE                                                       OSIM3560
          C     WRITE(UNIT2,851)J,ELORV1,ELORV2,SORV1,SORV2,PAR,S3,QWEEK(KWEEK),  OSIM3570
          C    $QOUT,QOUT2,QSPILL,PON,POFF,STCMAX                              OSIM3580
0318            IF(J.NE.24) GO TO 6000
0319            WRITE(6,9001)
0320      9001  FORMAT(1X,'THE POWER + SPILL VALUES FOR WK 24 ARE:')
0321            WRITE(UNIT2,853) PCWRS,ECHR24,POWR25
0322      6000  IF(J.NE.43) GO TO 7000
0323            SUMSPT=SUMSPT+SUMSP
0324            PSUM11=PSUM11+PSUM1
0325            PSUM22=PSUM22+PSUM2
0326            TOTIN1=TOTIN1+TOTIN
0327            TOTOT2=TOTOT2+TOTOUT
0328            THSUM=THSUM+THSUM
0329            THSUM1=THSUM1+THSUM1
0330            WRITE(6,9002)
0331      9002  FORMAT(1X,'THE SPILL AND POWER VALUES FOR WK 43 ARE:')
0332            WRITE(UNIT2,853) SUMSP,PSUM1,PSUM2
0333            WRITE(6,9003)
0334      9003  FORMAT(1X,'THE CUMLATIVE VALUES FOR THE SPILL + POWER ARE:')
0335            WRITE(UNIT2,853) SUMSPT,PSUM11,PSUM22
0336            WRITE(6,2999)
0337      2999  FORMAT(1X,'THE QIN AND QOUT VALUES FOR WK 43 ARE:')
0338            WRITE(6,2998) TOTIN,TOTOUT
0339            WRITE(6,2997)
0340      2997  FORMAT(1X,'THE CUMULATIVE VALUES FOR QIN AND QOUT ARE:')
0341            WRITE(6,2998) TOTINT,TOTOT2
0342      2998  FORMAT(1H0,60X,2F16.3)
0343            WRITE(6,7212)
0344      7212  FORMAT(1X,'THE WK 43 VALUES FOR ON AND OFF THERMILITO POWER ARE:')
0345            WRITE(6,2998) THSUM,THSUM1
0346            WRITE(6,7213)
0347      7213  FORMAT(1X,'THE CUMULATIVE THERMILITO POWER VALUES ARE')
0348            WRITE(6,2998) THERM,THERM1
0349            THSUM=0.D0
0350            THSUM1=0.D0
0351            SUMSP=0.D0
0352            PSUM1=0.D0
0353            PSUM2=0.D0
0354            POWR25=0.D0
0355            ECHR24=0.D0
0356            POWR25=0.D0
0357            TOTIN=0.D0
0358            TOTOUT=0.D0
0359      851   FORMAT(1H ,1X,I2,3X,2F9.2,2F9.0,F7.2,9F9.0)                    OSIM3600
0360      853   FORMAT(1H0,60X,3F16.0)
0361      852   FORMAT(1H ,130H WEEK  BEGIN     END     BEGIN     END     FLOOD   AOSIM3620
                $LLOW      WEEKLY    WEEKLY  OFFPEAK   SPILL    ONPEAK  OFFPEAK   STO
                $MAX                ,/2X,130H NO.    ELEV      ELEV   STORAGE  STORAGE  OSIM3640
                $PARAM  STORAGE   INFLOW  OUTFLOW  OUTFLOW   ENERGY  ENERGOSIM3650
                $Y                      )                                      OSIM3660
0362      855   FORMAT(1H1,//,51X,19H********WATER YEAR ,I4,5H ****   )        OSIM3670
0363      7000  TSTOR(KWEEK)=SORV2*.000001
0364            TMSIG(KWEEK)=S3*.000001                                        OSIM3680
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```
                C       IF(K.EQ.K)WRITE(62,860) (ISTOR(I),I=1,K)                OSIN3700
                C       IF(K.EQ.K)WRITE(62,860) (TENSTO(I),I=1,K)               OSIN3710
      0365      860     FORMAT(12F6.3)                                          OSIN3720
                C.....UPDATE RESERVOIR                                          OSIN3730
      0366              SORV1=SORV2
      0367              RLORV1=RLORV2                                           OSIN3750
      0368      500     CONTINUE                                                OSIN3760
      0369              STOP
      0370              END
```

```
0001                SUBROUTINE RULE
0002                IMPLICIT REAL*8 (A-H,O-Z)
              C.....THIS SUBROUTINE WILL CALCULATE THE WEEKLY RELEASE FROM OROVILLE   OSIM3790
0003                INTEGER UNIT1,UNIT2                                             OSIM3800
0004                COMMON/LARGE/QWEEK(2600),QIN,QOUT,QM1,PCP(8,52),SJ,SORV2,SORV1,
                   1 PAR,WIF,QIN2,QIN3,QIN4,WIF2,WIF3,WIF4,
                   1 TSTOR(2600),IEMSTO(2600),S1GMAX,PREDIC(4),PBAR(8),BARQ(52),
                   1 CORRE(52),QRICE(12),BORV(7,4),BASORV(7),JWEEK(52),N,J,KWEEK,
                   1 UNIT1,UNIT2,MAT(20),NN,KK,IYEAR,JM1
0005                DELTI=39-J
0006                DELTI=DABS(DELTI)
0007                IF(J.EQ.39) DELTI=1.0
0008                IF(J.GE.25.AND.J.LT.37)GO TO 44                                 OSIM3880
0009                SUMBAR=0.                                                       OSIM3890
0010                SUMPCP=0.                                                       OSIM3900
0011                JM1=J-1                                                         OSIM3910
0012                IF(JM1.EQ.0)JM1=52                                              OSIM3920
0013                J1 = J +1
0014                J2 = J +2
0015                J3 = J +3
0016                IF(J.EQ.50) J3=1
0017                IF(J.EQ.51)GO TO 4441
0018                IF(J.EQ.52)GO TO 4442
0019                GO TO 4950
0020          4441  CONTINUE
0021                J2 = 1
0022                J3 = 2
0023                GO TO 4950
0024          4442  CONTINUE
0025                J1 = 1
0026                J2 = 2
0027                J3 = 3
0028          4950  CONTINUE
0029                WIF1 = WIF + .CC000000001
0030                WI = WIF1/(WIF1+WIF2+WIF3+WIF4)
0031                IF(IYEAR.LT.1947)CALL NOBAIN(J,54)                              OSIM3930
0032                IF(IYEAR.LT.1947)GO TO 30                                       OSIM3940
0033                IF(KWEEK.EQ.1)GO TO 12                                          OSIM3950
0034                DO 5 I=1,8                                                      OSIM3960
0035                SUMPCP=SUMPCP+PCP(I,JM1)                                        OSIM3970
0036                IF(PCP(I,JM1).EQ.0)GO TO 5                                      OSIM3980
0037                SUMBAR=SUMBAR+PBAR(I)                                           OSIM3990
              C     WRITE(UNIT2,800)PCP(1,JM1),SUMPCP,SUMBAR                        OSIM4000
0038          5     CONTINUE                                                        OSIM4010
0039                IF(SUMBAR)6,6,7                                                 OSIM4020
0040          7     CONTINUE                                                        OSIM4030
0041                PAR=PAR*.8078+(SUMPCP/SUMBAR)*40.32                             OSIM4040
0042                GO TO 12                                                        OSIM4050
0043          6     CONTINUE                                                        OSIM4060
0044                PAR=PAR*.8078                                                   OSIM4070
0045          805   FORMAT(1H ,2I5,10F10.2)                                         OSIM4080
0046          806   FORMAT(1H0,13F10.2)                                             OSIM4090
0047          12    CONTINUE                                                        OSIM4100
0048                PAR=DMIN1(PAR,11.00)
              C.....LOCATE PROPER AREA OF FLOOD CONTROL DIAGRAM                     OSIM4120
0049                IF(J.GE.37.AND.J.LT.41)GO TO 15                                 OSIM4130
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0050            IF(J.GE.41.OR.J.LT.1)GO TO 20                                   OSIM4140
0051            IF(J.GE.13.AND.J.LT.24)GO TO 25                                 OSIM4150
0052      15    CONTINUE                                                        OSIM4160
0053            SLOPE=(100.-(PAR-4.)*12.5)*1000.                                OSIM4170
0054            IF(PAR.LT.4.)SLOPE=(93.75)*1000.                                OSIM4180
0055            IF(PAR.GE.11)SLOPE=187.5*1000.                                  OSIM4190
0056            S4=SLOPE*(DFLOAT(J)-37)
                C.....S4 IS THE REQUIRED VOLUME TO RESERVE FOR FLOOD CONTROL    OSIM4210
0057            GO TO 30                                                        OSIM4220
0058      20    CONTINUE                                                        OSIM4230
0059            S4=375000.+(PAR-3.75)*50000.                                    OSIM4240
0060            IF(PAR.LE.3.75)S4=375000.                                       OSIM4250
0061            IF(PAR.GE.11)S4=750000.                                         OSIM4260
0062            GO TO 30                                                        OSIM4270
0063      25    CONTINUE                                                        OSIM4280
0064            S4=375000.+(PAR-3.75)*50000.-68182.*DFLOAT(J-12)
0065      30    CONTINUE                                                        OSIM4320
0066            S4=AMAX1(0.0,S4)
0067            S3= 3538000-S4                                                  OSIM4340
0068            DELSTO=S3-SORV1                                                 OSIM4350
0069            IF(KWEEK-1) 32,32,31                                            OSIM4360
0070      31    CONTINUE                                                        OSIM4370
0071            QM1=QWEEK(KWEEK-1)                                              OSIM4380
0072      32    CONTINUE                                                        OSIM4390
0073            IF(KWEEK.EQ.1)QM1=26209.                                        OSIM4400
0074            IF(J.EQ.44)KK=0                                                 OSIM4410
                C....THIS LOGIC IS THAT OF RULE B-1 WITH THE RESERVOIR UNCONSTRAINED IN FEB
0075            IF(J.GT.43.OR.J.LE.RR) GO TO 38                                 OSIM4430
0076            GO TO 34                                                        OSIM4440
0077      38    CONTINUE                                                        OSIM4450
0078            CADJ=0.00
0079            DELTA=STOMAX-SORV1                                              OSIM4460
0080            KK=KK+1                                                         OSIM4470
0081            IF(SORV1.GT.S3)GO TO 34                                         OSIM4480
                C     WRITE(6,2005) DELTA,J
0082      2005  FORMAT(1X,'DELTA=',E15.5,' J=',I4)
0083            IF(DELTA)36,36,37                                               OSIM4490
0084      36    CONTINUE                                                        OSIM4500
0085            CC=0.25                                                         OSIM4510
0086            IF(J.GT.26.OR.J.LE.4) CC=1.0                                    OSIM4520
0087            IF(J.GT.4.AND.J.LE. 8) CC=0.5                                   OSIM4530
                C     WHEN WIF=1,QOUT=QIN.   THIS IS CORRECT IN THE "UNCONSTRAINED" CASE
                C  AGAIN IF WIF=0,QOUT WILL THE SAME AS BEFORE
0088            QOUT = WI*(                                                     CHNG
                1       BARQ(J)+WIF*(QIN-BARQ(J))+CORRE(J)*(1.00-WIF
                1 )*(QM1-BARQ(JM1))-DELTA*CC   +CADJ
                2    +(WIF2/WIF1)*(WIF2*QIN2 +  (1.-WIF2)*BARQ(J1))
                3    +(WIF3/WIF1)*(WIF3*QIN3 +  (1.-WIF3)*BARQ(J2))
                4    +(WIF4/WIF1)*(WIF4*QIN4 +  (1.-WIF4)*BARQ(J3)))
                C     WRITE(UNIT2,800)PAR,S4,S3,DELSTO,BARQ(J),CORRE(J),QOUT,QIN,DELTA  OSIM4770
0089            RETURN                                                          OSIM4550
0090      37    CONTINUE                                                        OSIM4560
0091            QOUT = WF*(
                1       BARQ(J)+WIF*(QIN-BARQ(J))+CORRE(J)*(1.00-WIF)*(QM1-BARQ(JM1))  CHNG00027
                1 )-AMIN1(DFLOAT(KK)/13.00,1.00)*DELTA   +CADJ
                2    +(WIF2/WIF1)*(WIF2*QIN2 +  (1.-WIF2)*BARQ(J1))
```

```
                     3   +(WIF3/WIF1)*(WIF3*QIN3 +  (1.-WIF3)*BARQ(J2))
                     4   +(WIF4/WIF1)*(WIF4*QIN4 +  (1.-WIF4)*BARQ(J3)))
               C      WRITE(UNIT2,806)PAR,S4,S3,DELSTO,BARQ(J),CORRE(J),QOUT,QIN,DELTI  OSIM4770
     0092              RETURN                                                            OSIM4590
     0093        34    CONTINUE                                                          OSIM4600
     0094              CADJ = 0.
               C      WRITE(6,2006)  DELSTO,J
     0095        2006  FORMAT(1X,'DELSTO=',F15.5,'J=',I4)
     0096              IF(DELSTO)35,35,40                                                OSIM4610
     0097        35    QOUT = WI*(
                    1      BARQ(J)+WIF*(QIN-BARQ(J))+CORRE(J)*(1.DO-WIF)*(QN1-BARQ(JN1))CHNG0032
                    1 -DELSTO+CADJ
                    2   +(WIF2/WIF1)*(WIF2*QIN2 +  (1.-WIF2)*BARQ(J1))
                    3   +(WIF3/WIF1)*(WIF3*QIN3 +  (1.-WIF3)*BARQ(J2))
                    4   +(WIF4/WIF1)*(WIF4*QIN4 +  (1.-WIF4)*BARQ(J3)))
     0098              GO TO 45                                                          OSIM4630
     0099        40    CONTINUE                                                          OSIM4640
     0100              QOUT = WI*(
                    1      BARQ(J)+WIF*(QIN-BARQ(J))+CORRE(J)*(1.DO-WIF)*(QN1-BARQ(JN1  CHNG0030
                    1 ))-.5*DELSTO+ CADJ
                    2   +(WIF2/WIF1)*(WIF2*QIN2 +  (1.-WIF2)*BARQ(J1))
                    3   +(WIF3/WIF1)*(WIF3*QIN3 +  (1.-WIF3)*BARQ(J2))
                    4   +(WIF4/WIF1)*(WIF4*QIN4 +  (1.-WIF4)*BARQ(J3)))
     0101              GO TO 45                                                          OSIM4660
     0102        44    CONTINUE                                                          OSIM4670
     0103        42    QOUT=QIN+(SORV2-2470000)/DELTI                                    OSIM4680
     0104              PAR=0.                                                            OSIM4690
     0105              S3=3538000.                                                       OSIM4700
     0106        45    CONTINUE                                                          OSIM4710
     0107              IF(J.GE.37.AND.J.LT.43) GO TO 46                                  OSIM4720
               C      WRITE(UNIT2,806)PAR,S4,S3,DELSTO,BARQ(J),CORRE(J),QOUT,QIN,DELTI  OSIM4770
     0108              RETURN                                                            OSIM4730
     0109        46    CONTINUE                                                          OSIM4740
     0110              QOUT=DMAX1((QIN+(SORV2-2470000.)/DELTI),QOUT)                     OSIM4750
     0111              IF(SORV1.LE.S3) QOUT=DMIN1(QOUT,228500.D0)
               C      WRITE(UNIT2,806)PAR,S4,S3,DELSTO,BARQ(J),CORRE(J),QOUT,QIN,DELTI  OSIM4770
     0112              RETURN                                                            OSIM47E0
     0113              END                                                               OSIM4790
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      0001            REAL FUNCTION ELEVOR*8(VOL)
      0002            IMPLICIT REAL*8(A-H,O-Z)
      0003            INTEGER UNIT1,UNIT2
                     C.....THIS FUNCTION CALCULATES THE ELEVATION OF THE RESERVOIR WHEN VOLUME
                     C.....IS GIVEN AS THE ARGUMENT                                          OSIM4820
      0004            COMMON/LARGE/QWEEK(2600),LIN,COUT,QM1,PC2(8,52),S3,SORV2,SORV1,
                     1 BAR,WIF,WIN2,WIN3,WIN4,WIF2,WIF3,WIF4,
                     1 ISTOR(2600),TEMSTO(2600),STORAX,PREDIC(4),PBAR(8),BARQ(52),
                     1 CURRE(52),WRICE(12),BORV(7,4),BASORV(7),JWEEK(52),N,J,KWEEK,
                     1 UNIT1,UNIT2,MA1(20),NN,KK,IYEAR,JM1
                     C.....FIND PROPER SET OF COEFFICIENTS                                   OSIM4850
      0005            IF (VOL-BORV(4,1)) 5,5,40                                            OSIM4860
      0006        5   CONTINUE                                                             OSIM4870
      0007            IF(VOL-BORV(2,1)) 10,15,15                                           OSIM4880
      0008        10  I= 1                                                                 OSIM4890
      0009            GO TO 70                                                             OSIM4900
      0010        15  IF (VOL -BORV(3,1) ) 20,25,25                                       OSIM4910
      0011        20  I= 2                                                                 OSIM4920
      0012            GO TO 70                                                             OSIM4930
      0013        25  I= 3                                                                 OSIM4940
      0014            GO TO 70                                                             OSIM4950
      0015        40  CONTINUE                                                             OSIM4960
      0016            IF(VOL-BORV(5,1))45,50,50                                            OSIM4970
      0017        45  I=4                                                                  OSIM4980
      0018            GO TO 70                                                             OSIM4990
      0019        50  IF(VOL-BORV(6,1))55,60,60                                            OSIM5000
      0020        55  I=5                                                                  OSIM5010
      0021            GO TO 70                                                             OSIM5020
      0022        60  IF(VOL-BORV(7,1))65,75,75                                            OSIM5030
      0023        65  I=6                                                                  OSIM5040
      0024            GO TO 70                                                             OSIM5050
      0025        75  I= 7                                                                 OSIM5060
      0026        70  CONTINUE                                                             OSIM5070
      0027            K=0                                                                  OSIM5080
      0028        801 FORMAT(10I10)                                                        OSIM5090
      0029            EL= BASORV(I) +30.                                                   OSIM5100
      0030        80  DELTA=(STORAR(EL)-VOL)/AREAOF(EL)                                    OSIM5110
      0031            IF(K.GE.20.OR.DABS(DELTA).LE..09) GO TO 90
      0032            EL=EL-DELTA                                                          OSIM5130
                     C   WRITE(6 ,800) K,EL,VOL,DELTA                                     OSIM5140
      0033        800 FORMAT(1H ,I5,F12.2,F12.0,F12.6)                                     OSIM5150
      0034            K=K+1                                                                OSIM5160
      0035            GO TO 80                                                             OSIM5170
      0036        90  CONTINUE                                                             OSIM5180
      0037            ELEVOR=DMAX1(290.00,EL)
      0038            RETURN                                                               OSIM5200
      0039            END                                                                  OSIM5210
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FORTRAN IV G LEVEL 21          STORSR          DATE = 75167          22/33/42          PAGE 0001

0001                 REAL FUNCTION STORSR*8(EL)
0002                 IMPLICIT REAL*8 (A-H,O-Z)
0003                 INTEGER UNIT1,UNIT2
                   C.....THIS FUNCTION CALCULATES THE STORAGE IN THE RESERVOIR WHEN ELEVATION IS
                   C.....THE GIVEN ARGUMENT                                          OSIM5240
0004                 COMMON/LARGE/QWEEK(2600),QIN,QOUT,QM1,PCP(8,52),S3,SORV2,SORV1,
                    1 PAR,WIF,QIN2,QIN3,QIN4,WIF2,WIF3,WIF4,
                    1 TSTOR(2600),ITEMS10(2600),STORAX,PREDIC(4),PHAR(8),BARQ(52),
                    1 CORRE(52),QRICE(12),BORV(7,4),BASORV(7),JWEEK(52),N,J,KWEEK,
                    1 UNIT1,UNIT2,MAT(20),MM,KK,IYEAR,JM1
0005                 I=IFIX(SNGL(EL-290.D0) /100)+1
0006                 IF (EL.GE.690.) I=7                                           OSIM5280
0007                 IF(EL.LE.290.) I=1                                            OSIM5290
0008           800   FORMAT(10I10)                                                 OSIM5300
0009                 Y= EL-BASORV(I)                                               OSIM5310
0010                 STORSR=BORV(I,1)+BORV(I,2)*Y+BORV(I,3)*Y*Y      +             OSIM5320
                    $BORV(I,4)*Y*Y*Y                                               OSIM5330
0011                 STORSR=DMAX1(0.D0,STORSR)
0012                 RETURN                                                        OSIM5350
0013                 END                                                           OSIM5360
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FORTRAN IV G LEVEL 21                AREAOR          DATE = 75167        22/33/42          PAGE 0001

0001                  REAL FUNCTION AREAOR*8(EL)
0002                  IMPLICIT REAL*8 (A-H,O-Z)
0003                  INTEGER UNIT1,UNIT2
                C.....THIS FUNCTION CALCULATES THE AREA OF THE RESERVOIR WHEN AN ELEVATION
                C.....IS GIVEN AS THE ARGUMENT                                          OSIM5390
0004                  COMMON/LARGE/QWEEK(2600),QIN,QCUT,QM1,PCP(8,52),S3,SORV2,SORV1,
                     1 PAR,WIF,QIN2,QIN3,QIN4,WIF2,WIF3,WIF4,
                     1 TS10R(2900),TRNSTO(2600),SIGMAX,PREDIC(4),PBAR(8),BARQ(52),
                     1 CORRE(52),QRICE(12),BORV(7,4),BASORV(7),QWEEK(52),N,J,KWEEK,
                     1 UNIT1,UNIT2,MAT(20),NR,KK,ITEAR,JM1
0005                  I=IFIX(SNGL(EL-290.00) /100)+1
0006                  IF(EL.GE.890.)I=7                                                 OSIM5430
0007                  IF(EL.LE.290.)I=1                                                 OSIM5440
0008                  Y= EL-BASORV(I)                                                   OSIM5450
0009                  AREAOR=BORV(I,2)+BORV(I,3)*Y*2.+3.*BORV(I,4)                      OSIM5460
                     &*Y*Y                                                            OSIM5470
0010                  RETURN                                                            OSIM5480
0011                  END                                                               OSIM5490
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FORTRAN IV G LEVEL  21                NORAIN          DATE = 75167        22/33/42            PAGE 0001

0001                  SUBROUTINE NORAIN(J,S4)                                          OSIN5500
0002                  IMPLICIT REAL*8(A-H,O-Z)
0003                  INTEGER UNIT1,UNIT2
                C.....THIS SUBROUTINE IS ONLY USED WHEN PRECIPITATION FOR THE INDEX    OSIN5510
                C.....STATIONS IS NOT AVAILABLE                                       OSIN5520
0004                  DIMENSION QFC(12)                                                OSIN5530
0005                  QSAVE=750.                                                       OSIN5540
0006                  IF(J.NE.1)GO TO 10                                               OSIN5550
0007                  READ(5,900)(QFC(I),I=1,12)                                       OSIN5560
0008            10    CONTINUE                                                         OSIN5570
0009                  IF(J.EQ.52) QSAVE=QFC(12)                                        OSIN5580
0010                  MM1=J/4.33                                                       OSIN5590
0011                  IF(MM1.GT.11) MM1=11                                             OSIN5600
0012                  MONTH=MM1+1                                                      OSIN5610
0013                  IF(MM1.EQ.0) MM1=12                                              OSIN5620
0014                  B=QFC(MM1)                                                       OSIN5630
0015                  IF(MONTH.EQ.1) B=QSAVE                                           OSIN5640
0016                  S4=B+(QFC(MONTH)-B)*(FLOAT(J)/4.33-(MONTH-1))                    OSIN5650
0017                  S4=S4*1000.                                                      OSIN5660
0018            900   FORMAT(12F6.1)                                                   OSIN5670
0019            901   FORMAT(1H ,12F10.1)                                              OSIN5680
0020            902   FORMAT(1H ,13F10.1)                                              OSIN5690
0021                  RETURN                                                           OSIN5700
0022                  END                                                              OSIN5710
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0001            BLOCK DATA
0002            IMPLICIT REAL*8 (A-H,O-Z)
0003            INTEGER UNIT1,UNIT2
0004            COMMON/LARGE/QWEEK(2600),QIN,QOUT,QM1,PCB(8,52),SJ,SORV2,SORV1,
               1 PAR,WIF,QIN2,QIN3,QIN4,WIF2,WIF3,WIF4,
               1 TJTOR(2600),IENSTO(2600),STOMAX,PREDIC(4),PBAR(8),BARQ(52),
               1 CORRE(52),CRICE(12),SORV(7,4),BASORV(7),JWEEK(52),N,J,KWEEK,
               1 UNIT1,UNIT2,MAT(20),NB,KK,IYEAR,JM1
0005            REAL*8 PBAR/ 0.29500E 02, 0.69900E 02, 0.63400E 02, 0.62300E 02,
               $ 0.45200E 02, 0.37500E 02, 0.39400E 02, 0.27800E 02 /
0006            REAL*8  BARQ/ 0.79845E 05, 0.77204E 05, 0.10486E 06, 0.10925E 06,
               $0.11719E 06,     0.13292E 06,     0.12133E 06,     0.12976E 06,
               $0.13287E 06,     0.11822E 06,     0.12706E 06,     0.15008E 06,
               $0.16735E 06,     0.17013E 06,     0.16831E 06,     0.17442E 06,
               $0.16541E 06,     0.15241E 06,     0.15243E 06,     0.14311E 06,
               $0.12800E 06,     0.11006E 06,     0.93201E 05,     0.76406E 05,
               $0.61710E 05,     0.48919E 05,     0.40796E 05,     0.36072E 05,
               $0.33326E 05,     0.31524E 05,     0.29733E 05,     0.28327E 05,
               $0.27501E 05,     0.26783E 05,     0.26096E 05,     0.26180E 05,
               $0.25818E 05,     0.25678E 05,     0.26269E 05,     0.25037E 05,
               $0.33760E 05,     0.28859E 05,     0.27430E 05,     0.30171E 05,
               $0.33660E 05,     0.45871E 05,     0.50195E 05,     0.44515E 05,
               $0.54934E 05,     0.73672E 05,     0.80549E 05,     0.89506E 05/
0007            REAL*8 CORRE/ 0.66390E 00, 0.70370E 00, 0.73310E 00, 0.76900E 00,
               $0.79490E 00,     0.78120E 00,     0.79010E 00,     0.84190E 00,
               $0.80230E 00,     0.83550E 00,     0.95460E 00,     0.78230E 00,
               $0.87710E 00,     0.84550E 00,     0.94650E 00,     0.95750E 00,
               $0.94600E 00,     0.98750E 00,     0.96690E 00,     0.98070E 00,
               $0.97510E 00,     0.98530E 00,     0.99190E 00,     0.98460E 00,
               $0.99290E 00,     0.99520E 00,     0.99240E 00,     0.99460E 00,
               $0.99380E 00,     0.99660E 00,     0.99710E 00,     0.99740E 00,
               $0.99820E 00,     0.99890E 00,     0.99890E 00,     0.99850E 00,
               $0.99610E 00,     0.99670E 00,     0.98430E 00,     0.98000E 00,
               $0.52490E 00,     0.87220E 00,     0.92470E 00,     0.97420E 00,
               $0.75140E 00,     0.75290E 00,     0.82970E 00,     0.72650E 00,
               $0.73950E 00,     0.53820E 00,     0.35950E 00,     0.87940E 00/
0008            REAL*8 CRICE/ 0.22000E 01, 0.22000E 01, 0.12200E 02, 0.10920E 03,
               $ 0.19880E 03, 0.18360E 03, 0.18640E 03, 0.10840E 03,
               $ 0.86900E 02, 0.51200E 02, 0.19200E 02, 0.10200E 02/
0009            REAL*8 SORV/8769.00,70256.00,244631.00,593210.00,
               1 1179913.00,2080969.00,3382036.00,266.2526500,1037.0229400,
               1 2529.9865000,4551.5111E0,7322.1810D0,10864.9810D0,15313.9200D0,
               1 2.5750290,6.3263600,8.8312D0,11.9845D0,15.1790D0,19.7300D0,
               1 23.7680D0,.0091700,.0074950,.0111D0,.0117D0,.0170D0,.0156D0,.0630D0/
0010            REAL*8 BASORV/ 0.29000E 03, 0.39000E 03, 0.49000E 03,
               $ 0.59000E 03, 0.69000E 03, 0.79000E 03, 0.89000E 03/
0011            END
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