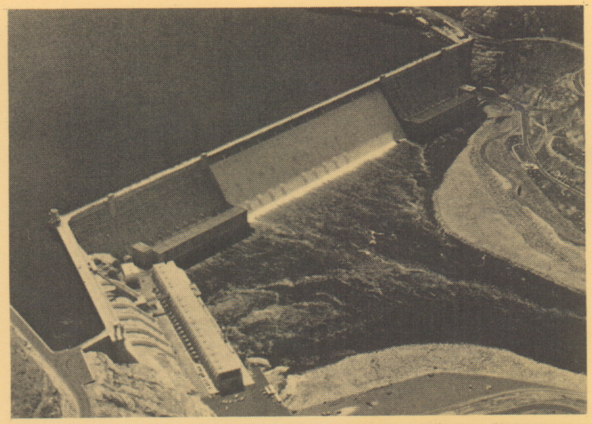
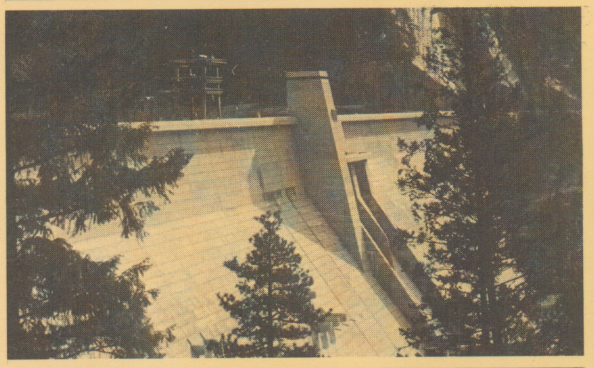
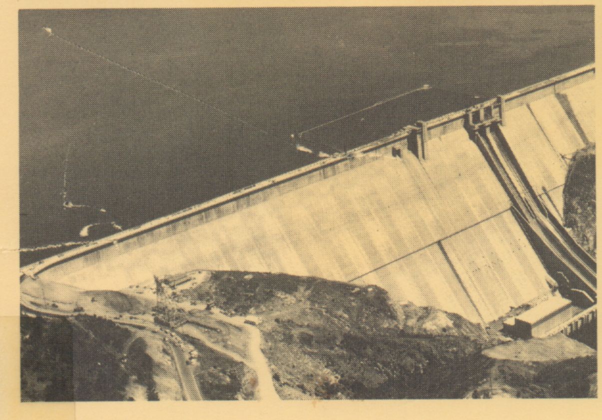
US Army Corps
of Engineers
North Pacific Division

Review of Flood Control
Columbia River Basin

Columbia River and Tributaries Study, CRT-63







Final Report

June 1991

COLUMBIA RIVER AND TRIBUTARIES
REVIEW STUDY

CRT 63

REVIEW OF FLOOD CONTROL
COLUMBIA RIVER BASIN

- FINAL REPORT -

U.S. ARMY CORPS OF ENGINEERS
NORTH PACIFIC DIVISION
JUNE 1991

REVIEW OF FLOOD CONTROL
COLUMBIA RIVER BASIN
FINAL REPORT

Executive Summary

This report documents the findings of a major hydrologic and reservoir system analysis study that has been underway since 1984, and that has been previously documented in two reports, "Preliminary Review of Flood Control, Columbia River Basin", and "Interim Report on Flood Control, Columbia River Basin". The study can be considered as two separate and somewhat independent topics: (1) a review of flood control criteria (rule curves) for major reservoirs; and, (2) an assessment of system flood control capability. The studies and findings of each element are discussed in separate chapters in the document.

Regarding the rule curve analysis, the report proposes revised rule curves for five projects in the Columbia River basin: Libby, Hungry Horse, Grand Coulee, Brownlee, and Dworshak. Analyzed from the standpoint of providing protection against an occurrence of a severe spring rainstorm, the proposed criteria are raised in years having a relatively low runoff forecast; in average to high forecast situations, no change is made in most cases. The proposed curves, considered preliminary in status, will undergo additional study in order to be officially adopted. In the meantime they will be the interim basis for operational guidance in actual operations.

The system flood control capability study has addressed the question of what degree of control the combined reservoir/levee system has in providing flood control along the lower Columbia River. Revised assessments of design flood magnitude in the lower Columbia, reflecting the current reservoir system and current operating policies, are presented. These are compared with the capacity of the levees in 20 drainage districts along the lower Columbia from River Mile 50 to 130. This comparison shows that all "Safe Levee Heights" would be exceeded by an occurrence of the "Levee Design Flood", a conservative design flood used for urban high hazard situations. A 100-year flood would exceed the safe levee height in 11 of the districts. The hydraulic data obtained from the study will be used in additional planning studies for the lower Columbia River.

PREVIEW OF FLOOD CONTROL

COLUMBIA RIVER BASIN

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I. INTRODUCTION

Purpose

This is the final report in a series of three reports dealing with the study of flood control in the Columbia River, primarily as it relates to the operation of the existing system of flood control reservoirs in the basin. The study was initiated in 1985 under the auspices of the North Pacific Division's Columbia River and Tributaries Review Study. The CR&T study is a comprehensive planning overview of the Columbia that is, among other things, evaluating operational policies and procedures in light of current multiple purpose operating objectives. One of the reasons for initiating the study was to address the recommendation contained in the Northwest Power Planning Council's (NPPC's) Fish and Wildlife Program which states:

> "federal project operators and regulators shall study the feasibility of improving fish flows throughout the Columbia River Basin. These studies shall explore: (A) Modification of existing federal project requirements for flood control..." (Section 704(b)(14)).

Evaluating the feasibility of improving river flows for the fishery dovetailed with similar concerns by the North Pacific Division office to investigate any conflicts between flood control criteria and operations for power generation and reservoir refill. Further, some of the flood control operating curves had been in need of modification from the standpoint of flood control operations as well. Thus, there was reason to undertake the study simply from the need to improve in-house operations. A third reason for the study is to evaluate system flood control capability, particularly in the lower Columbia River in the vicinity of Vancouver, Washington. This capability is affected by both the state of the levees in that area, and by the capability of the reservoir system to regulate flooding. To a degree this question relates to the consideration for rule curve modification, since adjustments to reservoir rule curves to benefit other water uses could adversely affect the flood control capability of the system. Actually, as the report will describe, the assessment of flood control capability is virtually independent form the rule curve investigations. The evaluation of flood control capability is pertinent to decisions as to the degree of protection currently existing in the floodplain and to the evaluation of whether levees need to be improved or other remedial measures taken.

This report is an explanation and presentation of results of studies that have been underway since the study's inception, with particular emphasis on the findings that have been made since the last report. That report, "Interim Review of Flood Control, Columbia River Basin", specifically addressed the feasibility of modifying flood control rule curves, and presented, in general terms, the portions of rule curves that appeared to be feasible for modification. The Interim Report was published in November 1985 to respond to the NPPC request in Section 704(b)(14) of the 1984 Fish and Wildlife Program. The first report in the study, "Preliminary Review of Flood Control, Columbia River Basin", gave an overview of flood control, discussed the conflicts between flood control and other operating criteria, discussed the capability of the lower river levee system, and recommended a strategy for future study. This final report is intended to replace both of the first reports in order that it will be a stand-alone document. It therefore contains some of the material that was contained in the previous reports, so that background information and continuity are preserved.

Study Objectives

The objectives of the study were to: (1) analyze the flood control capability of the system, as related to the ability to control floods on the lower Columbia and at other control points, to see if overall flexibility exists to adjust reservoir flood control requirements; (2) investigate flood control criteria at the major headwater storage projects to see if relaxing the criteria is feasible without impacting flood control objectives; (3) propose changes in project flood control criteria where feasible; and, (4) evaluate the resulting flood control capability picture on the lower Columbia and other control points. Objectives (1) and (2) were evaluated at the outset of the study and addressed in the Preliminary Report. The conclusion was that the system did not have excess capability for controlling large floods (in fact, it appeared the many levees in the lower Columbia would be overtopped if a large magnitude flood were to occur), but that flexibility existed for adjusting rule curves in years with lower than normal runoff forecast. Objectives (3) and (4) are discussed in this report.

Scope

The study, and this report, deals with the Columbia River basin, including the Willamette River. Excluded are adjacent basins that are within the boundaries of the North Pacific Division. It is primarily an operational study, dealing with operating rule curves for existing projects that provide significant spring flood control in the Columbia. The question of lower river flood control potential is also addressed since this is affected by the existing reservoir system. Flood control capability at tributary damage centers is given only limited consideration, in the context of examining the flood control rule curves at a nearby upstream project. The rule curve analysis is also limited in that it does not delve into questions of reducing flood protection, reallocating benefits, or shifting flood protection from storage to levees. For instance, it is conceivable that flood control criteria could be reduced substantially, and levees raised a corresponding amount to compensate. Such questions are left to possible future planning analyses. A fundamental premise of the study was that the existing flood control capability, as measured at the lower Columbia and other control points, would remain unchanged after any rule curve modifications were made. In effect, then, any changes would represent a "tightening up" of criteria that had been overly conservative with respect to flood control. The results described herein are to be considered preliminary in nature, although some of the findings will be utilized operationally on an interim basis. After the completion of this report the study will enter its third phase which is an in-house finalization of the rule curves and other operating guidance so that they may be officially adapted as operating criteria. During this phase, it is possible that some of the criteria may be refined and modified somewhat.

II. CURRENT SETTING

Description of System

Since the 1930's, the federal government and public and private utilities have constructed over 100 dams in the Columbia River basin for purposes of providing power generation, flood control, navigation, and irrigation. Those dams and their reservoirs upstream of The Dalles have capitalized on the natural potential of the river and enhanced that potential by storing water during the period of natural high flow (the spring snowmelt period), then releasing it during the season of natural low flow (primarily the November-February winter period). The benefits realized through this operation have significantly exceeded the cost of construction and operation, and have been a major facet in the economy of the Pacific Northwest. On the other hand, it is recognized that the dams and reservoirs have impacted the fishery of the northwest, despite substantial mitigation efforts, including hatchery construction; a significant investment in structural facilities such as fish ladders and by-passes that have been constructed at the dams; and, operational measures such as the barging of smolts and the Water Budget operation.

Of the 100 or so dams in the basin upstream from The Dalles, only 14 projects are considered as being significant system flood control projects. These are listed on Table 2-1 and are shown on the map of the basin, Figure 2-1. The 14 flood control reservoirs represent projects that have: (1) official flood control guidance that requires that storage space be reserved for regulation; and, (2) have enough storage capacity to be effective in reducing downstream flooding during the occurrence of a typical flood in the basin. Excluded from the list are projects that: (1) may provide incidental, yet not assured, flood control; (2) smaller reservoirs on tributaries that do not significantly effect the mainstem rivers; (3) natural lakes, now regulated during low flow periods, that would have otherwise provided natural "flood control" during the high runoff period. Also excluded are the reservoirs in the Willamette River basin and other

COLUMBIA RIVER BASIN

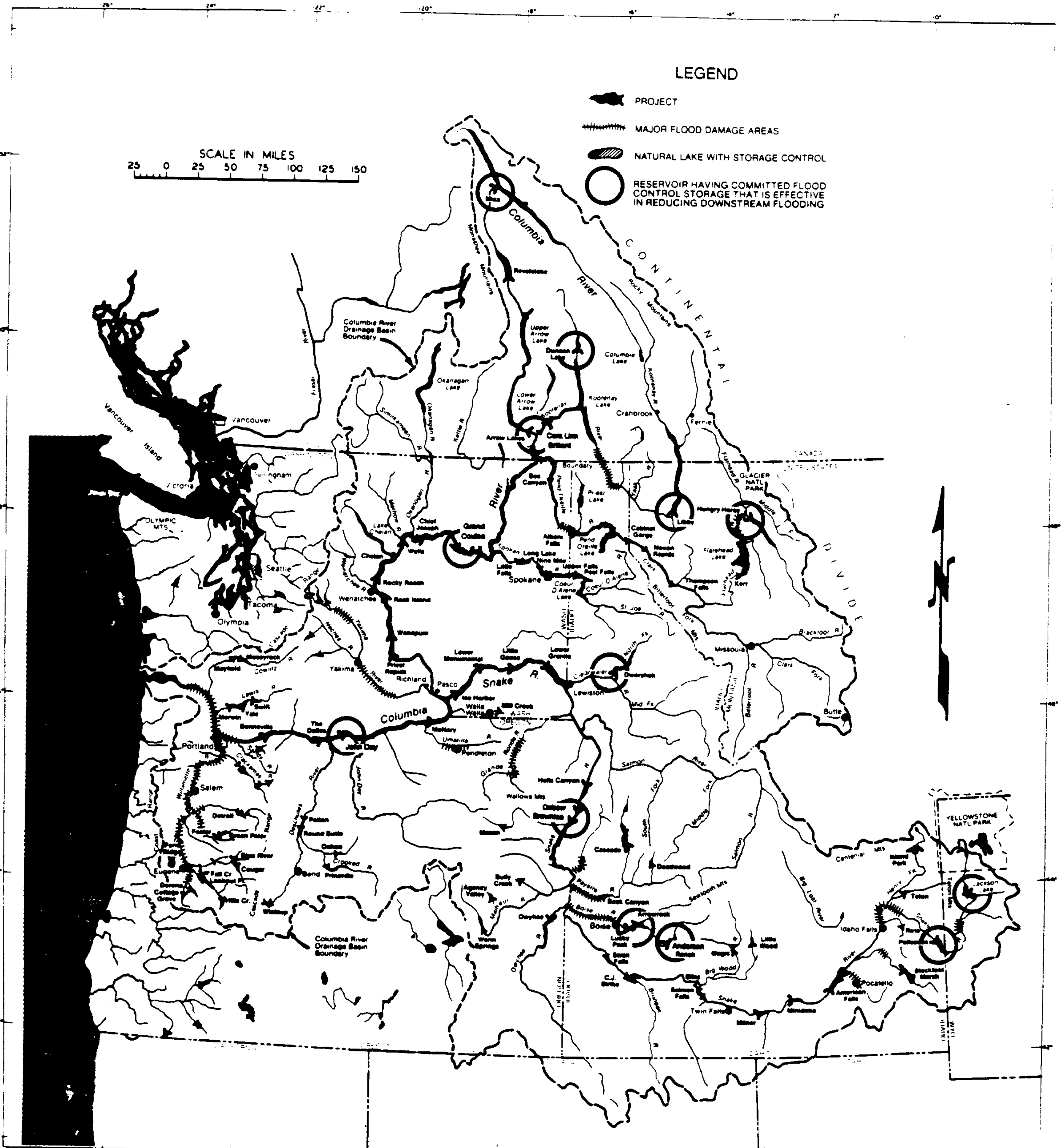

Figure 2-1

Flood Control Reservoirs

lower Columbia tributaries which provide flood control during the winter rain floods, but do not significantly reduce mainstem flows during the occurrence of a typical spring snowmelt flood in the Columbia basin. The total storage capacity of the 14 flood control reservoirs is 39.7 million acre-feet, or 86% of the total storage capacity of the system of 46 million acre-feet. This also represent 41% of the average annual runoff of the river at The Dalles and 30% of the runoff of the major flood of April-August 1974, indicating that complete control of flooding in the basin is impossible with reservoirs alone.

TABLE 2-1

COLUMBIA RIVER BASIN FLOOD CONTROL RESERVOIRS

RESERVOIRS WITH COMMITTED FLOOD CONTROL STORAGE
THAT IS EFFECTIVE IN REDUCING DOWNSTREAM SPRING FLOODING

PROJECT	RIVER	ACTIVE STORAGE, ACRE FEET: TOTAL	ACTIVE STORAGE, ACRE FEET: COMMITTED FOR FLOOD CONTROL	PROJECT OWNER	OPERATING AUTHORITY
Mica	Columbia	12,000,000	12,000,000 1/	B.C. Hydro	a/
Arrow	Columbia	7,145,000	7,145,000 1/	B.C. Hydro	a/
Duncan	Duncan	1,347,000	1,347,000 1/	B.C. Hydro	a/
Libby	Kootenai	4,980,000	4,980,000	COE	b/
Hungry Horse	S Fk Flathead	3,161,000	3,161,000	USBR	c/
Grand Coulee	Columbia	5,185,000	5,185,000	USBR	c/
Jackson Lake	Snake	847,000	1,400,000 2/ (Jackson Lake and Palisades combined)	USBR	c/
Palisades	Snake	1,200,000		USBR	c/
Anderson Ranch	S Fk Boise	423,000	988,000 2/ (Anderson Ranch, Arrowrock and Lucky Peak combined)	USBR	c/
Arrowrock	Boise	286,000		USBR	c/
Lucky Peak	Boise	278,000		COE	b/
Brownlee	Snake	980,000	980,000	Idaho Power Co	d/
Dworshak	N Fk Clearwater	2,016,000	2,016,000	COE	b/
John Day	Columbia	535,000	535,000	COE	b/
	TOTAL STORAGE	40,383,000	39,737,000		

1/ Total of Primary Flood Control and "On-Call" Storage.
2/ Combined requirement for multiple reservoirs.
a/ Columbia River Treaty.
b/ Direct Congressional.
c/ Section 7, 1944 Flood Control Act.
d/ FERC License.

The U.S. Army Corps of Engineers has, through various authorities enacted by Congress, the responsibility for flood control regulation of both Federal and non-federal flood control reservoirs in the United States. In the Columbia River basin this activity is planned and implemented by the Water Management Branch of the North Pacific Division office, in coordination with District offices. The North Pacific Division also serves, along with Bonneville Power Administration, as the United States Entity in the implementation of the Columbia River Treaty, through which the operation of the three Canadian storage projects have been planned and are operated by the U.S. for flood control. The Canadian Entity and owner of these projects is the British Columbia Hydro Authority, based in Vancouver, B.C. Another major federal entity involved in the reservoir operations for flood control is the Bureau of Reclamation, which is responsible for the regulation of several of the reservoirs making up the flood control projects in the basin. The Corps has the responsibility of regulating the Bureau projects through Section 7 of the 1944 Flood Control Act.

Within the Columbia River Basin flood runoff can be the result of spring snowmelt, sometimes augmented by spring rains, or by intense winter rainstorms augmented by snowmelt. The upper Columbia and Snake River basins are the predominate source of runoff during spring-summer flood events while the lower Columbia, lower Snake, and Willamette River basins produce the most significant pattern of winter runoff. The Portland-Vancouver area is subject to potential flooding and accompanying high hazards and economic loss in either season. Major storage projects in the upper Columbia Basin are most effective in controlling the spring-summer flood events while storage projects in the lower Snake and Willamette basin have the major role in controlling winter flood events.

Flood Control Capability

The system of flood control reservoirs is relatively new, having reached its full authorized storage capacity with the completion of Mica project in 1973. In the spring and summer of 1974 this system was tested by one of the largest floods of record, and reduced an unregulated peak of 1,010,000 cfs at The Dalles to 590,000 cfs, which is below major damage level. Benefits in the lower Columbia attributable to the reservoir system for this flood amounted to $240 million, which is equivalent to about $500 million at 1987 price levels. Since 1974 a succession of lower magnitude spring floods have also been successfully regulated, as summarized in Table 2-2. Despite the relative newness of the fully developed flood control reservoir system, Corps of Engineers water managers have for a long time been estimating how a fully developed system would be operated for flood control, and what the capability of the system was in terms of providing flood protection at damage centers. This was accomplished through computer analysis, utilizing historic and hypothetical floods and simulating how they would have been regulated if they had occurred with the full system development. These studies formed the basis for many of the rule curves and other flood control regulation criteria used today, and they provide a means of evaluating the effectiveness of the system in achieving flood control objectives.

TABLE 2-2

COLUMBIA RIVER BASIN
REGULATION OF FLOODS, 1974-1988

YEAR	PEAK FLOW AT THE DALLES UNREGULATED kcfs	PEAK FLOW AT THE DALLES REGULATED kcfs	PEAK STAGE AT VANCOUVER 1/ UNREGULATED Feet	PEAK STAGE AT VANCOUVER 1/ REGULATED Feet	DAMAGES PREVENTED LOWER COLUMBIA Millions of $
1974	1,010	590	30.6	21.1	240
1975	669	423	22.9	14.3	9
1976	637	419	22.2	14.5	16
1977	276	183	9.2	7.0	0
1978	565	313	20.1	9.9	6
1979	482	306	16.9	10.4	2
1980	544	341	19.2	10.3	5
1981	579	436	21.7	16.7	11
1982	759	422	25.4	14.6	15
1983	723	400	24.9	15.8	19
1984	628	376	22.5	13.0	11
1985	550	274	21.7	8.8	10
1986	719	335	24.4	12.5	16
1987	439	284	8.8	15.5	0
1988	342	236	10.0	14.7	0

1/ Stage at Vancouver, Washington gage. Datum is 1.82 feet NGVD. Zero damage stage is 16 feet.

A key factor in discussing the Columbia River system's capability to achieve flood control is the degree of protection afforded by levees that have been constructed at several damage centers in the basin. Important points of concern include levees around Lewiston, Idaho, Bonners Ferry, Idaho, at Kalispell, Montana, and at Pasco/Kennewick, Washington. By far the most extensive levee system, is that in the lower Columbia River in the vicinity of Portland/Vancouver. Here over 20 drainage districts have levees protecting 75,000 acres of land, some of it highly developed. Figure 2-2 shows the location of the major damage centers in the basin, and Table 2-3 is a summary of the characteristics of several key flood control locations. This table contains information describing the relative importance of each area, in terms of degree of protection and relative potential damage. The residual damages shown for an occurrence of the area's 100-year and Standard Project Flood under regulated conditions, and the exceedance of the area's levee capacity, indicate that the Lewiston and Portland/Vancouver vicinities are clearly the most important in terms of potential damages. Because of its relative importance in terms of potential damages and degree of control most of the analysis and discussion of flood control capability will center on the lower Columbia River.

Reservoir system flood control capability is measured by regulated flow frequency curves at selected control points, and by regulation studies of hypothetical floods such as the Standard Project Flood. For the Columbia basin the simulation studies made in the 1960's for the Columbia River Treaty Flood Control Operating Plan provided a means of constructing flood frequency curves that reflect regulated conditions. The current curve for spring and summer freshets at The Dalles, Oregon, which is relevant to damage levels in the Portland-Vancouver area, is shown as Figure 2-3. This figure contains a frequency curve for the unregulated condition as well as for the current condition of system reservoir regulation. As a result of the current study an updated and revised version of this frequency curve will be presented in this report (Figure 5-6). The second measure of flood control capability is the ability to regulate a Standard Project Flood, which is a conservative design standard that may be applicable for levees protecting major urban high hazard areas. In a 1969 report, "Lower Columbia Probable Maximum and Standard Project Flood" (Reference 3), the derivation of the SPF for the lower river is described. This flood was analyzed in 1984 as

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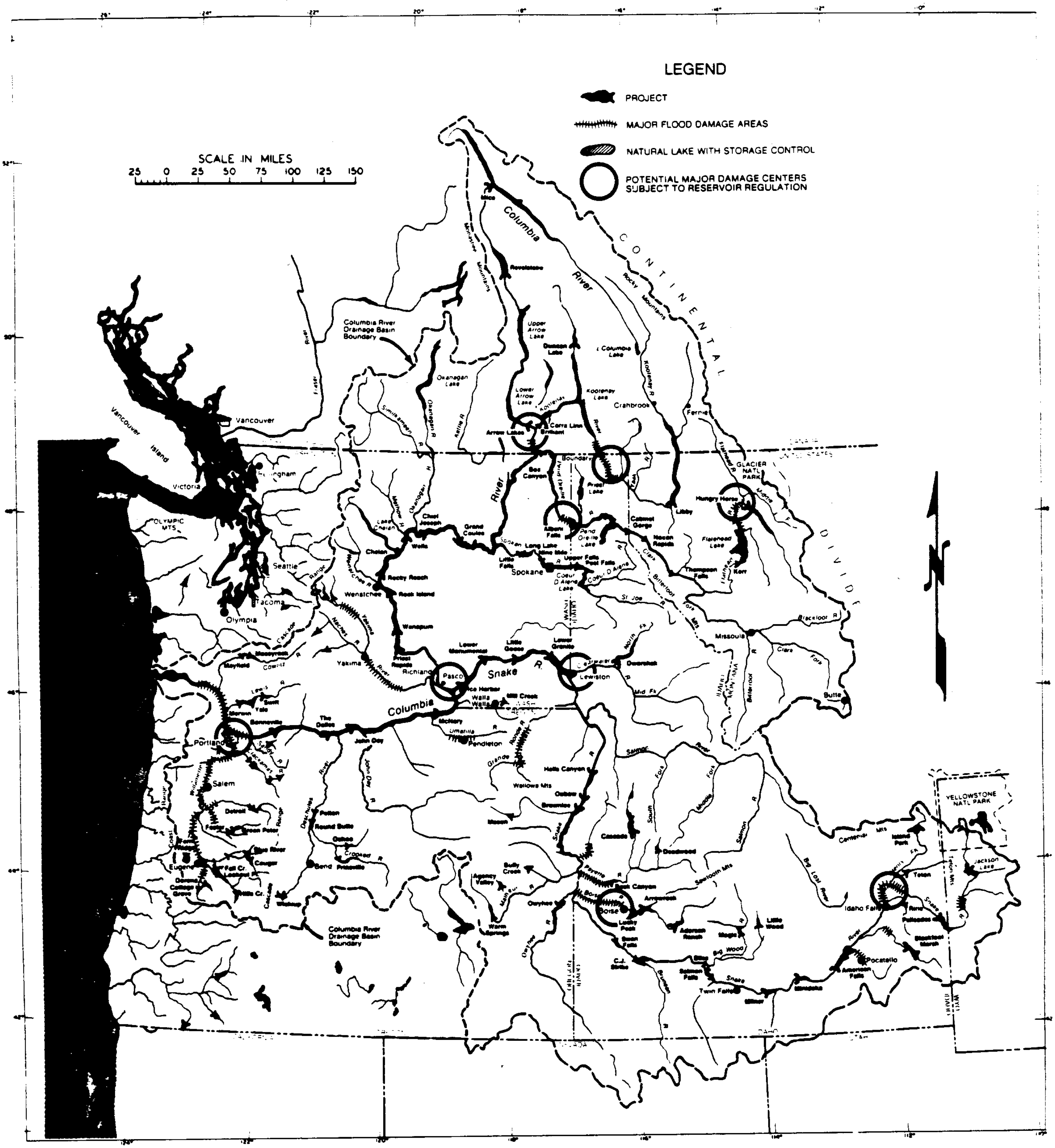


Figure 2-2. **Major Damage Centers**

TABLE 2-3

COLUMBIA RIVER BASIN
MAJOR DAMAGE AREAS SUBJECT TO RESERVOIR REGULATION

POTENTIAL DAMAGE AREA	REFERENCE POINT	CURRENT CAPABILITY	POTENTIAL DAMAGES IN MILLIONS OF DOLLARS: REGULATED 100-YEAR FLOOD	REGULATED STANDARD PROJECT FLOOD	LEVEE CAPACITY EXCEEDED 2/
Kootenai	Bonners Ferry	200 Year	0	50	3/
Columbia-Canada	Birchbank	4/	4/	4/	4/
Flathead	Columbia Falls	5 Year	10	20	3/
Pend Oreille	Albeni Falls	50 Year	14	30	3/
Upper Snake	Shelly	25 Year	11	3/	3/
Boise, Idaho	Boise	5 Year	27	3/	3/
Lewiston, Idaho	Lower Granite	SPF	0	0 5/	200
Tri-Cities, WA	The Dalles	SPF	0	0	7/
Portland/Vancouver	Vancouver	20 Yr-SPF 6/	40	240	1,400

NOTES:

1/ Damage figures are rough approximations, for relative comparisons in this table.

2/ Damages that would occur if existing levees were overtopped by flood greater than SPF.

3/ Major damage and levee overtopping has already occurred at indicated lower magnitude flood.

4/ Damage data not available. Flood-prone areas have relatively little development, but some potential damages exist.

5/ Lewiston levees are designed for SPF capacity.

6/ Levee capacity varies in 20 drainage districts upstream from River Mile 50. This is described in detail in Chapter IV of this report.

7/ Not available.

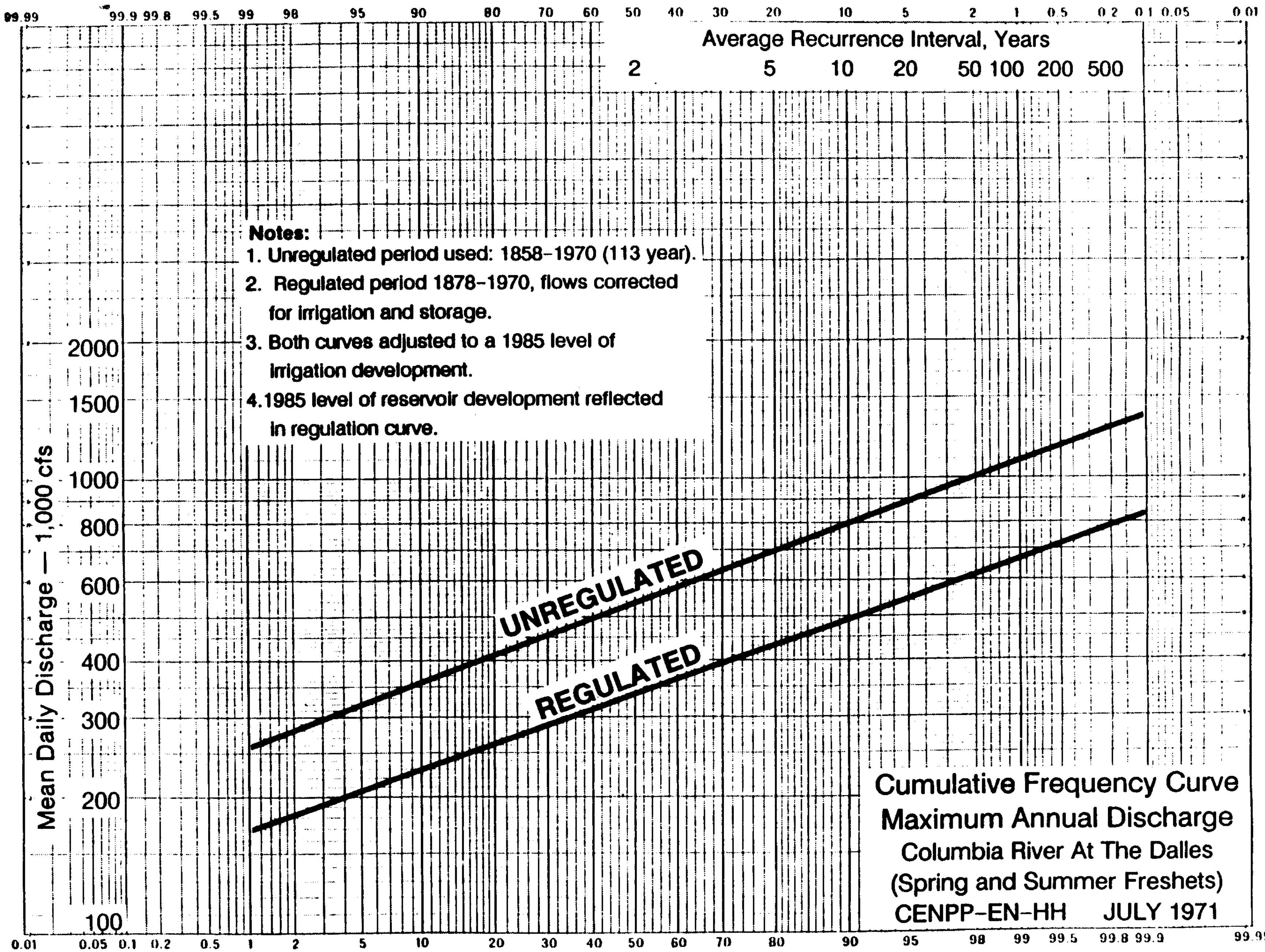


Figure 2-3. Cumulative Frequency Curve, Maximum Annual Discharge at The Dalles

part of the early phase of this study, and an updated estimate was made, as shown in Figure 2-4. The revision is due primarily to an updating of reservoir regulation and irrigation depletion assumptions made in the computer simulations. With the revision, the peak flow applicable to the levees in the Portland-Vancouver area, is 900,000 cfs.

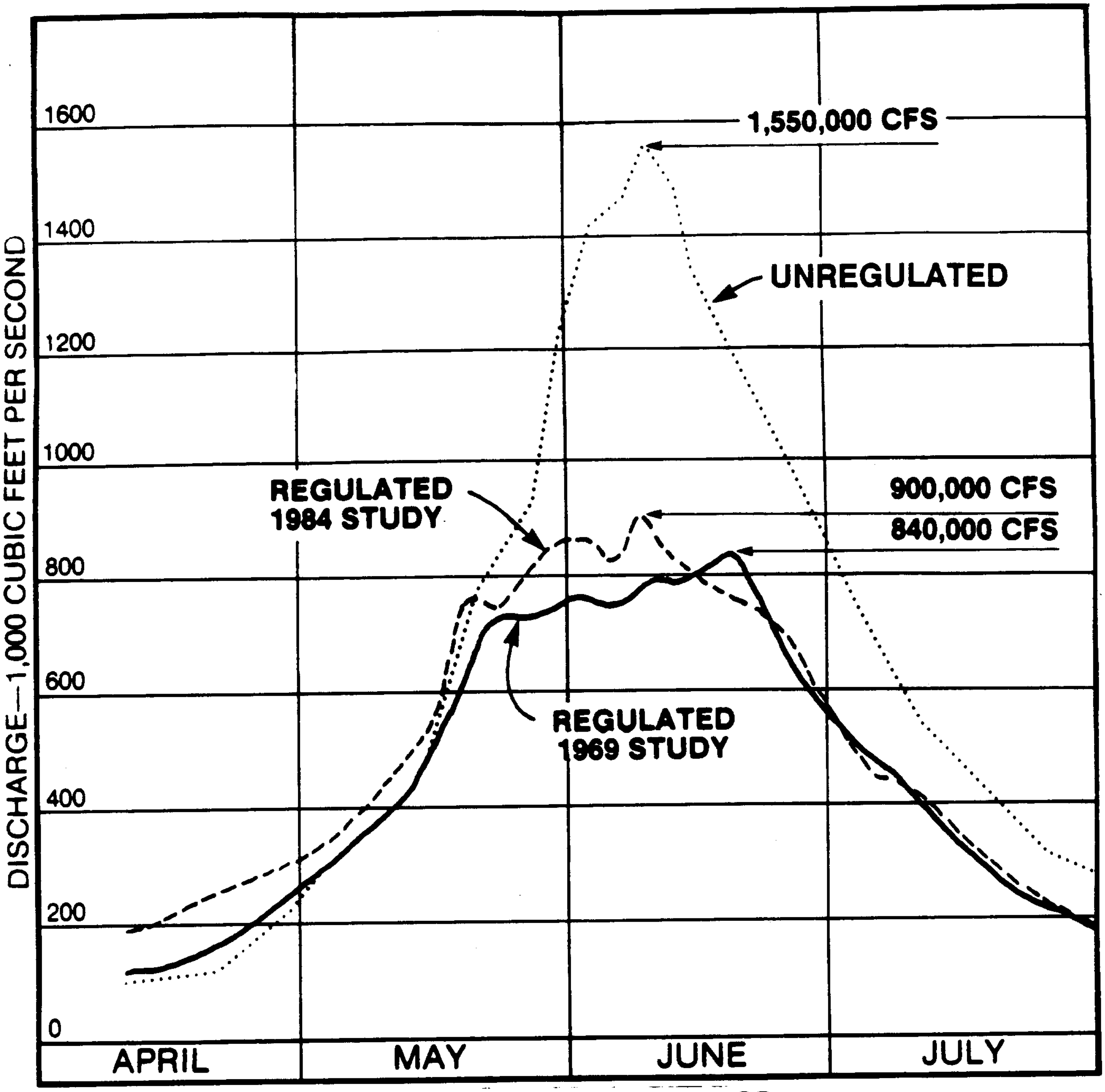
In the Preliminary Report, the capability of levees in the lower Columbia River was evaluated under current conditions of reservoir development, current flood regulation criteria, and existing state of levee structure. The findings indicated that most levees would be endangered and some overtopped by an occurrence of the 100-year and Standard Project Flood. This assessment, however, contained many preliminary assumptions which will be dealt with further in this report (Chapter V).

Current Flood Control Criteria

Hydrologic studies, in most cases made during the planning and design phases of project development, lead to the derivation of seasonal flood control storage reservation diagrams which specify the amount of drawdown needed at a specified time of year in order to regulate potential future flooding adequately. In the Columbia River basin with the primary source of flooding from snow melt, long-term forecasts of runoff are possible, thereby permitting a variable specification of drawdown depending upon the volume of runoff forecasted. This study's main objective is to evaluate existing flood control criteria to see if it can be modified without impacting flood control significantly, while benefiting other operational uses.

Prior to the construction of the Columbia River Treaty storage in the late 1960's flood control criteria was limited to project rule curves which were designed primarily for tributary protection. Since flood control storage capacity amounted to less than 10 million acre-feet before Treaty development, its regulation as a system was also relatively insensitive and non-complex.

Standard Project Flood



Columbia River at The Dalles, OR

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Figure 2-4. **Comparison of 1969 and 1984 Regulation Studies**

After Treaty ratification in 1964, a major effort to develop a system-wide flood control operating plan was undertaken. These studies led to an interim operating plan in 1968 and then to the document "Columbia River Treaty Flood Control Operating Plan" (Reference No. 2). The Treaty flood control studies featured detailed daily routings of over 30 years of record to develop and test the principles that were to be set forth in the Operating Plan, and they incorporated not only Treaty storage but other development planned or under construction at that time. Further details regarding the Treaty flood control studies can be found in a paper by Nelson and Rockwood (Reference No. 1).

The Treaty Flood Control Operating Plan contains the following basic principles of operation, which are not only applicable to Treaty storage but all flood control projects in the basin as well:

1. Two distinct periods of operations are recognized: (1) the winter drawdown period in which flood control storage space is attained in accordance with storage reservation curves; (2) the spring refill period during which flood regulation is implemented.

2. For purposes of regulation during the refill period, five categories of reservoir projects are established: (I) headwater reservoirs operated with fixed releases; (II) reservoirs operated for tributary protection; (III) major lakes operated for flood control; (IV) reservoirs operated with variable releases for downstream flood control; (V) run-of-river projects. Of these categories, (I) and (IV) are the most important for system regulation, and the Category IV reservoirs (Arrow, Grand Coulee, and John Day) represent those that require continual adjustment during the spring runoff to achieve the flood control regulation in the lower river.

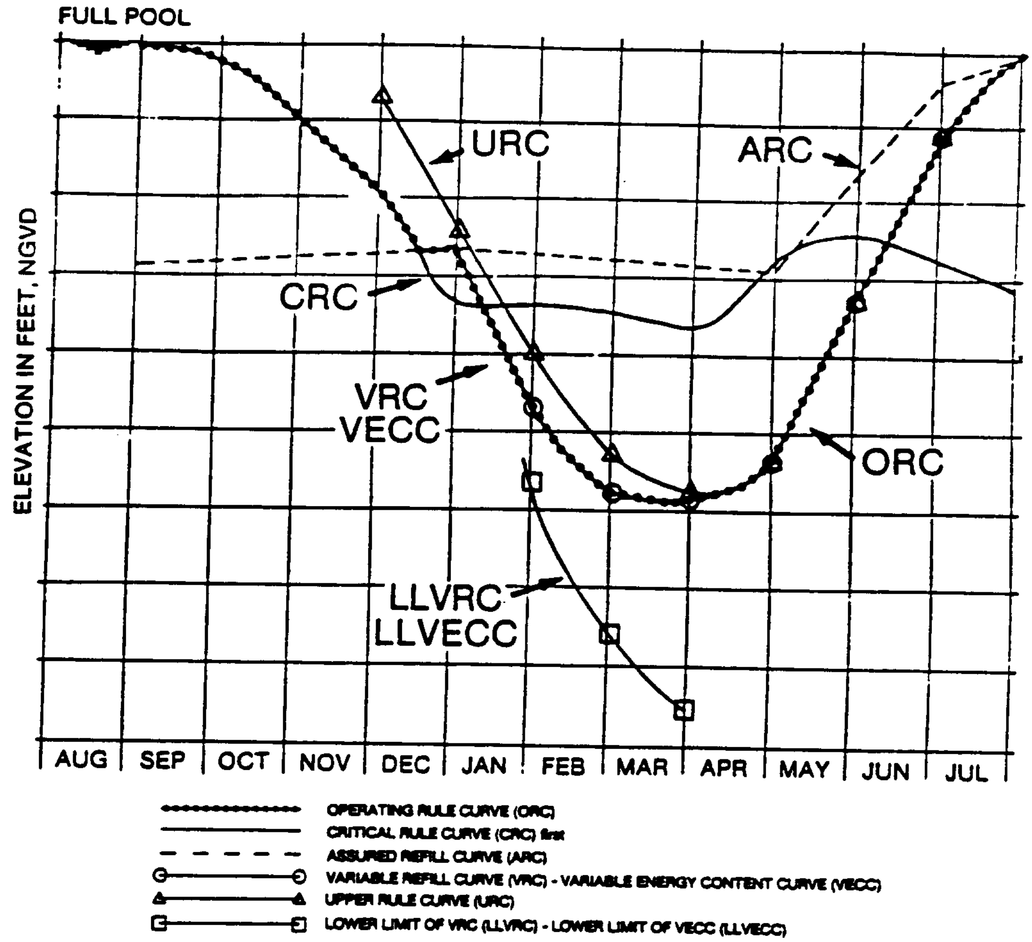
3. A variable controlled flow objective at The Dalles is utilized, in which years with higher runoff are regulated to a higher controlled flow to account for the inability to complete regulate all flood events and to make the most effective use of storage. Further, the controlled flow objectives can change during the course of a flood, as storage space is depleted in Category IV reservoirs.

4. Although guidelines exist for regulation during the refill period, emphasis is to be placed on forecasts of streamflow and reservoir operation in determining reservoir operations. These computer simulations utilize observed and forecasted hydrometeorological variables as well as hypothetical weather sequences to project operations as much as 90 days into the future.

The above principles, and the charges and tables contained in the Plan, have been reflected in the Columbia system flood control operation, and two major floods, - those of 1972 and 1974 - were successfully regulated through the use of this plan.

Other Operating Criteria

When viewed from a month-to-month perspective, reservoir regulation involves to a large extent the interpretation and following of operation "rule curves". Figure 2-5 defines these curves, most of which relate to operations for hydroelectric power generation. The Upper Rule Curve (URC), representing the flood control requirement, is determined from the flood control storage reservation diagram for the project in question. Since the URC restricts refill of the reservoir (until flood runoff begins), and the other rule curves - particularly the Variable Energy Content Curve (VECC) - exist in order to insure refill, conflict in operating guidance occurs if these two criteria are reversed (URC lower than VECC). In the Preliminary Report this was examined in detail by an analysis of the 40-year study period used in system regulation studies. This analysis showed that the URC controls primarily in the high runoff years when flood control is of greatest concern, but in the lowest years reservoirs are likely to be below the URC due to power drafts. However, with additional water being requested for fish migrations (i.e., the Water Budget), VECC's will be raised, thus increasing the likelihood of conflict with flood control criteria. This conflict will be discussed further in this report as modifications to flood control rule curves are presented.



	A	S	O	N	D	J	F	M	A	M	J	J	
1. Critical Rule Curve (CRC)	C	C	C	C	C	C	C	C	C	C	C	C	This curve is developed for each reservoir by the Critical Period Regulation Study, and prioritizes water in storage above the curve for secondary energy and storage below the curve for firm load until a volume forecast is available.
2. Assured Refill Curve (ARC)*	A	A	A	A	A	A	A	A	A	A	A	A	This curve is based on the second lowest streamflow in 30 years of record reduced by water required to meet loads, water required to fill upstream reservoirs, and at site and upstream water requirements.
3. Variable Refill Curve (VRC)* Variable Energy Content Curve (VECC)**						V	V	V	V	V	V	V	This curve is based on forecast volumes, reduced by a 95% forecast error, water required to fill upstream reservoirs, and at site and upstream water requirements.
4. Upper Rule Curve (URC)	U	U	U	U	U	U	U	U	U	U	U	U	This curve provides space for flood control based on Aug-Dec historical flows and Jan-Jul forecasts.
5. Lower Limit Variable Refill* Curve (LLVRC) Lower Limit Variable Energy Content Curve**						L	L	L					This curve is based on 1934-37 streamflow and serves as a limit on the potential total system and project draft to protect the system's capability to meet loads until the start of the spring freshnet.
6. Operating Rule Curve (ORC) The Operating Rule Curve will limit reservoir operation in respect to secondary generation. Reservoirs will be drafted below Operating Rule Curves if necessary for firm load requirements.	O	O	O	O	O	O	O	O	O	O	O	O	The monthly values for this curve are derived from the first 5 curves based on the following criteria: C or A whichever is higher, except that after 1 January, V will be used if it is below the higher of C or A. In all cases, if U is lower than the value thus determined, U will be used. In no case shall it be lower than L.

*Treaty Projects
**Pacific N.W. Coordination Agreement Projects

Figure 2-5. **Illustration Of Operating Rule Curves**

III. RULE CURVE ANALYSIS STUDIES

Overview of Studies

The studies for analyzing the existing flood control rule curves were basically a hydrology/operations analysis, incorporating a variety of methodologies. They are perhaps unique only in their scope, since the basin size is so large and the basin must be examined as a system as well as from the point of view of an individual project. The studies began in April 1984 with the development of a hydromet data base and an extensive program of model calibrations, and have proceeded through various other phases since that time.

Methodology

In general, flood control rule curves are designed to establish the upper limit to which a reservoir can be operated in order to provide flood control capability for downstream protection. They are expressed in terms of storage space (or elevation) versus season of the year. For reservoirs in the upper Columbia and Snake basins where the snowmelt is a major source of runoff, these rule curves are variable in nature, with more than one curve expressing the magnitude of runoff that is forecast knowing the amount of snow existing in the basin. Curves are generally at or near the full pool elevation in the summer and fall when there is essentially no flood potential, then are lowered through the winter to provide the maximum amount of storage just prior to the annual spring runoff that begins in April of each year. Existing curves have been constructed so that full evacuation of the reservoir is required when runoff forecasts indicate a large flood is possible. Studies have shown that, for the greatest floods, there is not enough storage space in the system to adequately control flooding to desirable zero-damage levels at downstream control points. In low runoff years, flood control requirements - as determined from the variable parameters - are not large, and often the reservoir will be operated at lower levels to meet other operating objectives. A major concern in developing flood control criteria is the fact that long-term forecasts are potentially subject to a large amount of error. This is caused primarily by the inability to predict future meteorological events that will occur after the date of the forecast (average subsequent conditions must be assumed), and by the inherent inability to determine the basin snowpack with a high degree of accuracy. From the flood control standpoint the greatest concern is the potential for significant unforecasted rain to occur, to the extent that runoff significantly exceeds that which would have otherwise occurred with the same snowpack under normal conditions. To deal with this potential, existing rule curves have been developed incorporating a factor of safety that covers, at least in part, the possibility of adverse forecast error. While the need for a factor of safety in flood control rule curves is real, on the other hand it is recognized that if the factor of safety is too conservative then rule curves will be set too low and other operational objectives will be impacted. Therefore, the quantification of the forecast error is of the utmost importance in the analysis of the rule curves. Since the unpredictable rain event occurs relatively infrequently, this quantification must include considerations such as probability of occurrence and risk of exceedance, as well as the quantity of water involved. In the development of many of the existing flood control rule curves, the factor of safety was based upon an examination of the historical record in which a few of the adverse rain events occurred, notably the 1948 flood. It is recognized that care must be taken in the interpretation of this record, since, for the type of occurrence being evaluated, it represents a highly limited sample. In the study just completed, forecast errors were examined in detail, through the use of both the historical streamflow record, and with the use of a computer model that permitted the generation of synthetic flood events. Through the use of the latter approach, a broader range of combinations of possible events (snowpack, rain, etc.) than have occurred in the historical streamflow record could be investigated. When combined with information from historical streamflow records, decisions can be made as the degree to which existing flood control curves can be modified.

Hydrometeorological Data Base

The first activity of the rule curve analysis studies was the development of a comprehensive database containing streamflow, precipitation, temperature, and snow data. These data were for the most part taken from archive tapes obtained from agencies responsible for data collection and archiving. In the case of streamflow data, extensive effort went into the development of "local flows", which are typically uncontrolled tributary flows between major dams or control points, and "inflows", which are the inflow to headwater reservoirs. A variety of approaches were used to reconstruct or estimate flows to fill missing records. The result of this effort was a complete set of daily inflows and local flows from water year 1929 through 1984 available for this study. These streamflows were used extensively for river model simulations of the reservoir system, to compute unregulated flows, and for calibrating watershed models. Precipitation and air temperature data were obtained for the period 1948 through 1982. Missing intervals in the data were filled by regression estimates with neighboring sites. These data were used in calibrating watershed models and the development of synthetic storms.

Watershed Modeling

A major part of the rule curve study was the computer modeling of river basins, or watersheds, to evaluate the effect of rainstorms falling on the snowpack. The computer program, "SSARR" (Streamflow Synthesis and Reservoir Regulation) was used for this purpose, as well as for most of the other hydrologic analysis in the overall study. The SSARR program was developed by the North Pacific Division office, primarily for operational streamflow forecasting for reservoir regulation. A description of the program can be found in Reference 4. The elements of the watershed portion of the program are displayed in graphical form on Figure 3-1. The program can be considered a conceptual hydrologic model that is capable of simulating on a continuous basis; that is, throughout all seasons of the year. For this study one of the more complex options of the program, the "snowband" option was employed. With this option each watershed is divided into "bands" of elevation on which snow, rain, soil moisture, etc. are accounted for individually before combining to produce a river response. This is illustrated in Figure 3-2.

A "model" of a watershed is developed by specifying certain characteristics that define hydrologic indexes and relationships. These are determined through a process of "calibration", in which observed hydrometeorological data, primarily precipitation and temperature, are used to simulate observed streamflow. Model

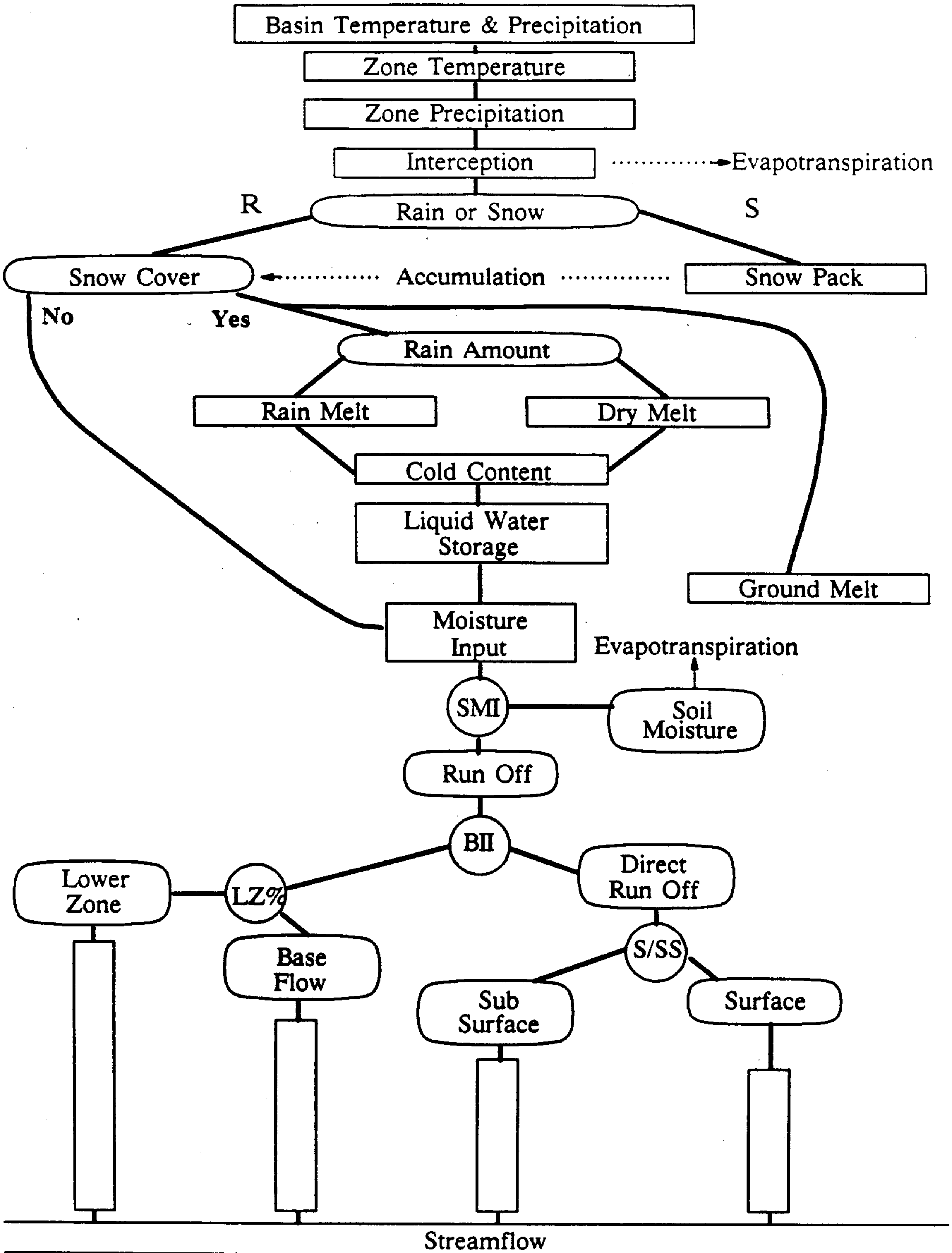


Figure 3-1. **SSARR Watershed Model**

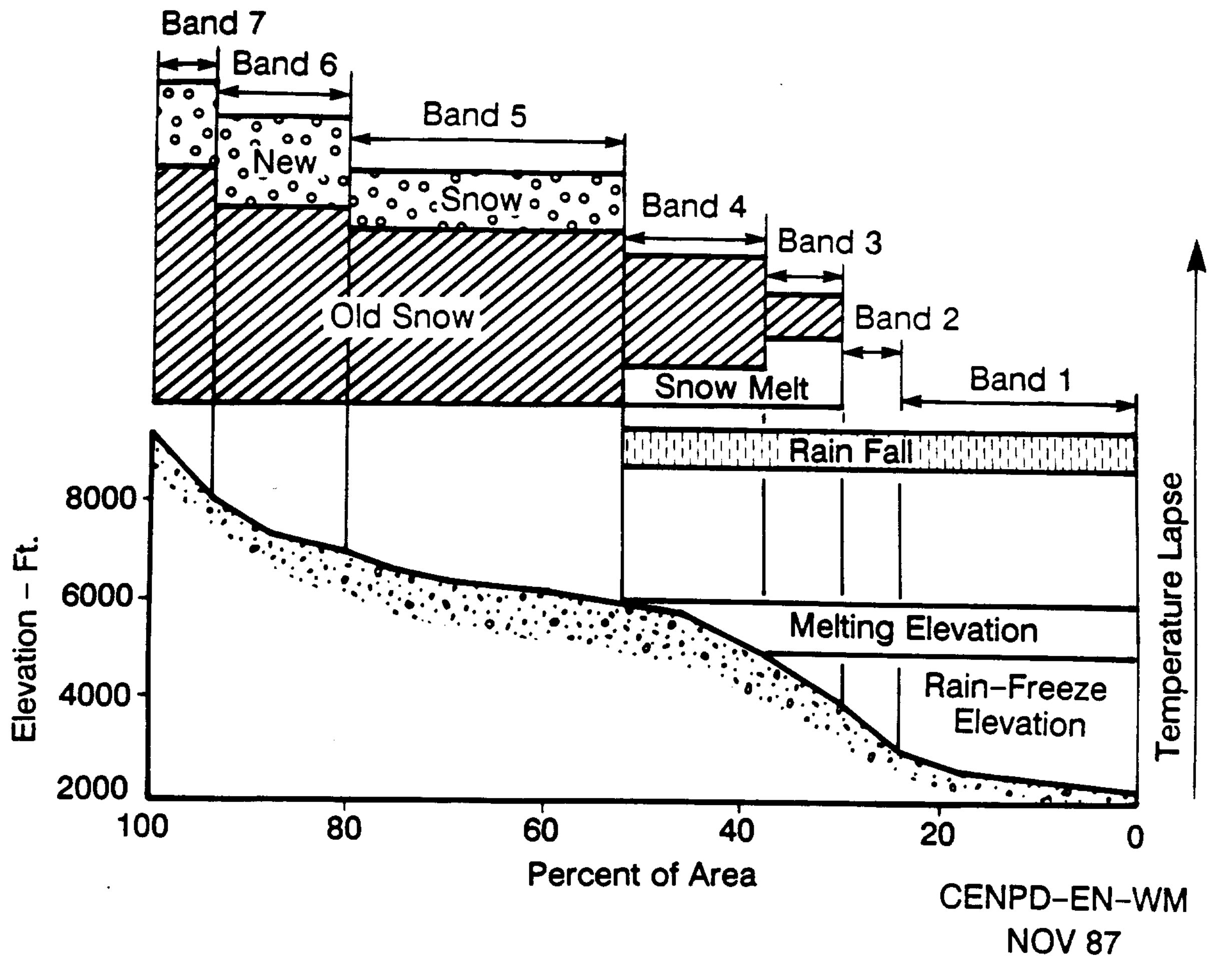


Figure 3-2. **Illustration of Rain & Snow Simulation on Elevation Bands**

parameters, initially estimated by general knowledge and by guidance from other completed models, are adjusted through a trial-and-error process until a satisfactory fit is obtained. The model can then be tested using another period of data for further verification. Calibrating and testing the watershed models was a major effort in the study, involving several man-years of work. The results of this work are not displayed in this report because of the voluminous content involved. Reference 12 describes a typical calibration effort, and the Interim Report contains a brief summary of the calibration results.

The investigation not only used watershed models of individual basins (e.g. Dworshak Dam inflow), but had to link individual models together to form a model of the entire river basin as well. To facilitate this, the overall model had to simulate the river system (flood wave translation and modification, diversions, local inflows, etc.) and the reservoir system, in addition to the watershed calculations. This is depicted by the schematic diagram shown in Figure 3-3. With 70 watersheds (each having several zonal subdivisions), 56 river reaches, 48 combining points, and 30 reservoirs, this model represents an exceptionally large and detailed configuration.

Design Storm Study

An important facet of this study was the derivation of synthetic spring rainstorms that could be utilized to quantify the effect of rain falling during the spring runoff season. This was essentially a probability analysis, considering both temporal and spacial variation of precipitation. Expanding upon what was used in the Interim Report, several historic storms were investigated including the 1948, 1964, 1969, and 1981 events.

In order to determine the probability of precipitation events, the precipitation for the Columbia basin was related to a single index value which represented the weighted average basin-wide precipitation. The index values were obtained by combining weighted precipitation amounts from sixty stations according to a fixed procedure. With a 52-year index reference, this daily index could then be processed to determine its probability distribution for each of several durations of precipitation ranging from 1 to 30 days in length. For a desired basin index probability (e.g., 100-year) and duration, the corresponding station values are then determined by reversing this procedure. To determine a synthetic basin storm of the given probability, a historic storm pattern was utilized to determine the spacial and temporal distributions for the synthesized index value. Total storm station amounts were determined by factoring the historic pattern to produce the desired index quantity. Daily values at each station were proportioned from the storm total after the historic daily pattern. In this way several storms having a given recurrence interval but differing aerial and temporal patterns, could be derived. To obtain a more critical timing sequence the 1969 storm was also advanced by 30 days. Another part of the analysis was to derive subbasin indices, which were derived in the same manner except that the indexes were determined for major subbasin damage centers. With this information, precipitation amounts could be determined that give desired probabilities at subbasin damage centers in addition to The Dalles. More information on this analysis can be found in Reference 10.

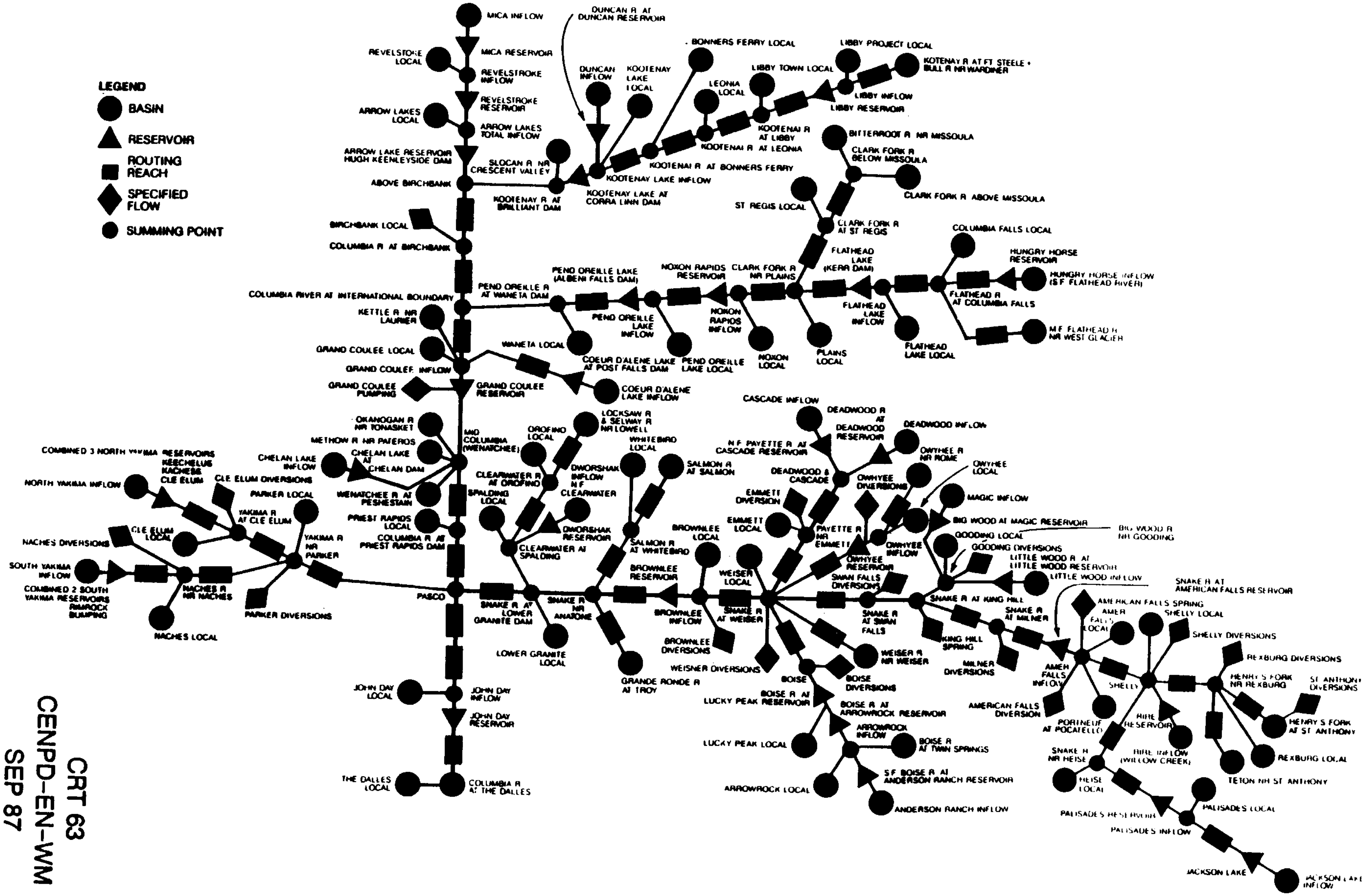


Figure 3-3. **SSARR Hydrologic Model Schematic, Columbia basin above The Dalles**

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Reservoir Regulation Simulations

As shown on Figure 3-3, a significant part of the watershed model is the reservoirs and regulated lakes in the Columbia River system. In the watershed simulations that provided information for the rule curve analysis these reservoirs had to be regulated to provide as reasonable a simulation of real-life conditions as possible. Critical in these simulations is the assumption of future knowledge about runoff volume, streamflow, and reservoir operating conditions. Since a 100% knowledge of future conditions is impossible in real-life, the same must be duplicated, as much as possible, in the simulation runs. For instance, the simulations do not anticipate in advance that a synthetic rainstorm will eventually occur. Thus, reservoirs are more full than they would have been with perfect foresight. As the rainstorm develops, the reservoir regulation assumed in the simulation attempts to regulate as would have been done in real-life, with a degree of "imperfection" inherent in the results. The strategy is to attempt maximum obtainable reduction in downstream flooding under conditions of limited future knowledge, while at the same time not filling storage too soon in case additional rain or snowmelt occurs.

Historic Flood Analysis

The second major phase of the rule curve studies was the analysis of historical floods in light of current and proposed conditions. This provides an independent approach in evaluating the rule curves, and has several secondary benefits in terms of the study's overall goals. This work was undertaken in much the same manner that had been done for development of the Columbia River Treaty Flood Control Operating Plan, wherein 30 years of record were simulated (Reference 1). In the current study the object was to expand upon the old study in several ways: (1) the period of record has been expanded to begin in 1929 and end with the most recent year; (2) the study is based upon daily flows for a 12-month period where the previous study utilized a 4-month springtime period only; (3) the current study reflects the latest system power study analysis, updating power regulation to the latest loads and resources; (4) the current study contains the latest in reservoir regulation policies, irrigation depletion rates, hydraulic characteristics of structures, etc.

As described in the description of the hydromet data base, the first step in this analysis was to develop a file of "inflows" and "local flows", suitable for input to the SSARR model configuration being used. This file has been completed for the period of record, 1929-1984. The simulation of historic floods was accomplished with the SSARR program using a system configuration similar to that shown of Figure 3-3, except that in place of the watersheds the historic flow data were entered.

Since operations for power represent a major regulation objective, particularly during the winter period, the simulations had to incorporate power - as well as other - operating considerations. Since the SSARR program does not explicitly simulate hydropower operations, this was accomplished by using the Hydro System Seasonal Regulation (HYSSR) computer program. The HYSSR program is a major systems analysis program used in the North Pacific Division for power planning. Operating on a monthly computational time step, it is capable of simulating how the reservoir system would be operated to meet system power loads, given hydro and thermal resources, and operating constraints such as the water budget operations for fisheries purposes. Before executing the SSARR runs on a daily computational time step, the HYSSR program was executed and mean monthly project discharges were transferred to files for direct input into SSARR. The HYSSR regulation would be one reflecting specific assumptions, rule curve modifications, etc., that were desired for the rule curve investigations. The HYSSR monthly flows provided a guideline for the more precise daily flow simulation; in numerous cases the constant average monthly flows had to be adjusted to reflect a more reasonable daily operation. A typical case where this occurred was when a reservoir filled or emptied in the middle of the month.

As with the regulation of the watershed simulations, a realistic foresight assumption had to be reflected in the historic flood simulations. This was facilitated by using synthetic water supply forecasts, which were developed as an early part of the study. These forecasts were derived for the 1929-1982 period of record based upon recorded meteorological data, and reflect, to the extent possible, how the future runoff would be forecasted given a repeat of the conditions experienced in the historic year. Forecasts are available for each month during the January-July period. An example of one of the historic regulation studies is contained in Figure 3-4, wherein the results at The Dalles of the 1974 flood simulation are displayed. This flood is of particular interest since it is one of the largest in the period of record for the basin and it is the only major flood that was regulated with the reservoir system as is known today. This figure shows a comparison between the historic regulation of the flood with the simulated regulation using the SSARR model. Although this flood is a relatively recent occurrence, it can be seen that there are a number of periods when significant differences occur between the two hydrographs. These differences are the result of current operating criteria and power operating requirements differing from that which existed in 1974. The current study, therefore, provides a means to demonstrate how historic floods, even those of recent past history, would be operated under current criteria. It will further be used to examine proposed operating criteria.

The historic flood analysis was used to determine peak flows at downstream control points resulting from operations with the current flood control criteria. These were then compared with operations utilizing revised flood control rule curves, to determine the impact of these curves on the resulting peak at the damage center. These data also provided the basis for deriving a revised flood frequency curve at The Dalles. Historic flood simulations also were useful in examining alternative rule curves for Grand Coulee.

Rule Curve Analysis

With the analytical tools developed as described in the foregoing paragraphs, the existing rule curves could be studied to evaluate whether flexibility exists to modify the rule curve while maintaining the project's overall existing flood control capability. As previously described, flood control curves for reservoirs in the Columbia basin are actually composed of a family of curves (or "parameters"), each relating to the water supply forecast in effect. The objective of the study is to analyze the flood control requirements independently for the range of these parameters. This may lead to some parameters being changed while others remain as currently derived. The basic goal of the analysis is to determine the minimum flood control space requirement that is associated with a given parameter (forecast), given the possibility that an unforecastable rainstorm could occur thereby producing runoff in excess of the forecast.

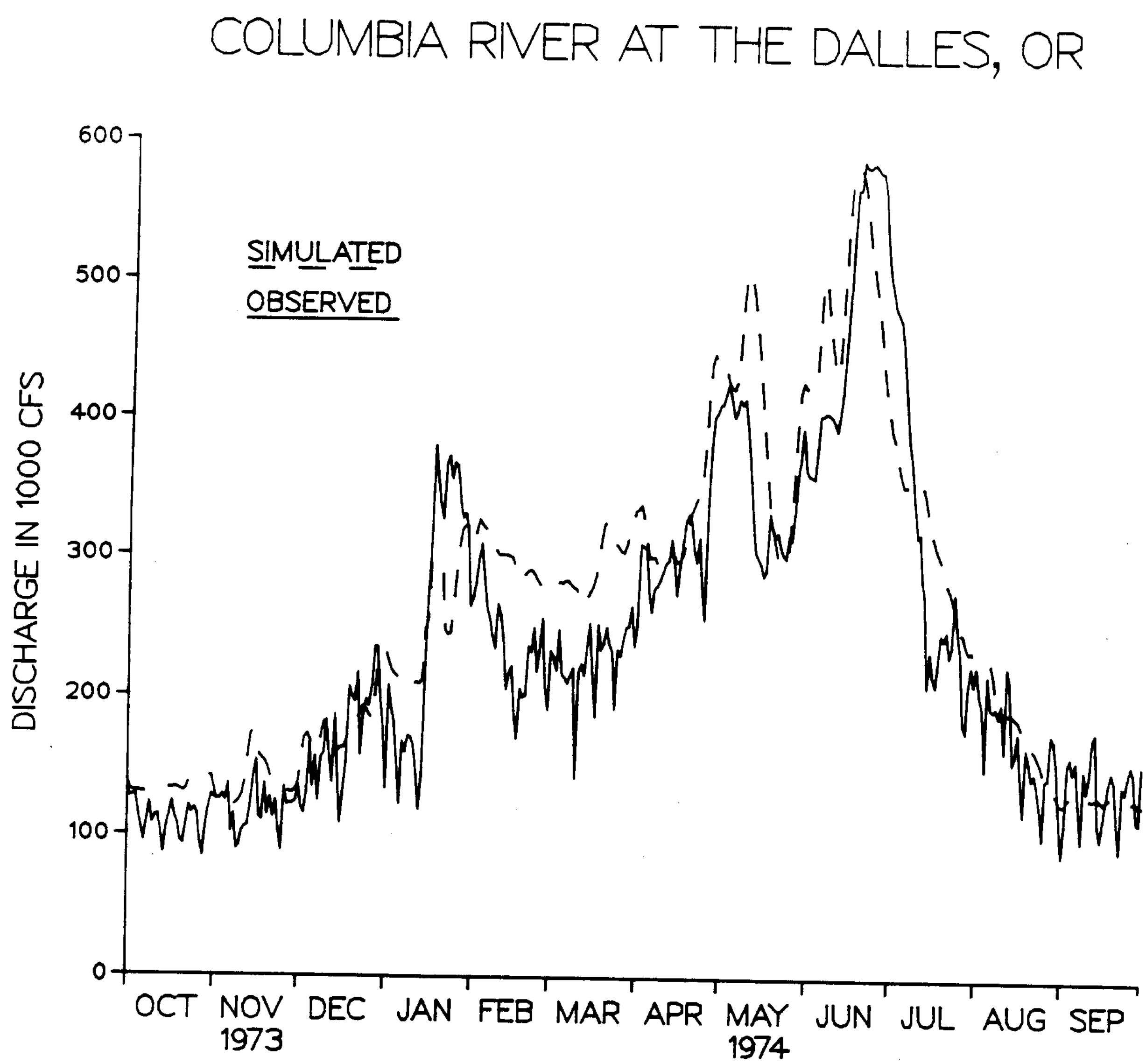

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Figure 3-4. Observed Regulation vs Simulated Reguation at The Dalles.

Two basic approaches were used for the rule curve analysis:

- Envelope Curve Based Upon Historic Flows. The first method utilizes the streamflow data base that had been developed to see if the existing flood control criteria envelope individual year flood control requirements (storage space), on a plot of storage versus runoff forecast. This method gives a broad scale analysis of the rule curve, which can then be refined by the second form of analysis. Figure 3-5 is an example of the envelope curve, in this case for the Hungry Horse project. The computation is a simple determination of the storage requirement (inflow minus outflow) that is associated with a specified period of time in which the reservoir would be storing for flood control when operating as part of the existing system flood control operating plan. In the example shown the storage period is defined as the requirement for regulating the flow at The Dalles, a requirement that is established in the Columbia River Treaty Flood Control Operating Plan. A secondary consideration in this analysis is also the operation to control the flow at Columbia Falls to a discharge below 48,000 cfs, if outflow had not already been reduced by the requirement at The Dalles. The storage requirement is computed for each year of the period of record and plotted against the simulated forecasted runoff for that year. The straight line superimposed is the flood control requirement taken from the current, official flood control curve. It can be seen that for some years the required storage exceeds the amount called for by that rule curve. This means that, for that particular year, the releases from Hungry Horse would have to exceed the minimum desirable flows for a period of time. This is not necessarily a serious ramification if the increased flow is small. In other years the official rule curve required storage space in excess of that actually needed. In the description of the results for each project, the same type of plots will be used to display proposed alternative flood control requirements.

- Watershed Simulation Analysis. The second method of analysis involves the use of the SSARR watershed model to simulate the effects of a rainstorm of given magnitude on the river basin, and to determine the resulting downstream peak flow at damage centers as regulated by the project or projects being investigated. In evaluating a new rule curve,

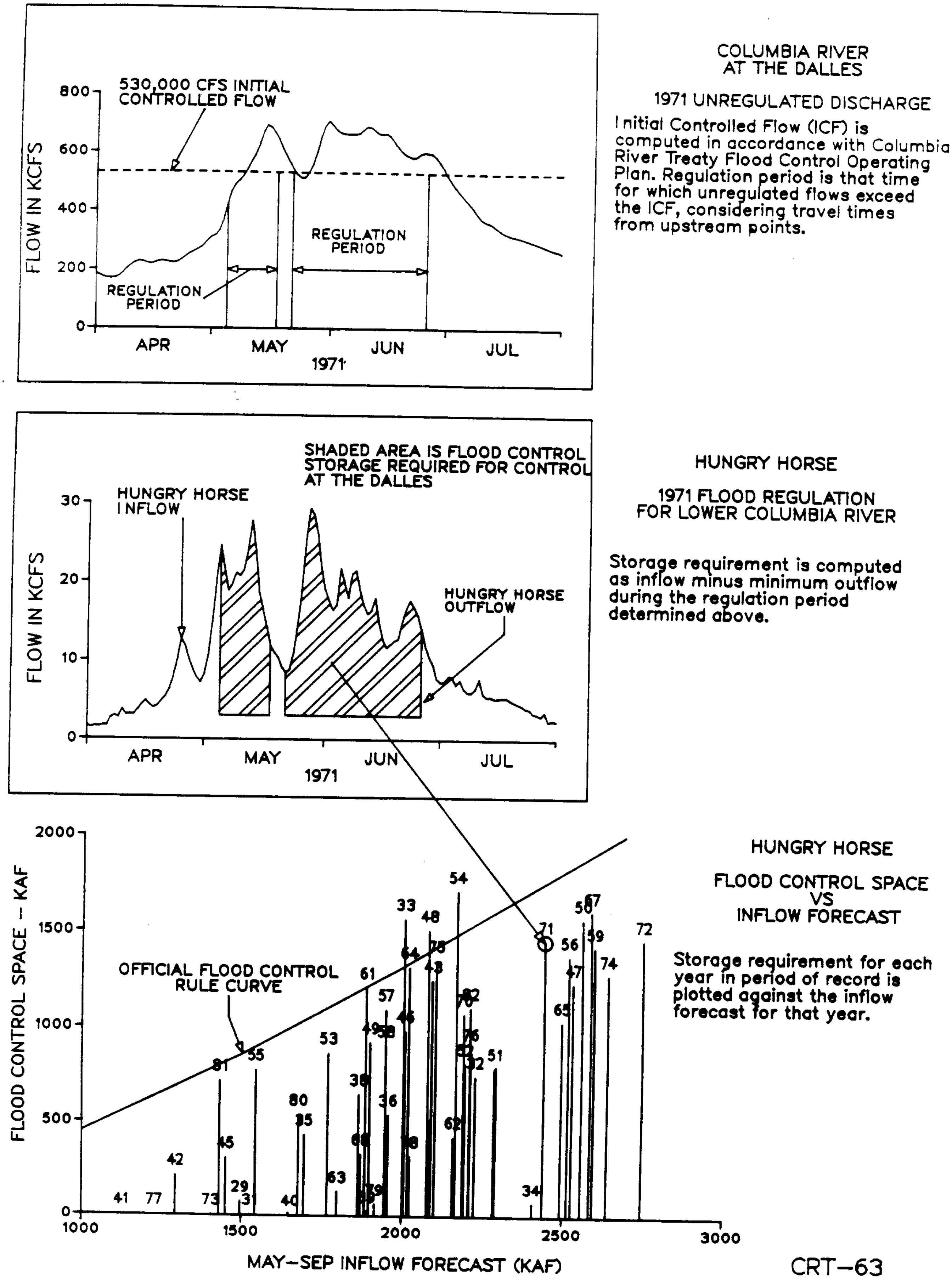

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Figure 3–5. Determination of Envelope Curve for Rule Curve Analysis.

the new curve can be compared against the current criteria under the assumed hypothetical storm event. The advantages of utilizing the hypothetical rainstorms instead of historical streamflow records is that the streamflow records do not contain enough occurrences of storm events to evaluate a wide range of conditions -- varying magnitudes of snowpack and varying magnitudes and timing of storm events. A typical analysis is illustrated in Figure 3-6, for Hungry Horse project. Here, as an example, the effect of a hypothetical 100-year rainstorm is shown as it falls on two initial conditions - an extremely low snowpack (and runoff forecast), and a moderately low forecast. The resulting flows (a combination of rain and snowmelt) at the downstream control point, Columbia Falls, are shown as hydrographs of streamflow versus time. By comparison, the flow that would have resulted had no rainstorm occurred, is also shown. This figure also shows a composite plot of several such rain/snow events, with peak flows plotted versus magnitude of forecast. A line is drawn representing the 1% exceedance probability as computed from the combined probability of the rain and snow event. Using this plot, decisions can be made as to the capability of the project to control flooding under all forecast conditions, and whether there are "regions" within the range of forecasts in which flood control criteria can be modified. This methodology was used in the Interim Report studies, and led to conclusions regarding the feasibility of modifying the current flood control curves. The above discussion refers only to one project and corresponding control point in the basin. Because the reservoirs are also operated as a system for the regulation of flooding in the lower Columbia River, the above analysis must also be extended to the entire Columbia. This was done in the analysis, and plots similar to that shown in Figure 3-6 were developed for the Columbia River at The Dalles. As will be discussed in Chapter IV, the investigation of any rule curve had to consider both the system and the local control point objectives, taking the one or the other that resulted in the most stringent control at the project.

The final placement of a rule curve parameter was determined by both the envelope curve and watershed simulation analysis described above. The basic criteria used was that the flood control rule curve should provide protection at the downstream control point (either the local tributary or at The Dalles) with a minimum risk

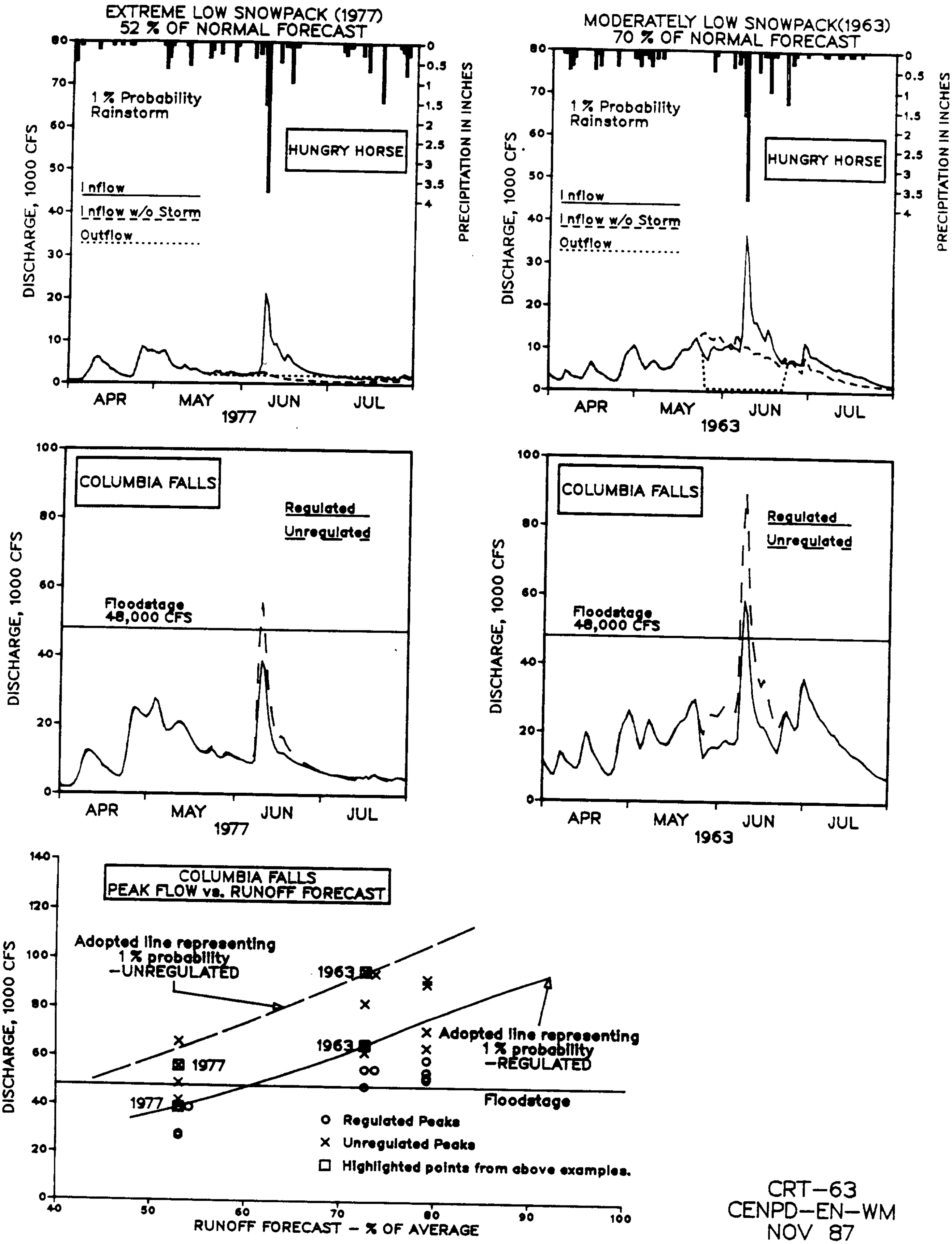

Figure 3–6. Illustration of Watershed Simulation Analysis.

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of failing to provide flood control protection. The degree of protection for an area is typically expressed in terms of probability of exceedance in any year. A relatively large flood, for instance, is one that has only a 1% chance of being exceeded in any given year. This equates to one exceedance in a 100-year period on the average; hence the term "100-year flood". If a protected area has the capability of being protected (by an combination of levees or upstream storage) against a 1% flood, then it is considered to be a relatively high degree of protection. In highly urbanized areas where loss of life is of concern, however, a higher degree of protection might be expected. A more infrequent probability flood or a Standard Project Flood (SPF), might be an appropriate degree of protection in such cases. Often, rural areas with low population and relatively minor damage impacts will have a lower degree of protection than a 1% flood.

In this study the proposed rule curves were tested by applying a 1% or 100-year rainstorm to the rule curve condition being evaluated. The 1% criteria was chosen for all areas except Lewiston as being a reasonably high standard, yet not overly conservative. For Lewiston, however, a SPF rainstorm was utilized, since the design standard for the Lewiston levees is the Standard Project Flood. An examination was made of the sensitivity of the choice of the rainstorm criteria, and this factor was found to be relatively insensitive compared to a number of other assumptions that had to be made in the analysis.

IV. RESULTS, RULE CURVE ANALYSIS

Overview

This section of the report describes the results of studies, described in the previous chapter, to evaluate current flood control rule curves and propose revisions to those curves where it would be beneficial. This section represents a direct follow-up to the Interim Report on Flood Control, which assessed the feasibility of modifying rule curves and delineated "regions" (in terms of runoff forecast magnitude) wherein it appeared that some modification would be possible. The results described herein represent a refinement to the previous analysis, and in some cases the conclusions have been revised from what the earlier studies had shown. In the descriptions that follow the results are compared with what had been stated in the Interim Report, and reasons given for any substantial changes.

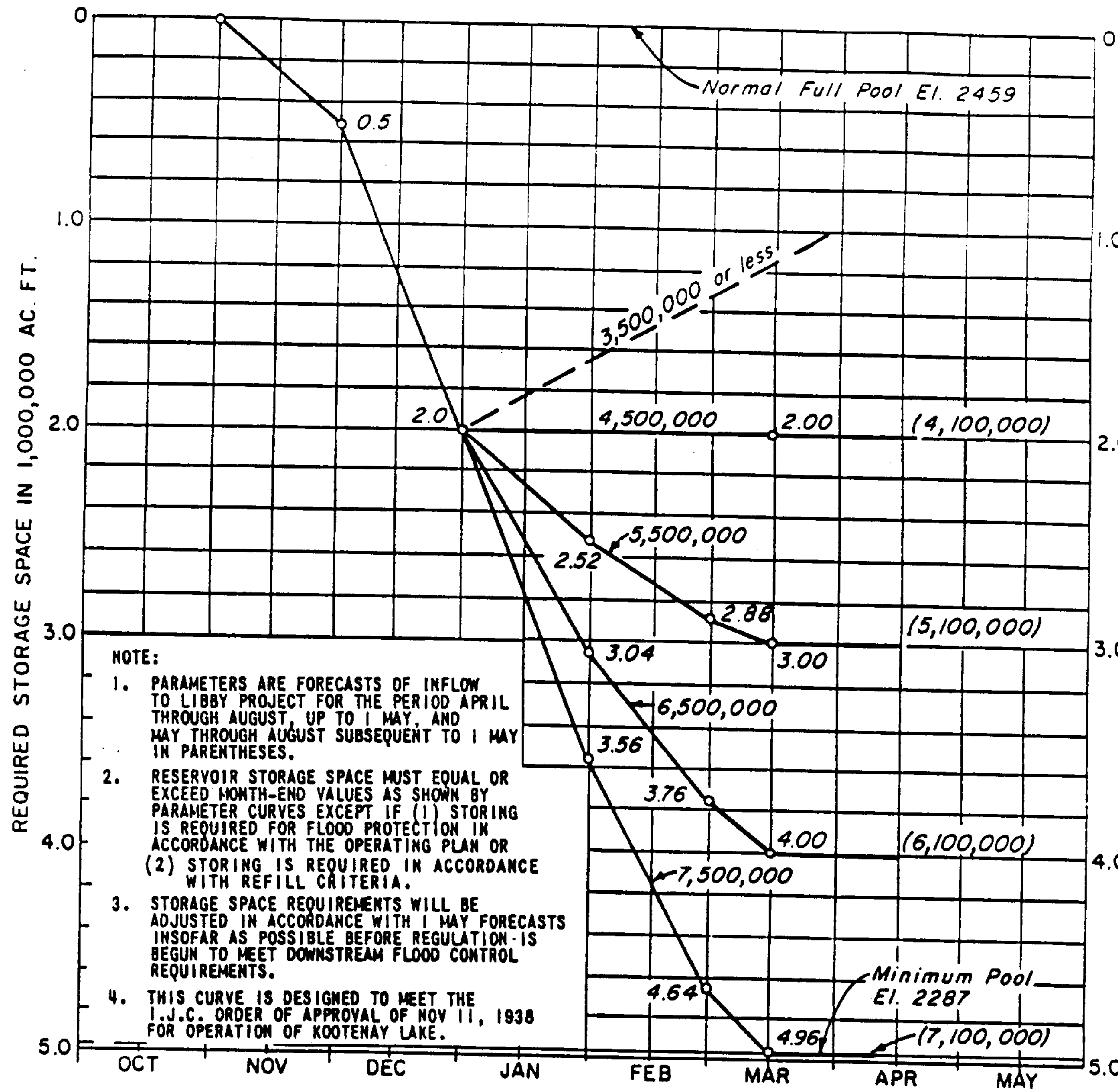
The following rule curve discussions are presented for the Libby, Hungry Horse, Grand Coulee, Brownlee, and Dworshak projects. As discussed in the introductory chapter of this report, several other projects in the basin are considered to have flood control capability on a system basis. However, because their influence in providing instream flows or achieving significant flood reductions is relatively minor (e.g., the upper Snake projects); or, there is legal/institutional limitations precluding unilateral changes (e.g., the Canadian Columbia River Treaty projects), they have not been included in this analysis.

The flood control rule curves presented reflect one underlying basic assumption: that the current flood control capability of the reservoir system will not be degraded by the action to modify the curves. This principle was established after studies described in the Preliminary Report showed that the lower Columbia River levee system had little or no excess capability to withstand flooding. Benefits, therefore, are to be gained by modifying only portions of the curves, wherein the resulting increased downstream flood stages are of little or no consequence; i.e, they occur in years where runoff was already low and flood damage inconsequential. In no case have the curves been modified in the high forecast regions where the flood control storage space is needed the most - and in fact is in short supply when the region's largest floods occur. Of course, the modifications to the rule curves in the years with low runoff are needed the most, in terms of providing more flexibility for maintaining instream flows and refill objectives for power, water supply, and recreation.

Libby Project

The Libby project in northwestern Montana is operated by the Corps of Engineers for flood control and power generation, and additionally provides recreational opportunities on the reservoir and in the downstream reach of the Kootenai River. Flood Control criteria were established during the planning and design of the project, and were later reformulated in the flood control studies for the Columbia River Treaty in the late 1960's and early 1970's. The existing flood control rule curve is contained in the project's Water Control Manual, dated July 1984 (Reference 7). This diagram, shown on Figure 4-1, is the current official authority for seasonal flood control operation for the project. In addition to this curve, two additional diagrams are designed for operating Libby reservoir during the spring refill period. Although these curves were a factor in the analyses undertaken, they do not have a direct bearing on the reservoir space allocation prior to the runoff season and thus are not discussed in this report.

The flood control operation at Libby project is related to river control both for the lower Columbia River and for the Kootenai River. Historically, before the dam was constructed, the farmland in the vicinity of Bonners Ferry, Idaho was subjected to significant flooding by the Kootenai, despite the fact that levees had been constructed over the years for flood protection. Major damage protection afforded by the Libby project is now approximately to a 200-year flood, as evidenced by the stage-frequency curve for Bonners Ferry, Figure 4-2. This indicates that the probability of flooding to major damage stage is on the order of once in 200 years. On the other hand, there is some evidence that levees have not been maintained to their original standard, thus potentially lowering the degree of protection.



Flood Control Operating Plan
Columbia River Treaty
SEP 72

Figure 4-1. **Libby Project Flood Control Storage Reservation Diagram**

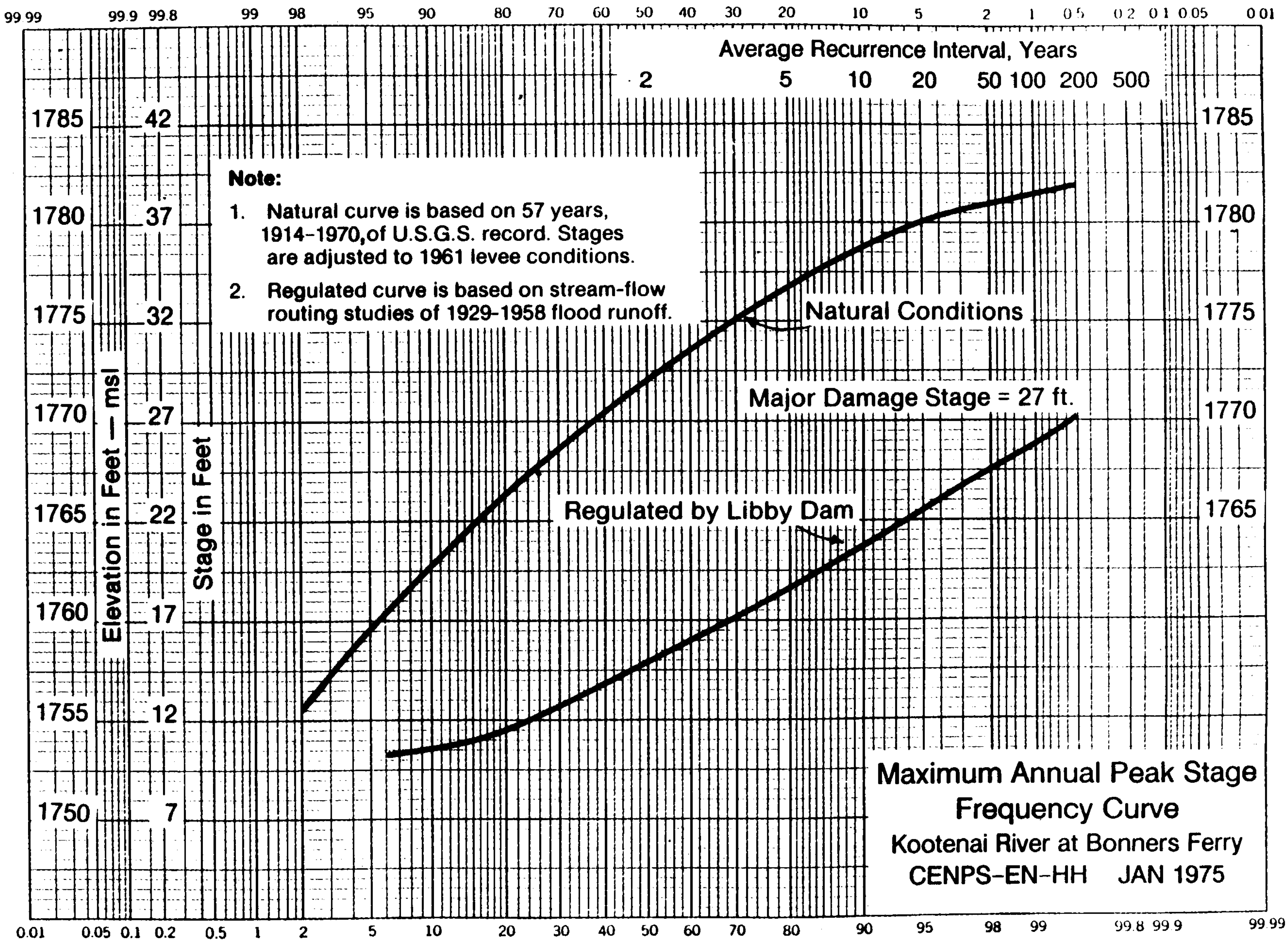


Figure 4-2. Maximum Annual Peak Stage Frequency Curve at Bonners Ferry

Libby project is also a major element in the Columbia River system regulation for flood control, providing about 12% of the total possible storage space available to regulate a major flood. The Columbia River Treaty Flood Control Operating Plan stipulates the method of operation for the Libby project once a flood is underway; generally, the regulation objectives for the lower Columbia serve to provide the desired flood control objectives in the Kootenai River as well.

The existing flood control diagram is providing adequate and reasonable flood control criteria for the project, although, as will be seen, some modification of the curves appears to be feasible. One problem associated with the curve is that an early evacuation of part of the reservoir storage, by the end of December, must be accomplished in order to insure that the reservoir can be fully drafted should a large runoff year materialize. This requirement limits the flexibility of the reservoir's operation during the winter drawdown period, impacting power operations, and possibly flood control objectives. This problem, which could possibly be eased by modification of the Kootenay Lake International Joint Commission Rule Curve, will not be discussed in this report since rate and timing of drawdown are planned to be studied in a later phase of the study.

The existing flood control curves, and proposed modifications to the curves, were analyzed following the methodology described in Chapter III. Figure 4-3 shows the results of the envelope curve analysis, which in this case, represents storage needed for regulation for control at The Dalles in accordance with the Columbia River Treaty Flood Control Operating Plan. Superimposed on this curve is the current 15 March flood control storage space requirement based on the official rule curve. Comparing the plotted points against this curve shows that for most years the current criteria provide adequate storage space to regulate for system requirements. In a few years, however, (1948, 1954, 1971, etc.), there is not enough space in the reservoir to regulate without having to increase outflow above the desirable release of 4,000 cfs. It is recognized that there is little that can be done about such instances, and the objective in constructing a rule curve would be to minimize these cases as much as possible. It can be seen that for the lowest runoff years, there appears to be a tendency

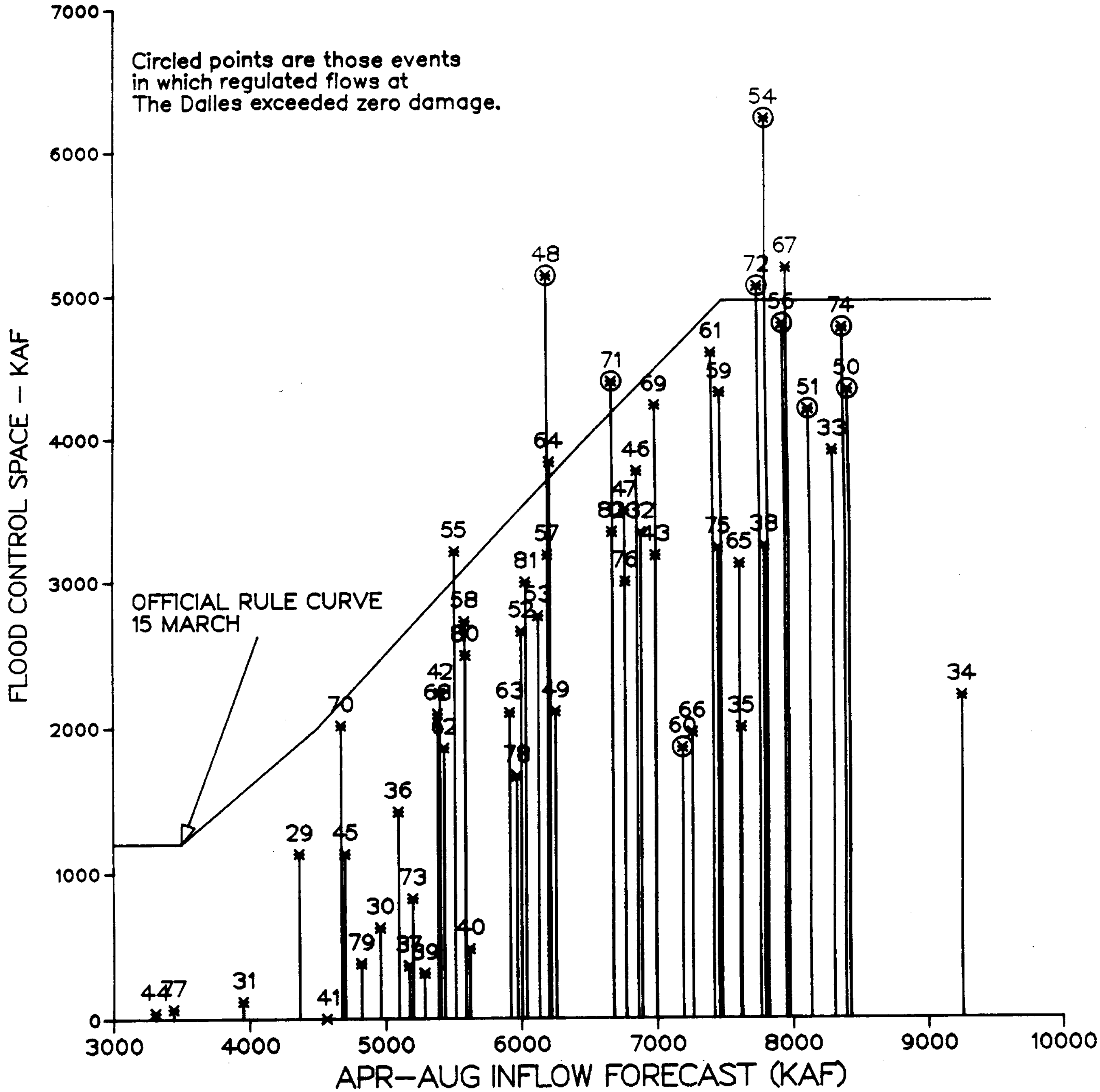


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Figure 4-3. Libby Project, Flood Control Storage Requirement for System Control.

to have excess space required by the rule curve than it theoretically needed, at least as evidenced by the historical period of record. The analysis that is described in the following paragraphs checks to see if this excess also exists for local control at Bonners Ferry.

The analysis of the local flood control requirement employed primarily the simulation of synthetic floods from hypothetical rainstorms, following the methodology described in Chapter III. This analysis expanded upon the similar studies done in 1984 for the Preliminary Report. Once the watershed model was assured to have been calibrated and a consistent method of regulating the extreme events was established, simulations were made for Libby storage amounts differing from the official rule curve values. Four storm patterns were simulated, all having 100-year, 30-day precipitation quantities. Temperatures during the storm were the same as experienced in the historic event. The four storms chosen represent an extreme in temporal variation, from early to late in the season, and thus are believed to be a good test of a range of possible occurrences. The effect of these storms on the inflow to Libby dam, given a 1973 snow condition (77% of normal forecast), are compared on Figure 4-4. Simulations were run for a complete range of snow conditions, but most of the analysis was confined to forecasts that are less than 90% of normal, since this is the region where changes in the rule curve would be feasible.

The results of these simulations are summarized on Figure 4-5, which shows the Bonners Ferry elevation resulting from different storage assumptions, given various snow conditions (forecasts) and rainstorm patterns. It can be seen that, for a given forecast and initial storage space, a range of stage results at Bonners Ferry for each storm pattern. This is due to the fact that some patterns of rainfall have a more favorable timing that permits a more effective regulation at Libby. The 1981 pattern, for instance, results in consistently low stages while the 1969 pattern tends to produce the highest stages. The "1969 Early" pattern, in which the 1969 storm has been advanced in time 30 days, has been discounted somewhat in interpreting the results, since it likely represents an occurrence with greater than 100-year recurrence interval.

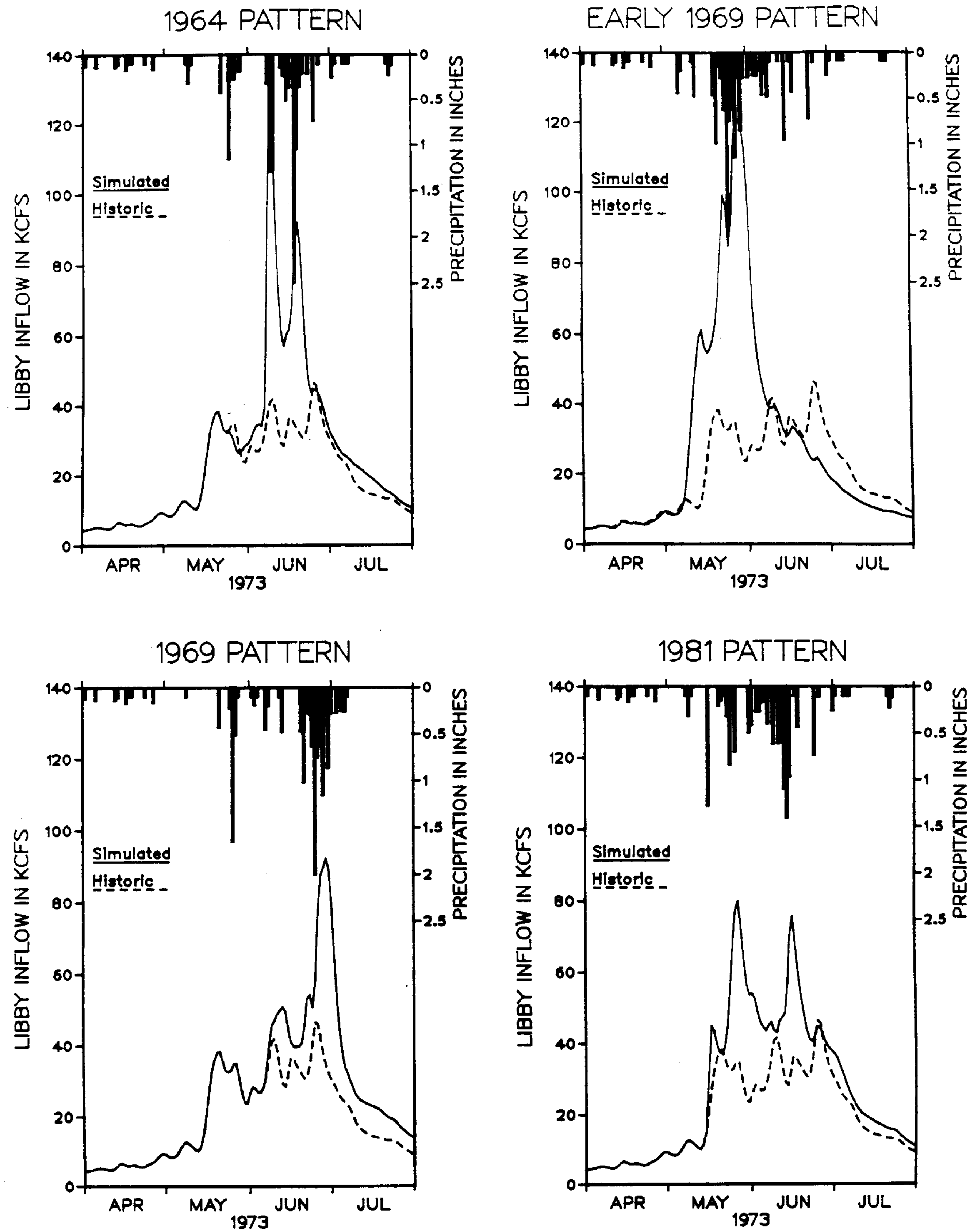

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Figure 4-4. Libby Project, Watershed Simulations, Different Storm Patterns.

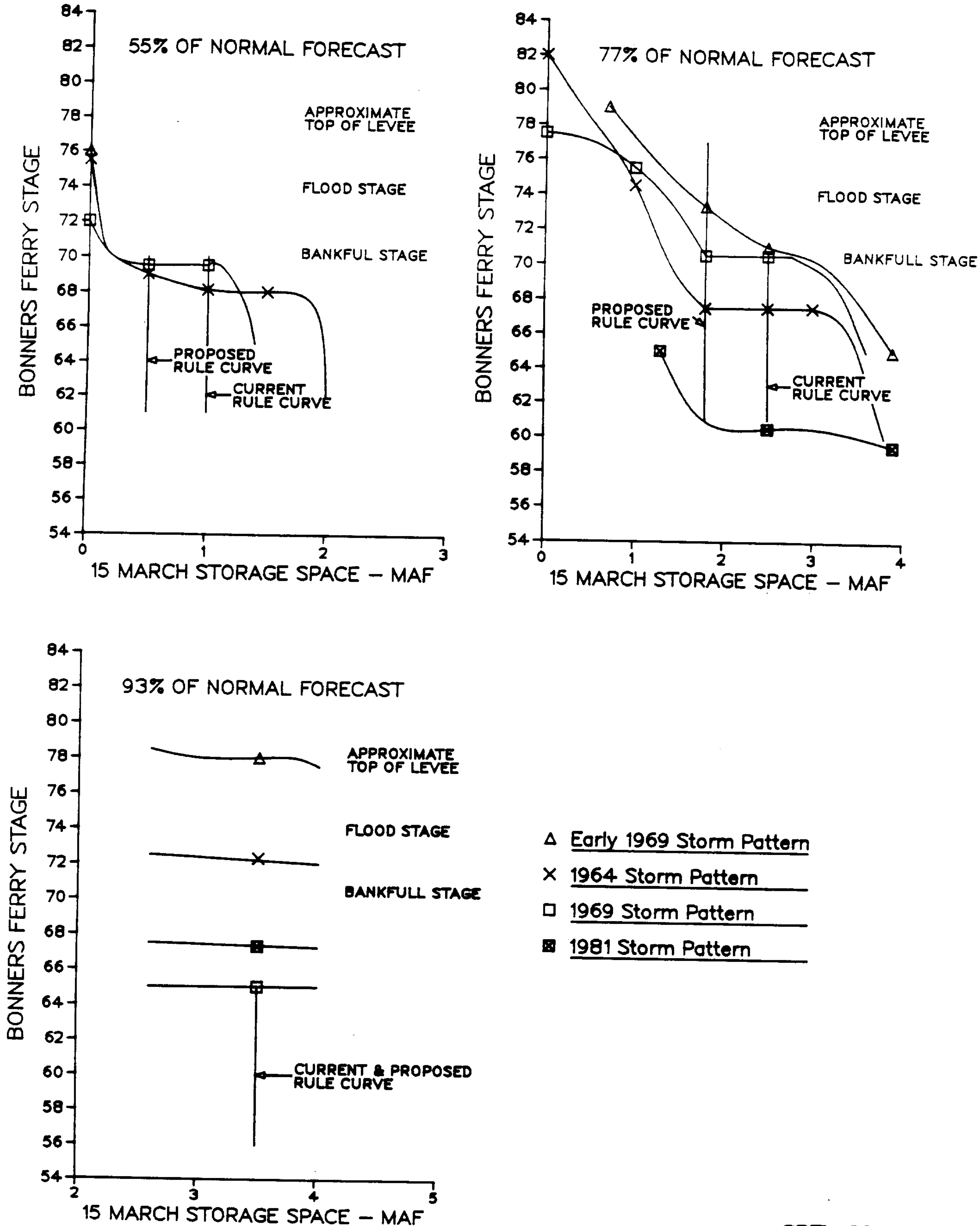

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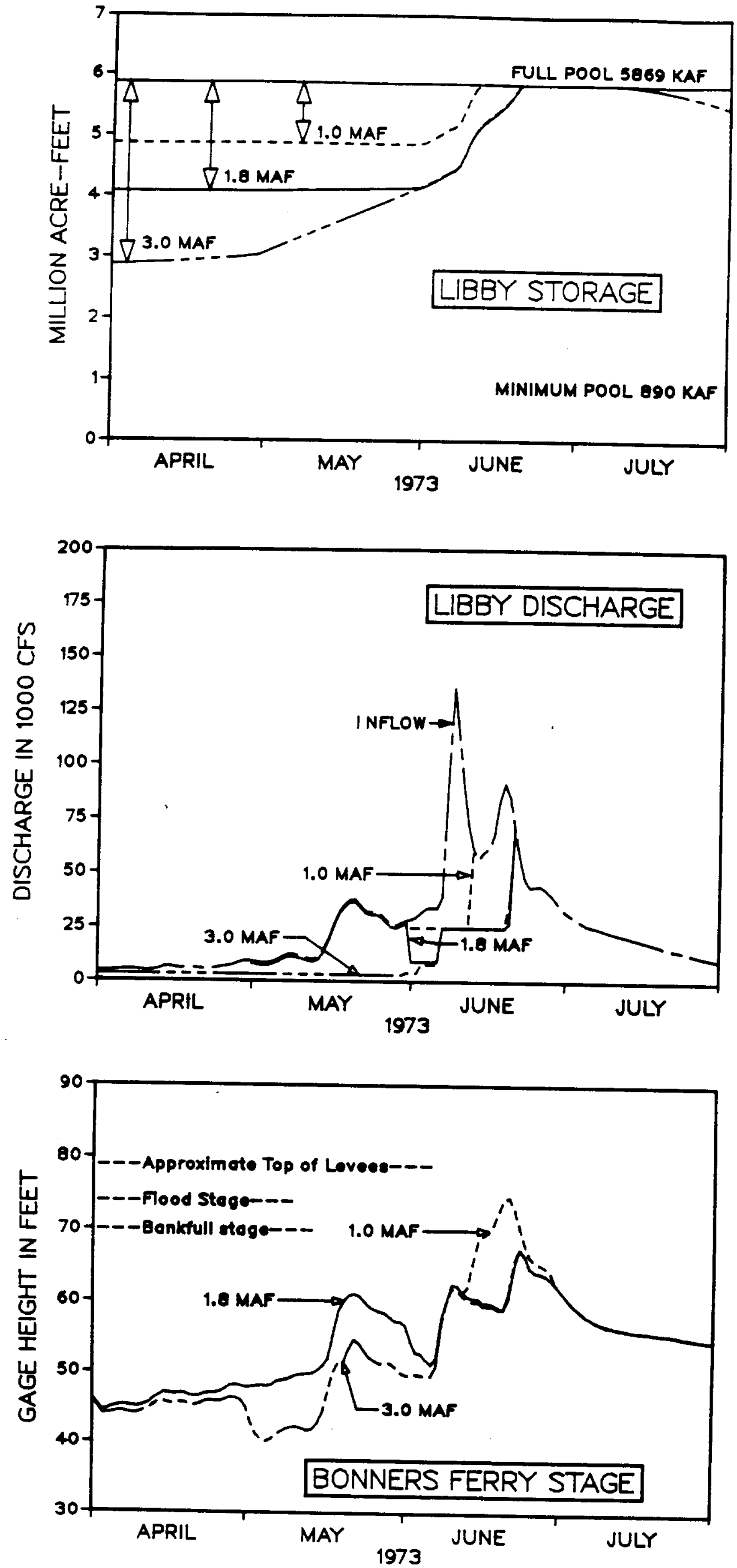
Figure 4–5. Libby Project, Watershed Simulation Results.

For one of the snow/storm scenarios (77% normal forecast, 1964 storm) the hydrographs depicting the operation of Libby under these alternative initial storages are shown on Figure 4-6. The outflows in each scenario are determined by following predetermined operating rules, so that the simulation is as objective as is possible. In most cases, the Flood Control Refill Curve becomes the most important parameter to follow as the reservoir is being filled, in order that filling does not occur prematurely. This leads to an important principle that can be seen on Figure 4-6; that in some cases a change in the initial storage amount will result in little or no change in the eventual peak stage at Bonners Ferry. This is due to the fact that the operation occurring between 15 March and the occurrence of the storm will compensate for the alternative storage assumed on 15 March.

Based upon the results of the simulations and other analyses as summarized on Figure 4-3 through Figure 4-5, a proposed revised rule curve requirement for Libby is shown on Figure 4-7. This curve depicts the change in the maximum drawdown requirement, expressed on the current flood control storage reservation diagram as being on 15 March. When plotted in terms of the traditional drawdown curve, the proposed flood control requirement is depicted on Figure 4-8, and is compared with the existing diagram.

On Figure 4-9 the storage requirement for control at The Dalles is again plotted, this time showing the proposed revised rule curve. On this figure the individual years in the 1929-1987 historic period illustrate the distribution of forecast magnitude and the relative occurrence of drawdowns of various magnitudes. It can be seen that the occurrence of years having the greatest change in the rule curve is relatively infrequent; yet, on the other hand these years are extremely important operationally. The revised curve envelopes the flood control requirement more closely than the official curve in the lower years and is considered to be a more reasonable requirement in this forecast region.

Before being adopted as an official rule curve, the proposed revision to the existing curve will undergo some additional analysis, primarily to determine the most effective timing of drawdown. Along those lines, it is possible that



This chart compares the flood regulation of a flood augmented by a synthetic 100-year rainstorm.
It compares the regulation for assumed 1 April starting storage spaces of 1.0, 1.8, and 3.0 million acre feet.

Snow conditions on 1 April: 77% of normal.
Storm pattern: 1964.

REGULATION GUIDANCE

1. Operate to 30 April Flood Control Refill Curve. 3.0 MAF case is below FCRC, so minimum outflow is released during April. 1.0 and 1.8 MAF cases are both above FCRC, so inflow is passed in April and May. This brings the 1.8 and 3.0 MAF alternatives together by the beginning of the storm. Higher releases are required for the 1.0 MAF alternative.

2. Increase releases above normal releases when it is obvious that a major storm is in the offing. This occurs on June 6th in all cases.

COMMENTARY

This example illustrates the effect of flood control storage space. Resulting peak stage at Bonners Ferry may not be substantially changed by excess space, but is dramatically effected by a shortage of space.

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Figure 4-6. Libby Project, Comparison of Regulation, Alternative Space Requirements.

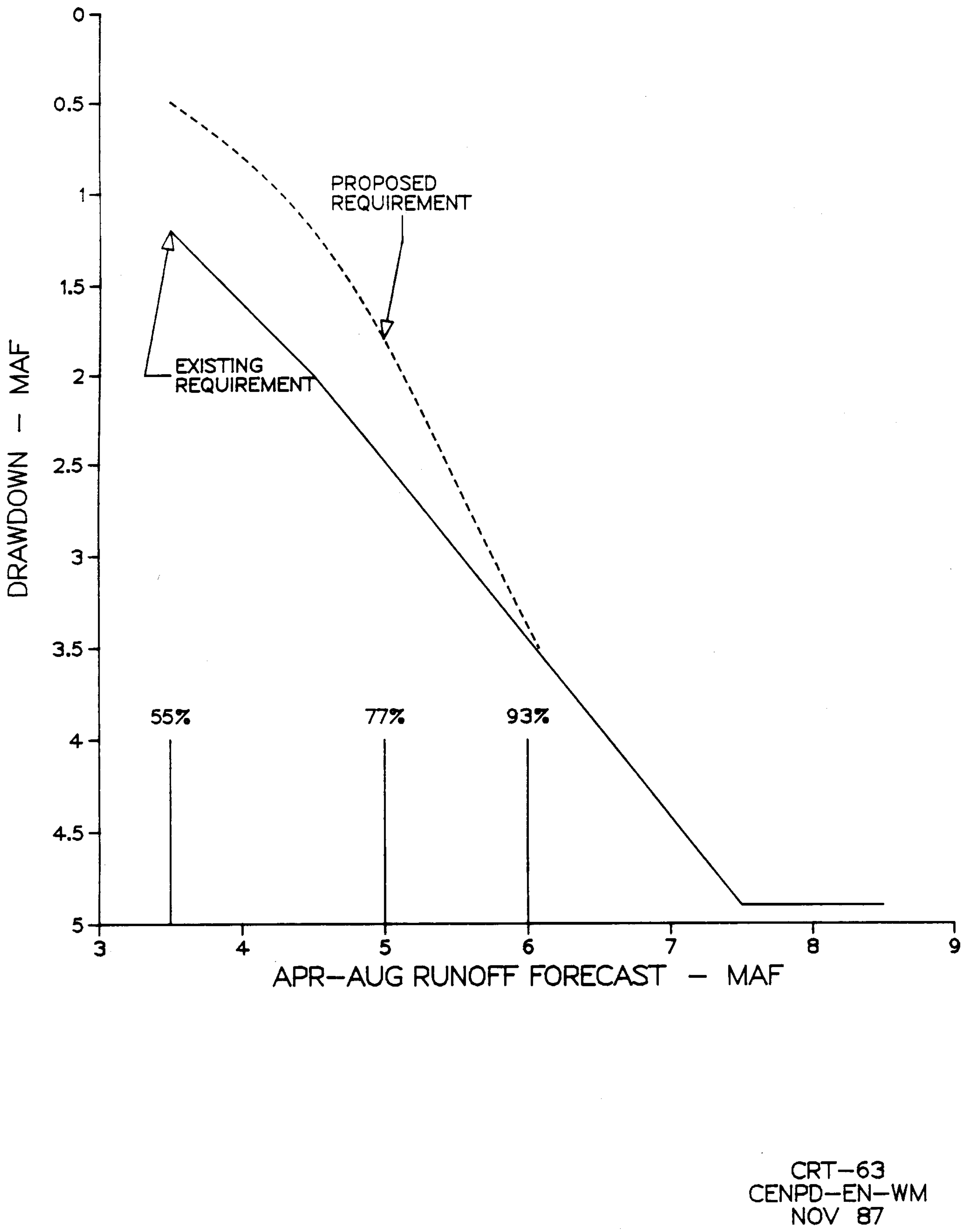


Figure 4—7. Libby Project, 15 March Drawdown Requirement, Existing and Proposed.

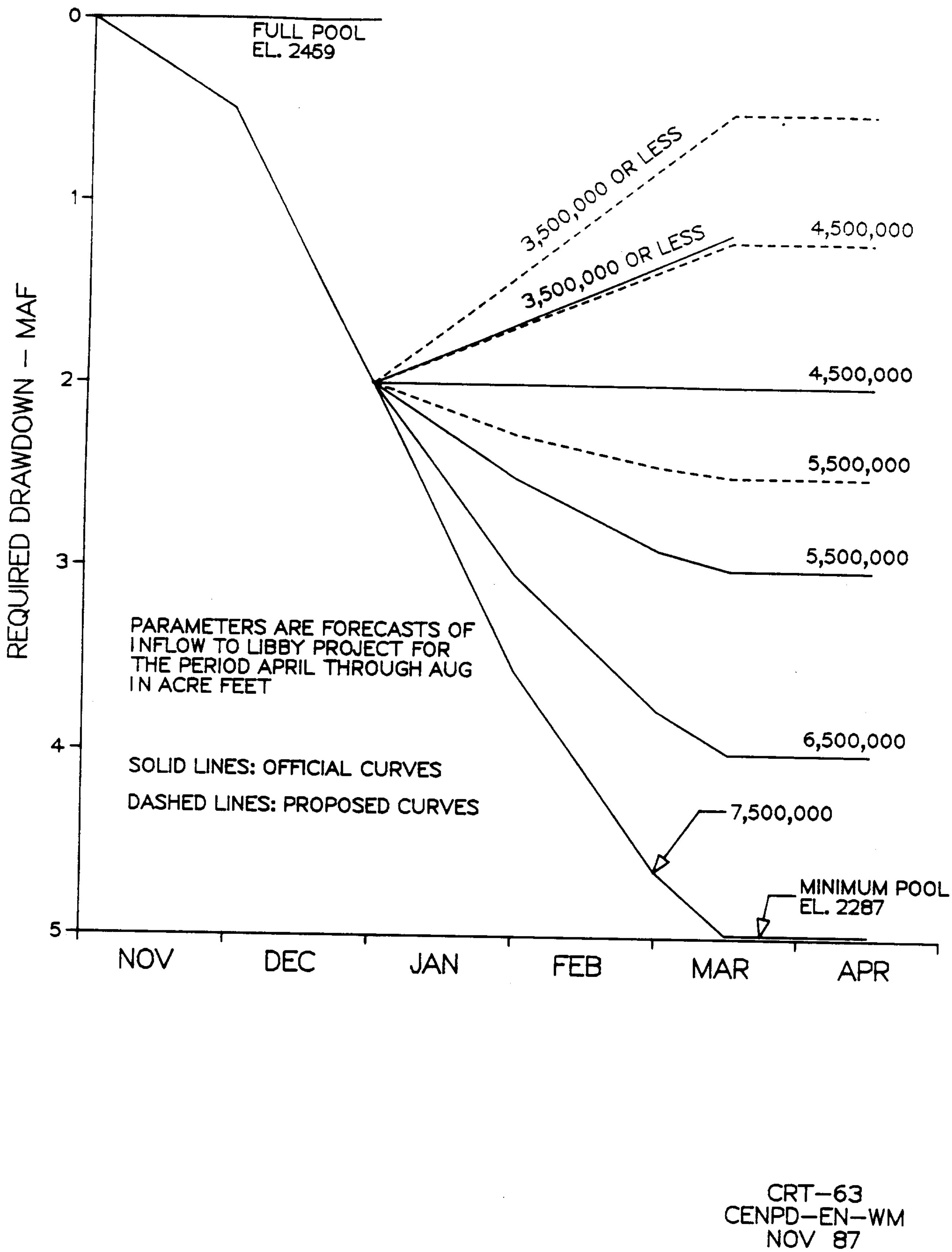


Figure 4–8. Libby Project, Existing and Proposed Rule Curves.

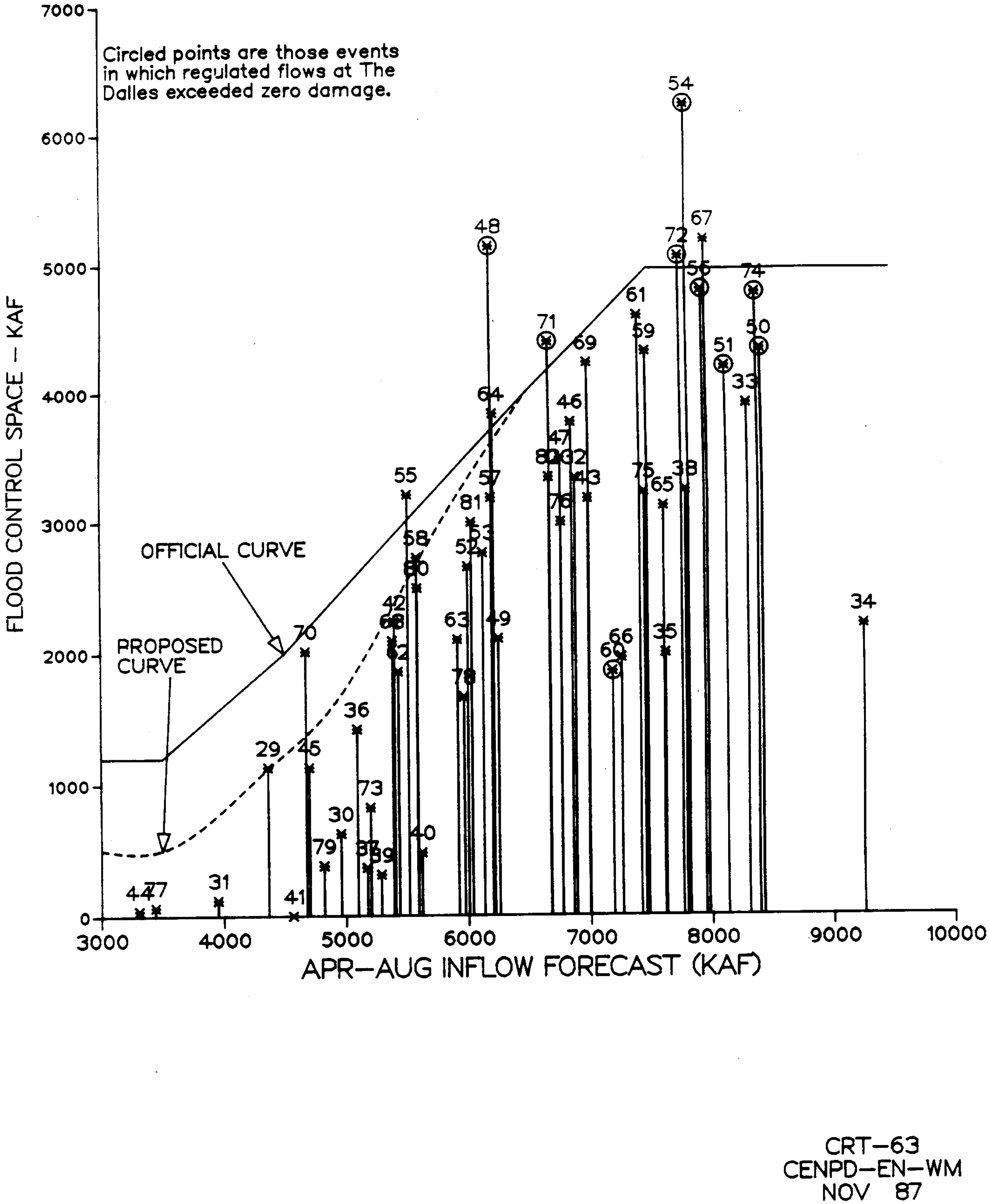


Figure 4-9. Libby Project, System Control Requirement, Comparison of Existing and Proposed Rule Curves.

the Kootenay Lake IJC rule curve would be examined to ascertain the feasibility of its being changed. Neither of these two items significantly bears on the magnitude of the maximum Libby drawdown described above.

The proposed rule curve is essentially the same as the tentative proposal contained in the Interim Report (Figure 16).

Hungry Horse Project

Hungry Horse Dam and Reservoir is located in western Montana in the Flathead River basin, a tributary to the Clark Fork River. The project is located near the mouth of the South Fork Flathead River, where it joins the Middle and North Fork tributaries near Columbia Falls, Montana. The dam construction by the U.S. Bureau of Reclamation in 1950 for flood control and power generation, is operated through Section 7 of the Flood Control Act of 1944 by the Corps for flood control, in coordination with the Bureau. The reservoir provides flood regulation which benefits the downstream flood plain from Columbia Falls to Flathead Lake, located 40 river miles further downstream. In addition to the local flood control objective, the storage space at Hungry Horse is an element in the system flood control for the lower Columbia River, the storage amounting to approximately 8% of the total storage in the system.

The nominal flood stage at Columbia Falls, above which damage will occur, is 13 feet. The corresponding flood stage discharge is assumed, for purposes of this study, to be 48,000 cfs, and major flood discharge is 70,000 cfs. These are approximate reflections of damage levels since river levels are also affected by the elevation of Flathead Lake. Since the project controls only 37% of the drainage area above Columbia Falls, the exceedance of the bankfull discharge is a relatively frequent event, even when Hungry Horse Dam releases minimum outflows. This can be seen on the frequency curve of maximum annual peak discharge at Columbia Falls, Figure 4-10, where the 48,000 cfs flow is exceeded once very two years on the average.

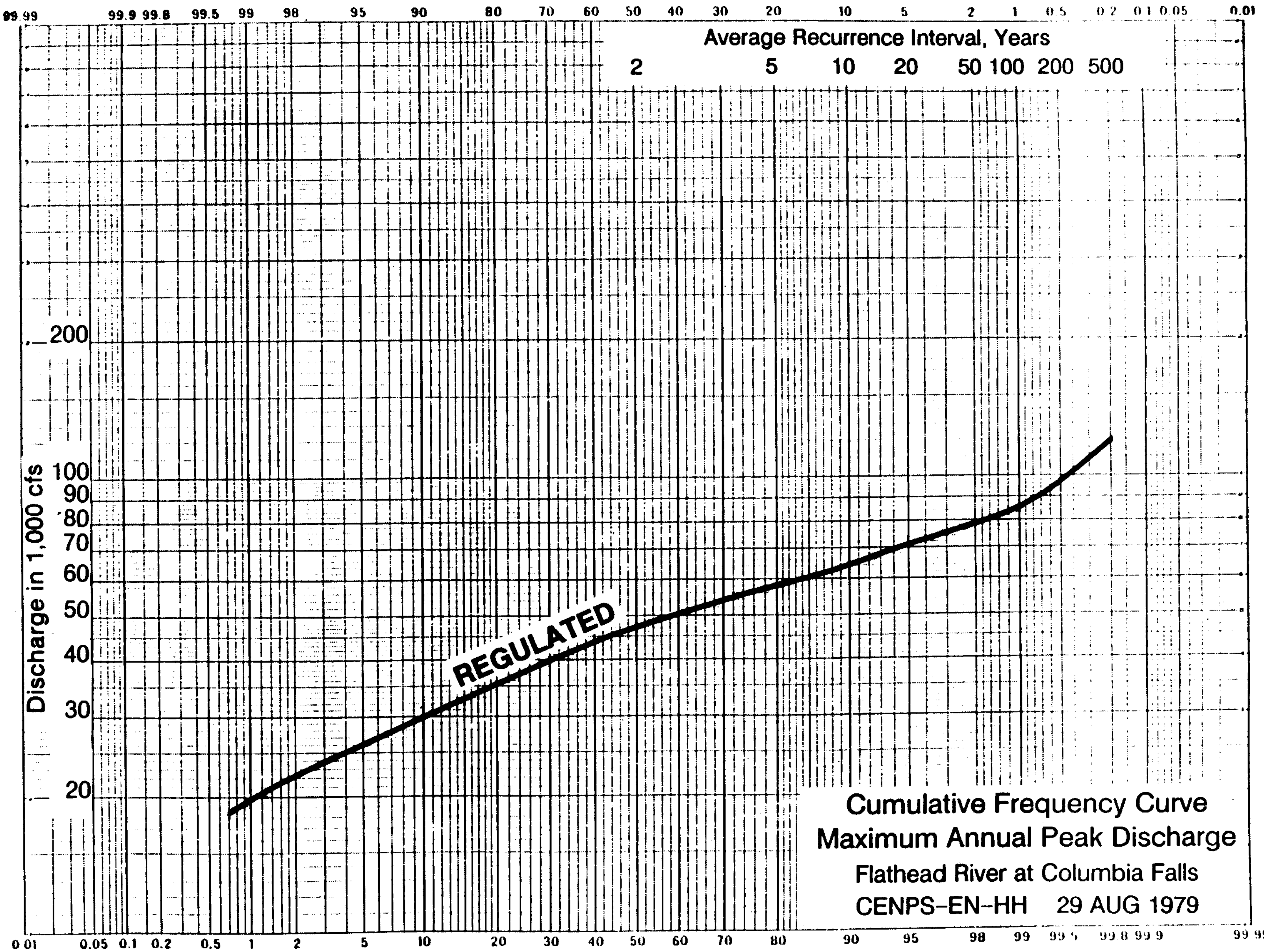
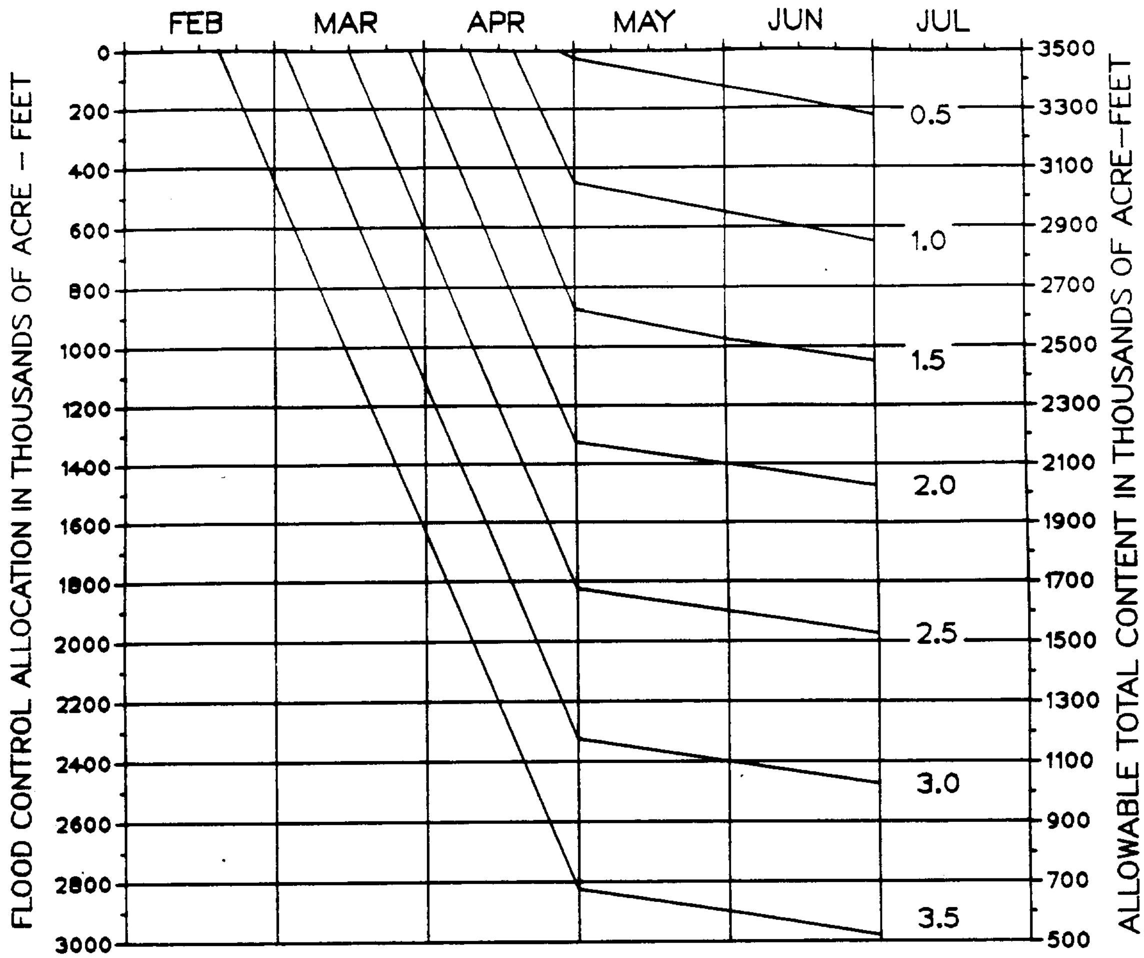


Figure 4-10. Cumulative Frequency Curve, Maximum Annual Peak Discharge at Columbia Falls

The existing seasonal flood control rule curve (Figure 4-11) was established in the 1955 Reservoir Regulation Manual, and has been used since, despite some recognized limitations. One problem is that the rate of drawdown is unrealistically steep for good regulation practice. Typically in actual operations the reservoir is lowered earlier and at a more moderate rate of drawdown. Flathead Lake downstream forms a restriction in the operation, since it can involuntarily trap water released from Hungry Horse if it is at a low level. Thus, to release water into the system downstream from Flathead Lake, the Hungry Horse Reservoir must be drafted early and gradually.

The analysis performed on the Hungry Horse rule curves followed the methodology described in Chapter III, and results were similar to those found for the Libby project. The envelope curve analysis produced the curve shown in Figure 4-12. This suggests that, for controlling flow at The Dalles, the existing curve provides adequate storage reservation on 1 May to control inflow satisfactorily. It does suggest, however, that more storage space than is necessary is called for in years that have forecasts of less than 2 million acre-feet. Furthermore, there is some indication that, for the highest forecasts, the storage requirement is more than is necessary for complete control.

The above findings were evaluated further by the simulation of historic and synthetic floods, with particular emphasis on the regulation for local flood damage areas. Figure 4-13 is a plot summarizing the results of these simulations. Unregulated and regulated flows at Flathead River at Columbia Falls are plotted versus Hungry Horse inflow runoff forecast as percent of normal which within the analysis lead to an adopted lines of 1% probability. The 1% probability line for regulated flow when compared with assumed flood stage at 48,000 cfs shows that only flood control requirements for runoff forecasts of 60% of normal or less can be changed without effecting the frequency of damaging floods. In this study alternatives to the existing rule curve were tried and the results were plotted on Figure 4-14 as proposed rule curves. In Figure 4-14 two separate runoff forecasts of 52% and 70% of normal are shown with regulated peak flow at Columbia Falls plotted versus flood control storage space requirement in each case. For the 52% of normal forecast, testing alternatives of storage requirement indicated that required storage space could be reduced



NOTE:

These paremeters represent runoff volume anticipated at Hungry Horse Dam between forecast date and September 30. They were determined from recorded flood flows on Flathead River at Columbia Falls and on the Columbia River at The Dalles and the release rates adopted for the Flood Control Operation Plan.

The ordinate of the parameter for any given forecasted runoff is the space required in Hungry Horse Reservoir on the date of the forecast to control the flow at Columbia Falls and at The Dalles so as to reduce flood damage insofar as practicable on the Flathead River and the Lower Columbia River.

Factors of safety beyond enveloping curves determined from recorded floods are incorporated in the parameters as follows:

200,000 acre–feet prior to May 1.
200,000 acre–feet on May 1 decreasing uniformly to zero on June 30.

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DEPARTMENT OF THE INTERIOR
BURAU OF RECLAMATION
BRANCH OF PROJECT PLANNING
HYDROLOGIC STUDIES OFFICE

FLOOD STORAGE ALLOCATION PARAMETERES
HUNGRY HORSE RESERVOIR

Figure 4–11. Hungry Horse Project, Existing Flood Control Diagram

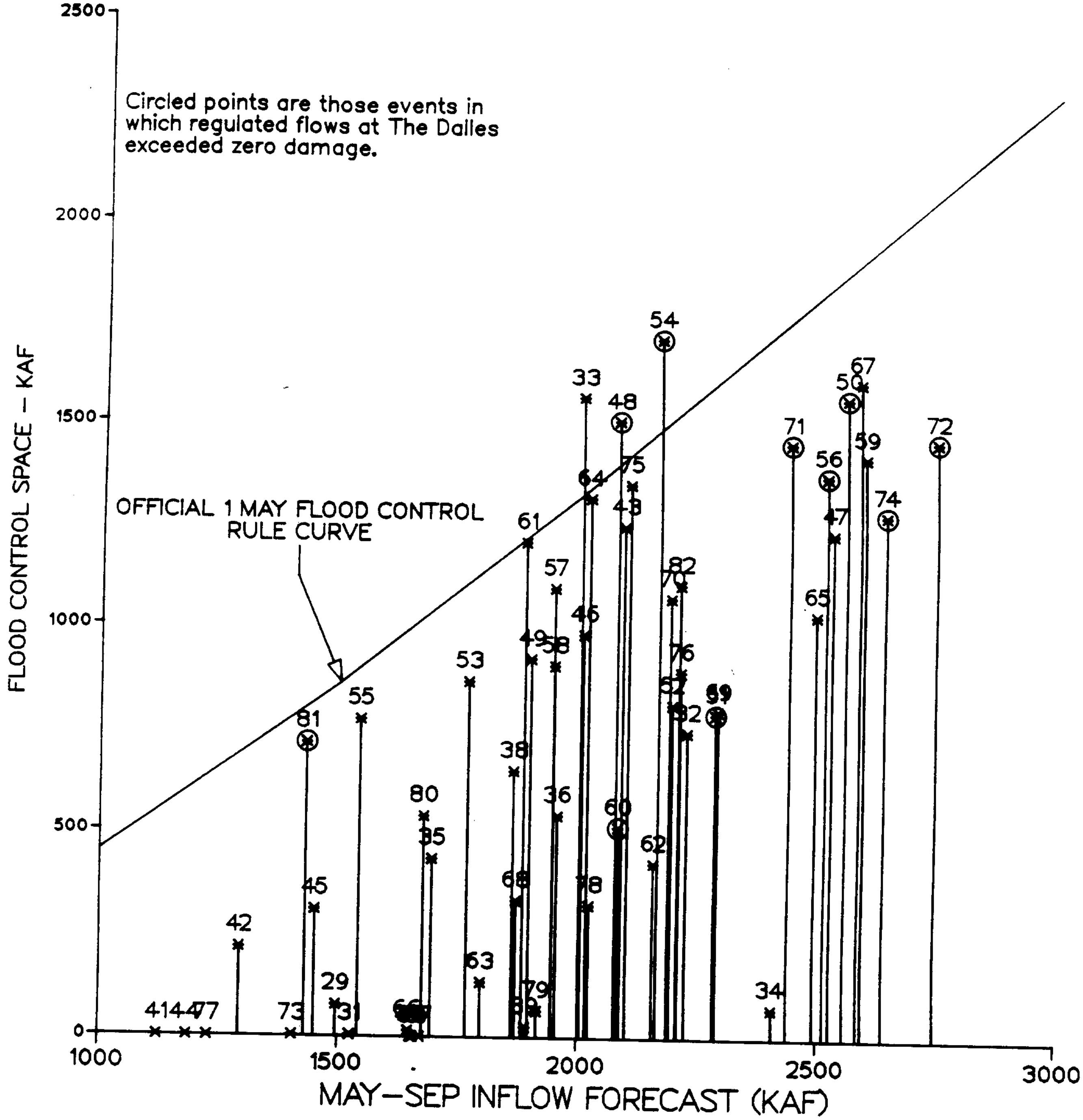

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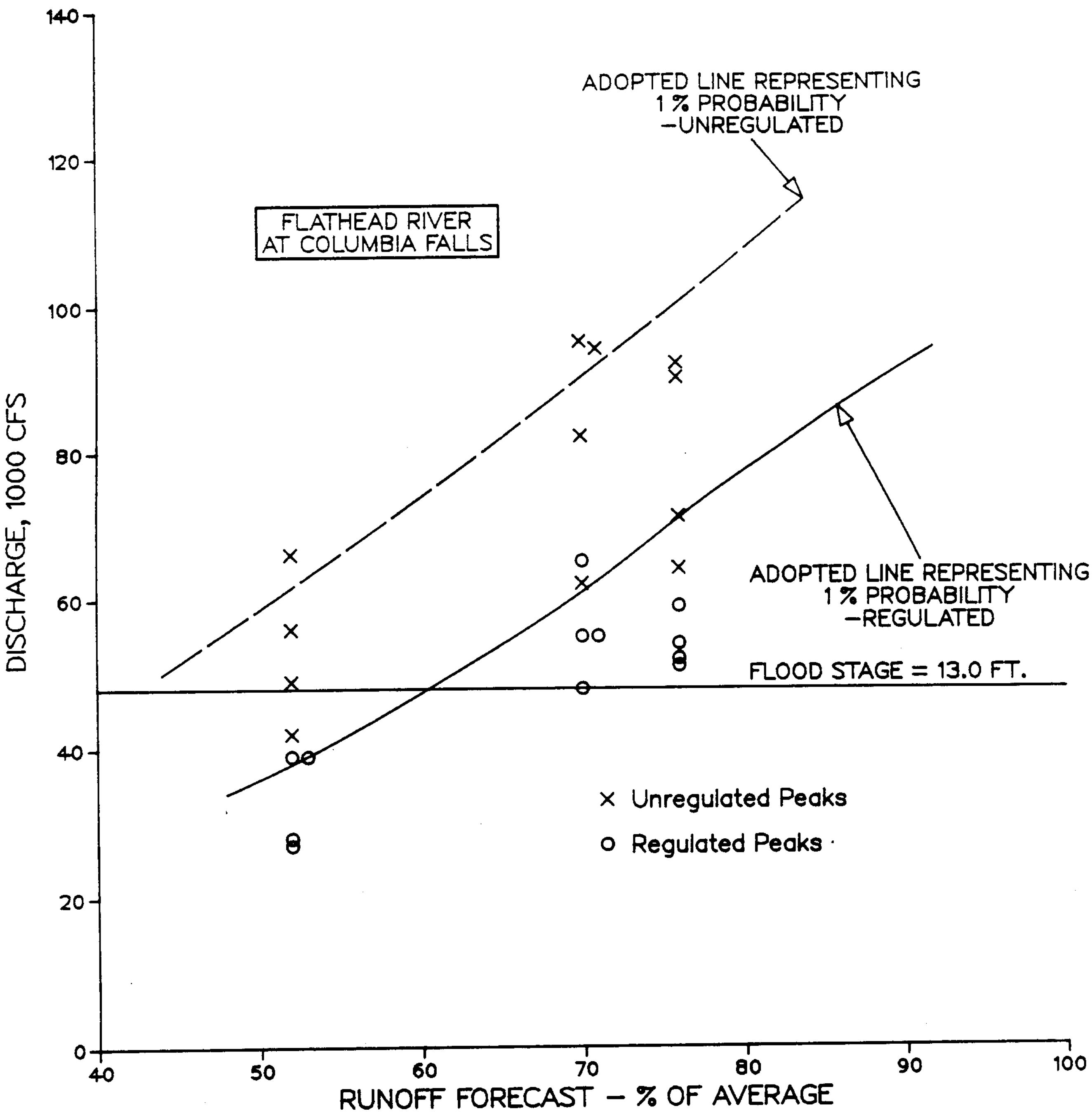
Figure 4-12. Hungry Horse Project, Flood Control Storage Requirement System Control.



NOTES

1. Refer to Figure 3—6 for explnation of derivation of this figure.
2. Reflects existing official Flood Control Rule Curve for Hungry Horse

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Figure 4—13. Hungry Horse Project, Watershed Simulation Results.

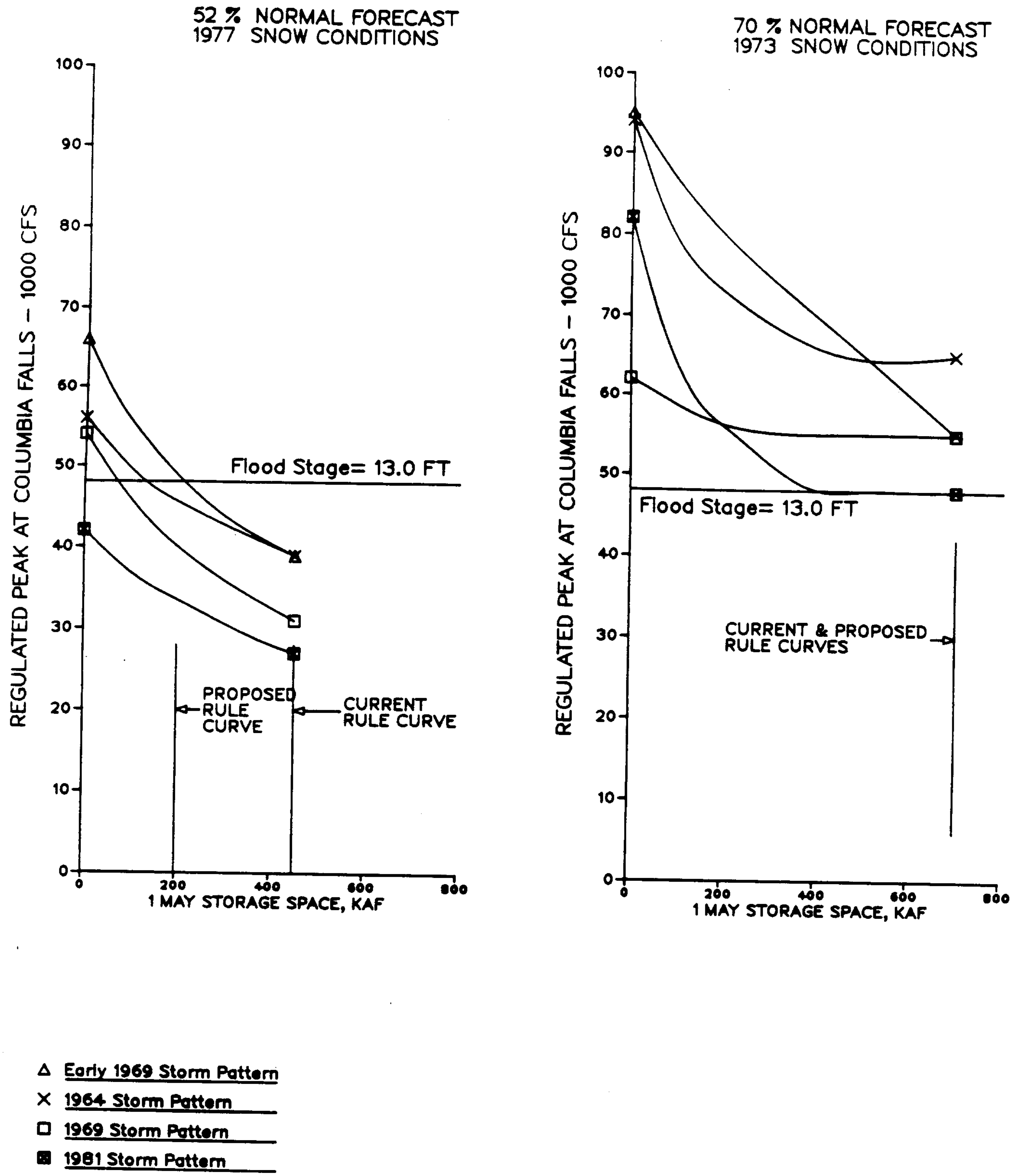

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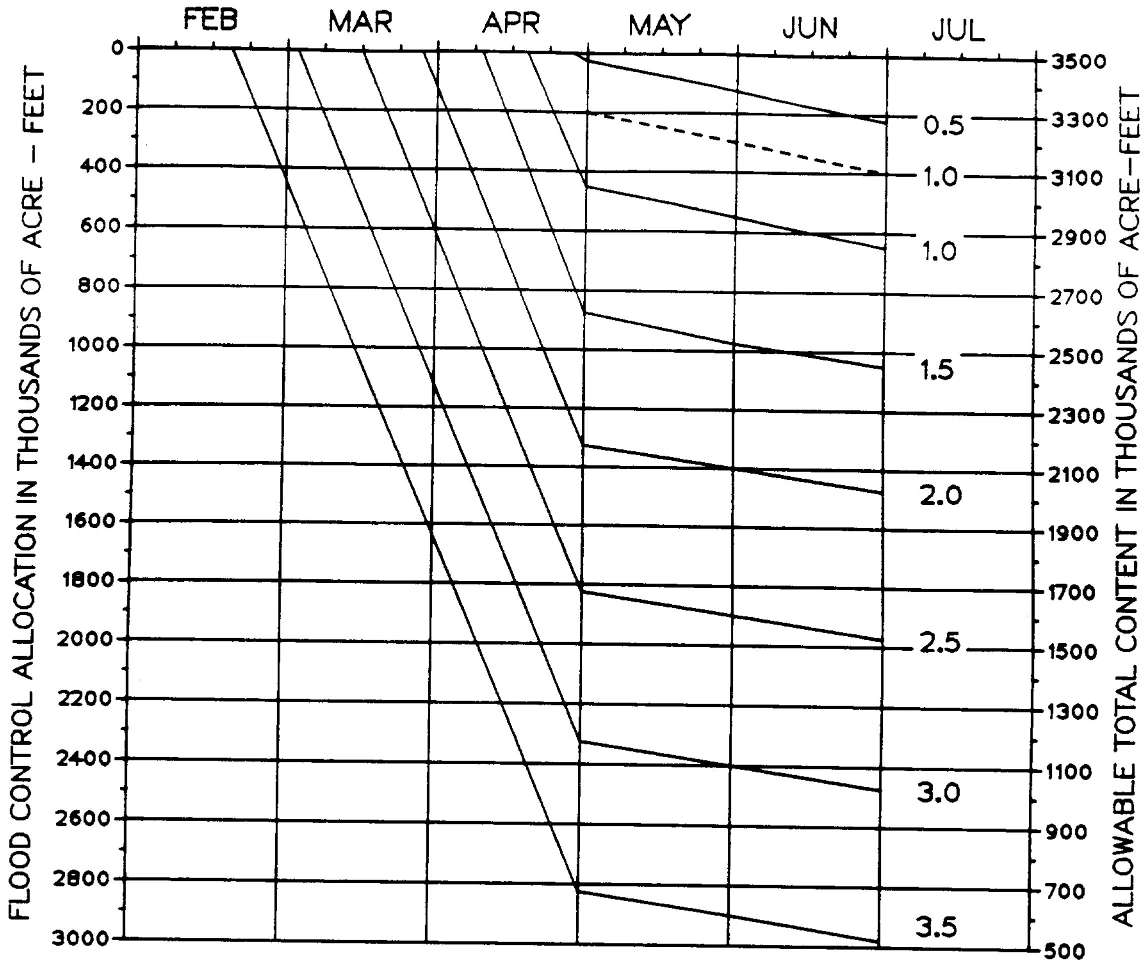
Figure 4-14. Hungry Horse Project, Determination of Proposed Flood Control Rule Curves.

to 200,000 acre-feet without producing damaging flow. This yields one point on the proposed flood control rule curves. The other example of 70% of normal forecast shows that reduction in flood control storage space would cause increased damaging flows and, therefore, no change is proposed for this forecast level. Overall, the proposed flood control rule curve raises regulated discharges in the forecast region below 60% of normal, where they would have otherwise been below bankfull level; yet it does not result in increased flow above the 48,000 cfs flow level. The proposed rule curve modification is shown on Figure 4-15 in terms of the existing flood control diagram. The dashed line (1,000,000 acre-feet parameter) on 1 May corresponds to the 50% of normal forecast parameter and a required draft of 200,000 acre-feet. Other aspects of the existing flood control diagram such as the late winter-early spring draft rate require further investigation before a proposal can be officially adopted.

The rule curve modification deemed acceptable confirms the preliminary conclusions reached in the Interim Report, in which the region of forecasts lower than 60% of normal would be the limit of acceptable change. This is a relatively insignificant change, since runoff this low has occurred only a few times in the past 50 years of record. The limitation to further change is the relatively low bankfull flow that currently exists at Columbia Falls, and the assumed criteria that this flow should be protected against with a 1% risk. If these assumed constraints are eased, then further modification of the rule curve would be feasible.

Grand Coulee Project

The Franklin D. Roosevelt reservoir formed by Grand Coulee dam is perhaps the most important of all flood control reservoirs in the Columbia River Basin. With 5.2 million acre-feet of storage space (13% of the total system storage) located relatively close to the lower Columbia damage center, this project provides the capability of a fined-tuned regulation at The Dalles control point, taking into account storage operations at other projects in the system and unregulated runoff emanating from the Snake River and other tributaries. In the Columbia River Treaty Flood Control Operating Plan Grand Coulee project is classified as a "Category IV" project, along with Arrow and John Day reservoirs. This classification is defined as being a reservoir operated with variable releases primarily for the control of the lower Columbia.



NOTES:

1. Refer to Figure 4–11 for explanation of basic curves.

2. Solid lines represent existing, official rule curve. Dashed line is the proposed revision. For a 0.5 maf forecast, no storage space is required.

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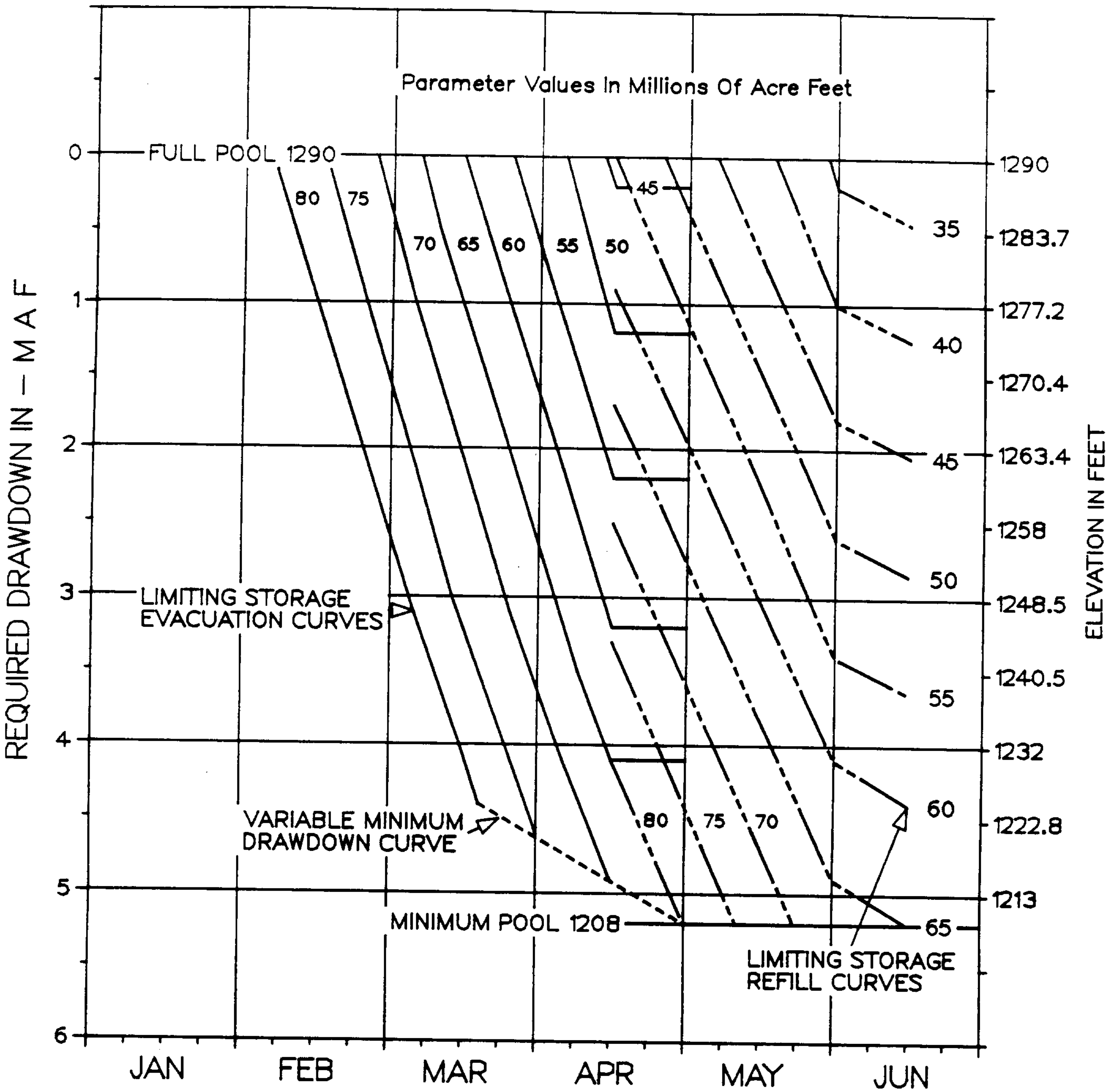
Figure 4–15. Hungry Horse Project, Current and Proposed Flood Control Rule Curves.

In addition to its flood control capability, the Grand Coulee project has the largest installed capacity of any reservoir in the system (6,180 megawatts), and it provides irrigation water to farmland in eastern Washington by pumping from the reservoir into Banks Lake. Additionally, there is recreational and commercial usage of the lake during the summer period; and, the project is important in providing water for the mid-Columbia Water Budget operation. All of these project functions result in pressure to keep the reservoir as high as possible and thus tend to be in conflict with flood control operating objectives.

The current flood control storage reservation for Grand Coulee was formally agreed upon by the Bureau of Reclamation and Corps of Engineers on July 21, 1978. This curve and its attendant rules were established after interagency studies were conducted in the mid-1970's, following the authorization of the Grand Coulee Dam Third Powerhouse. At the time of these studies a great deal of concern and uncertainty existed about the problem of dissolved gas supersaturation caused by water having to be passed over spillways. In an attempt to reduce high flows during the April-May fish migration period, the storage reservation diagram was developed so that reservoir drafting would be complete prior to this period. In more recent years, however, structural modifications, expanded powerhouse capacity, and other factors have reduced the concern for dissolved gas supersaturation to the extent that it is seen desirable to modify the storage reservation diagram so that a later draft of storage occurs. This results in less conflict with power operation and leaves more water in storage during May for the Water Budget operation in low water years.

The official storage reservation diagram, Figure 4-16, is a complex combination of several series of curves, making interpretation somewhat difficult. The parameter on the series of curves is defined as the April through August forecasted runoff at The Dalles, minus corrections for upstream storage space at projects other than Grand Coulee. "Limiting Storage Evacuation Curves" define the basic drawdown requirement in anticipation of the spring flood. Maximum drawdown, reached on 15 April, can be held until it is determined that storing is required for the flood control operation. A second set of curves, "Limiting Storage Refill Curves", restrict the degree to which the reservoir may be filled after 15 April. The difference between the two sets of curves permitted filling



GRAND COULEE DAM
(FRANKLIN D. ROOSEVELT LAKE)

FLOOD CONTROL STORAGE RESERVATION DIAGRAM

PREPARED PURSUANT TO FLOOD CONTROL REGULATIONS FOR GRAND COULEE DAM & FRANKLIN D. ROOSEVELT LAKE (33 CFR 208)

BUREAU OF RECLAMATION

EFFECTIVE DATE 21 JULY 1978 FILE NO. 511

Figure 4–16. Grand Coulee Project, Official Flood Control Rule Curve.

to reduce spill and dissolved gas supersaturation. As mentioned above, this objective has less meaning today than it did when the curves were originally constructed. For this study, the most significant aspect of the Grand Coulee rule curve is the maximum drawdown requirement, defined as a function of runoff forecast and storage space corrections. This relationship is extracted from the storage reservoir diagram and is shown on Figure 4-17. Also shown is the interim operating requirement currently agreed to between the Corps and Bureau of Reclamation. This curve was developed in 1982 when agencies agreed that the early drawdown required by the official curve was not necessary. The third rule curve shown on Figure 4-17 is as proposed by this study. The fourth curve is the uppermost position for the rule curve examined during this study. In the investigations of rule curve revisions, these curves were evaluated, along with other alternatives not pictured.

The investigation of the Grand Coulee flood control criteria amounted to essentially an analysis of the entire Columbia system, since (a) the requirement at Grand Coulee is in part a function of the storage space existing in the rest of the system; and (b) the control point for Grand Coulee, The Dalles, is the same as the for the entire system. The analysis involved simulating both historic and synthetic floods under alternative scenarios of rule curve changes, and evaluating the resulting impact in terms of the lower river flood peaks. A model of the entire Columbia River system had to be used, as described in Chapter III. For upstream storage space requirements, the proposed new rule curves were used in the case of Libby, Hungry Horse, Dworshak, and Brownlee. These simulations, therefore, were the ultimate test of all rule curve changes on the system's flood control capability.

Figure 4-18 is a plot showing the results - at Grand Coulee and The Dalles -of one simulation involving a synthetic rainstorm. This represents a very small portion of all output from the computer run - leaving out the other reservoirs in the system - but serves to illustrate the alternative operations at Grand Coulee and the resulting flows at The Dalles. A total of 107 computer simulations were made, including both those that were a re-regulation of historic floods, and those that included a synthetic storm. The simulation in Figure 4-18 starts with 1 April snow conditions representing a 100% of normal volume forecast

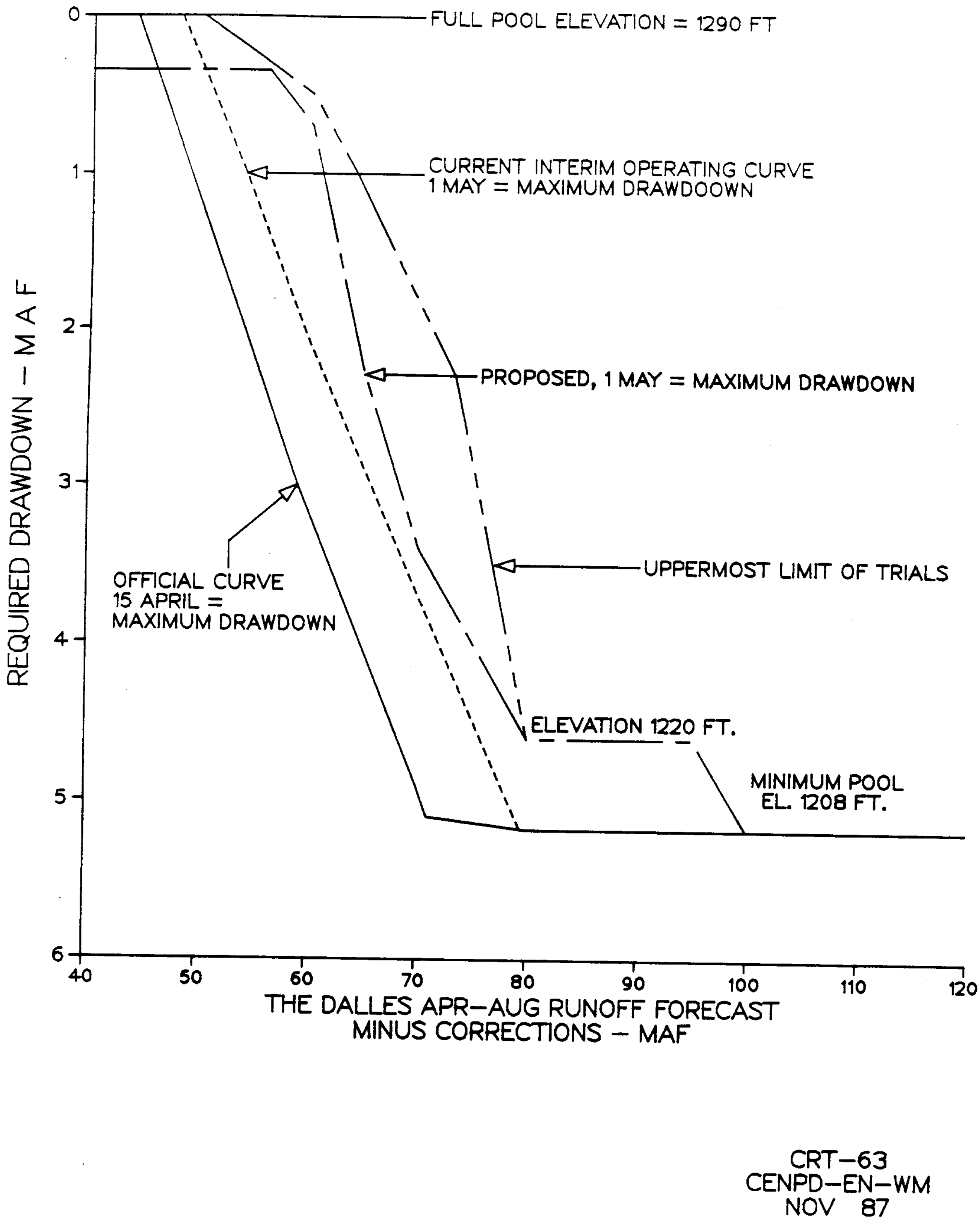
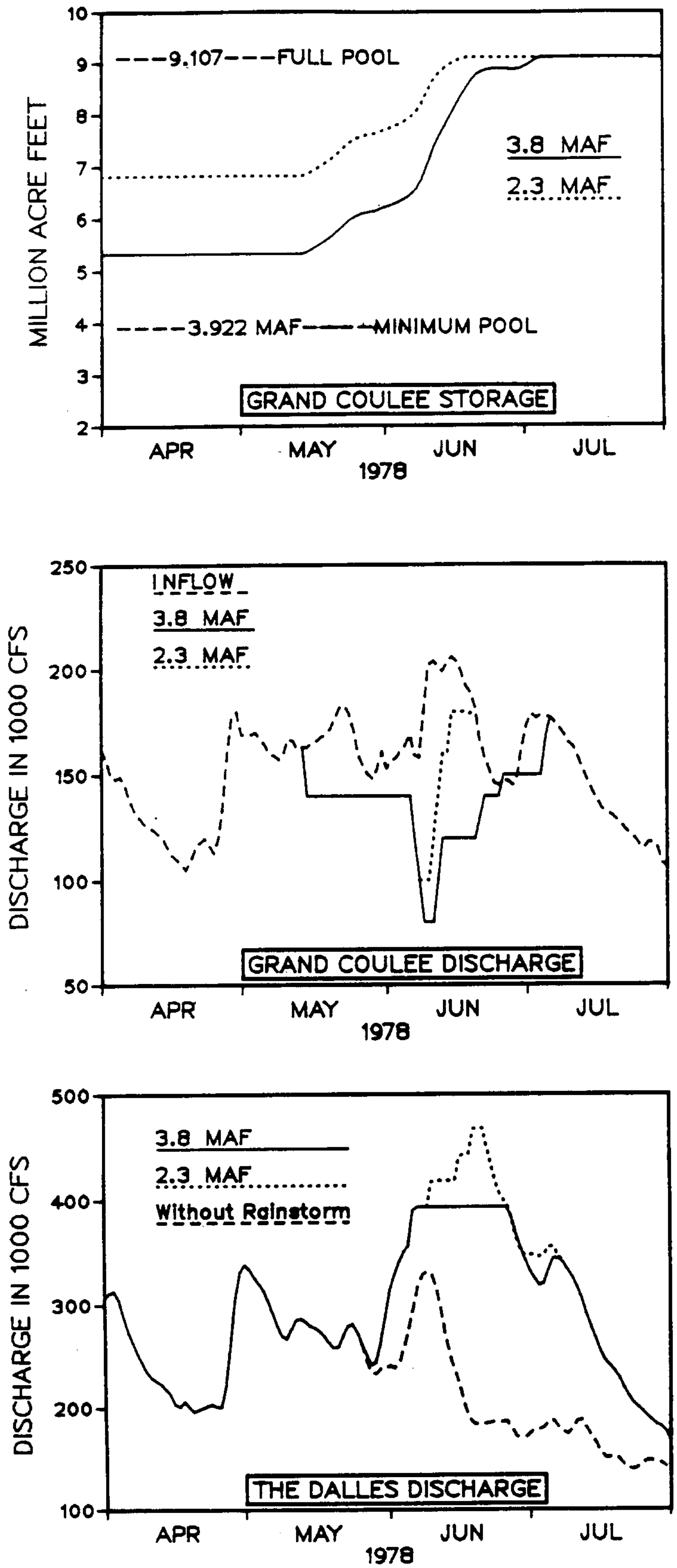


Figure 4–17. Grand Coulee Project, Comparison of Alternative Rule Curves.



NOTES

This chart compares two simulated system flood regulations; differing only by the trial 1 April flood control storage space requirements assumed for Grand Coluee Dam. One trial is 3.8 million acre-feet from the proposed rule curve. The other is 2.3 million acre-feet, the uppermost trial.

FLOOD SIMULATION

1. Snow conditions reflect a 100% of normal forecast for The Dalles; this forecast minus a correction for storage space in upstream reservoirs results in entering the Grand Coulee rule curve with a 73.2 maf parameter (see Fig. 4-17).
2. The April through July rainfall and air temperature sequences are drawn from a historical year, but are augmented for a 30-day period by a 100-yr precipitation above The Dalles with timing and temperatures patterned after a storm in 1964.

REGULATION GUIDANCE

1. Storage at reservoirs other than Grand Coulee are in accordance with new proposed flood control requirements.
2. Grand Coluee is refilled in expectation of a normal runoff volume until it becomes apparent that a larger event is occuring. Subsequently, an effort is made to preserve storage space behind Grand Coulee Dam to maintain control and reduce the peak flow at The Dalles.

COMMENTARY

1. In both cases of 1 April starting storage shown on this chart, The Dalles peak discharge was reduced by Grand Coluee storage. In the case of the trial flood storage space of 2.3 million acre-feet, The Dalles non-damaging flow level of 450,000 cfs was exceeded slightly (peak=468,000 cfs). The 3.8 million acre-feet trial storage space controlled flow at The Dalles to less than 400,000 cfs.
2. The flood scenario and flood storage space trials shown on this chart are an example of many other such simulations performed to evaluate flood storage space requirements for Grand Coluee.
3. For comparsion, the flow at The Dalles without the 100-yr rainstorm is shown. This reflects regulation by the official rule curves.

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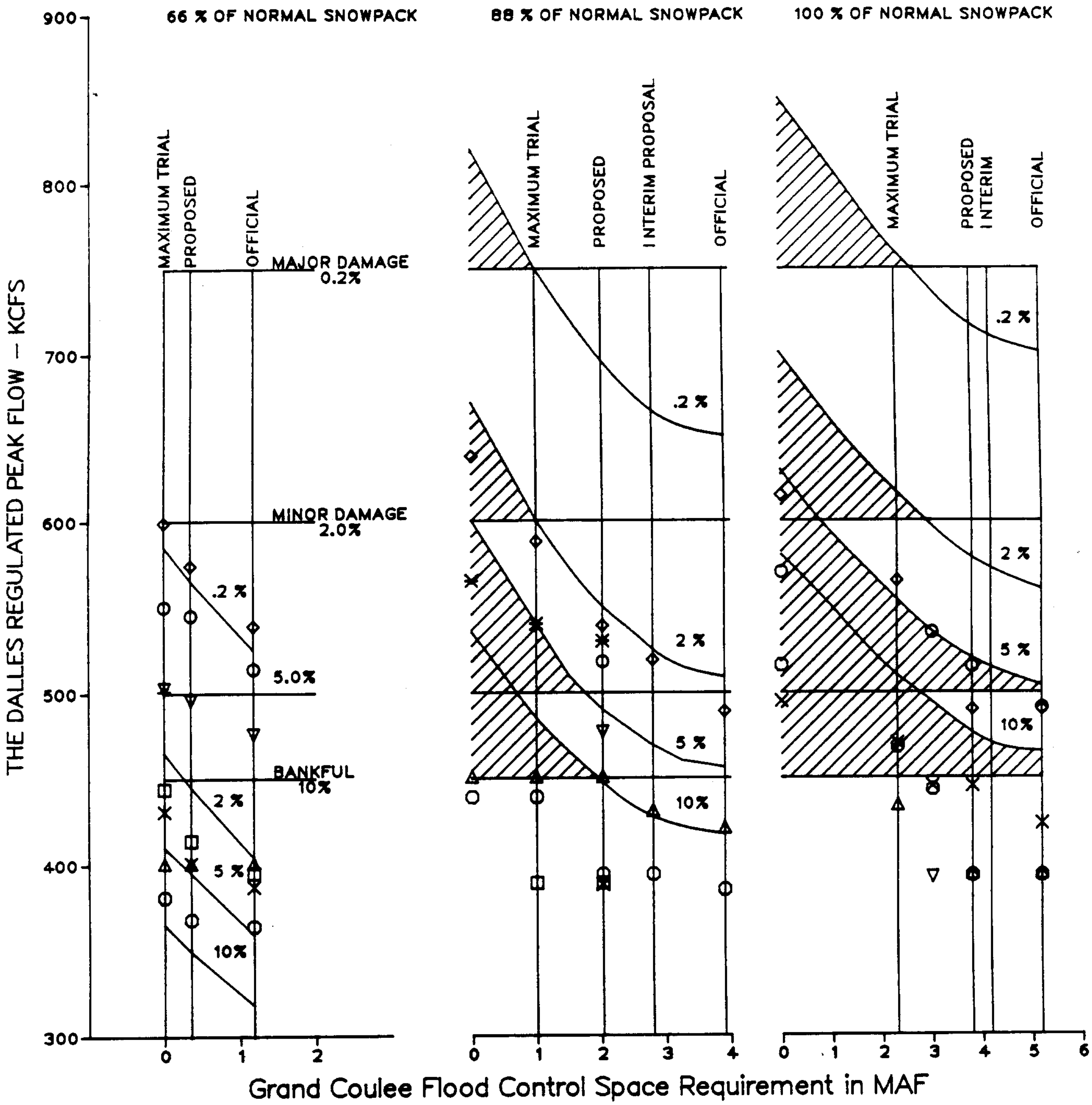
Figure 4-18. Grand Coulee Project, Example of Simulations to Investigate Alternative Storage Requirements.

for the April through August period. The precipitation and temperature sequences after 1 April are as occurred historically in 1978, except for a 30-day period where a synthetic storm of 100-year recurrence interval patterned after a storm in 1964 replaces the historic sequences. Two system flow regulation simulations are shown, differing only by the assumed trial flood control storage space behind Grand Coulee Dam of 2.3 and 3.8 million acre-feet and the resulting releases at Grand Coulee. These simulations demonstrate how Grand Coulee storage space requirement versus the regulated flow at The Dalles was investigated.

The scenarios evaluated in the analysis of alternative flood control requirements included (1) the official rule curve; (2) the interim rule curve now being used in operations; and, (3) several proposed alternatives which incorporated changed configurations of the official and interim curves. For the proposed alternatives one factor investigated was to limit the maximum drawdown in average to above-average years to elevation 1220 feet, and permit drawdown to minimum pool (elevation 1208 feet) for only the most extreme runoff forecasts. The proposed curve on Figure 4-17 shows configuration of the elevation 1220 limit. The purpose for this modification is to permit pumping into Banks Lake in more years, since pumping is restricted when the lake is lowered below 1220 feet. A second basic change evaluated was alternatives of higher rule curves for extremely-low to low runoff forecasts. The elevation 1220 feet restriction was evaluated primarily by the historic flood simulations, while the raised rule curves in low runoff years were evaluated using synthetic storm simulations.

The results of the synthetic storm simulations for different assumed storage amounts at Grand Coulee are summarized on Figure 4-19. This plot shows the peak flow resulting at The Dalles from changed flood control storage amounts at Grand Coulee, given several forecast conditions (snow pack) and several rainstorm patterns. Like similar analyses for Libby and Hungry Horse, the range of forecasts investigated with storm simulation was limited to those less than 100% of normal; however, as is discussed later, forecast ranges greater than 100% were investigated using historic floods. The results of the simulations produced a wide range of variation in peak flow at The Dalles depending upon such factors



NOTES

1. Curves represent percent chance of regulated flow being exceeded.
2. Horizontal lines are study defined flood control criteria expressed as allowable percent chance of being exceeded.
3. Cross—hatched areas represent violations of the study defined critera.
4. Each symbol shown represents the regulated peak flow resulting from the simulation of a synthetic flood through the reservoir system.

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Figure 4—19. Results at The Dalles of System Simulations with Varying Flood Control Space at Grand Coluee.

as storm temperature, distribution of storm precipitation, distribution of snowpack within the basin at the beginning of the storm and starting storage content for Grand Coulee. Results from simulations are represented by symbols (triangles, squares, diamonds, etc.) with all simulations for a particular storm having the same symbol; for example, triangles are a 30-day, 100-year storm with a 1964 distribution pattern.

Also shown on Figure 4-19 are curves of percent chance of exceeding a regulated flow, conditional upon the snowpack. The construction of these curves was guided by variation of simulated flows with trial flood control storage space requirement at Grand Coulee. The conditional exceedance frequencies were determined for official rule curve requirements by separate statistical analysis based on available historic data. The curves of percent chance of exceedance are compared with horizontal lines representing allowable percent chance of exceedance, which are study determined criteria that will assure no change in flood control capability of the system. These same criteria used in the Interim Report are shown below in Table 4-1.

TABLE 4-1

DAMAGE-FREQUENCY CRITERIA AT THE DALLES

THE DALLES FLOW	VANCOUVER STAGE	REFERENCE TERM	EXCEEDANCE FREQUENCY USED FOR THIS STUDY
450,000 cfs	16 feet	Bankfull	10%
500,000 cfs	19 feet		5%
600,000 cfs	22.5 feet	Minor Damage	2%
750,000 cfs	26 feet	Major Damage	0.2%
950,000 cfs	30 feet	Levee Overtopping	0.05%

The crosshatch regions on Figure 4-19 indicate where the study determined criteria are violated, meaning there is an indicated possibility of compromising system flood control capability. For the 66% and 88% of normal snowpacks the proposed flood control requirement for Grand Coulee does not effect system flood control capability, since the crosshatch region does not intersect the proposed storage space for any of the criteria levels. For the 100% of normal snowpack at the two lower criteria levels at 450,000 cfs and 500,000 cfs, the crosshatch region crosses the proposed storage space indicating possible compromise. The position of the crosshatch regions at the higher criteria levels of 600,000 cfs and 750,000 cfs assure no compromise of system flood control at the indicated frequencies. The overall message of Figure 4-19 is that the proposed rule curve for Grand Coulee will have minor impact on current flood control capability. Conversely, if alternatives allowing more storage in Grand Coulee (such as the "Maximum Trial" shown on Figure 4-19) are considered, the crosshatch areas indicate that flood control capability is increasingly compromised.

Further investigation into the 100% of normal and larger forecast conditions (snowpacks) reveals that overall system flood control capability is not compromised with the proposed curves. Simulations based on re-regulation of historic floods for larger forecasts and regulation of synthetic storms for normal forecasts show essentially no change in regulated flows between the official and proposed flood control requirement at Grand Coulee. Although a complete set of re-regulated historic floods is not yet available for statistical analysis, a simplified approach was utilized to demonstrate the probable effect of the proposed flood control requirement. Figure 4-20 is a pair of annual frequency curves, one (Curve B) showing current regulated flow frequency, and the other (Curve A) likely changes in regulated flow frequency if proposed rule curves are implemented. The annual regulated flow frequency curve showing current flood capability (see Chapter V for more discussion, Figure 5-6) was updated as part of this study. The curve reflecting proposed changes shows that only below 450,000 cfs is there a noticeable change in the frequency curve. This analysis suggests that damage-causing flows larger than 450,000 cfs will not be increased in frequency and thus the major objective of maintaining current flood control capability is met. Considering the alternative trial draft requirements which would allow more storage in Grand Coulee than the proposed flood control rules, the resulting flow frequencies indicated by curve A on Figure 4-20 would raise above the 450,000 cfs flow level and, therefore, would not be acceptable.

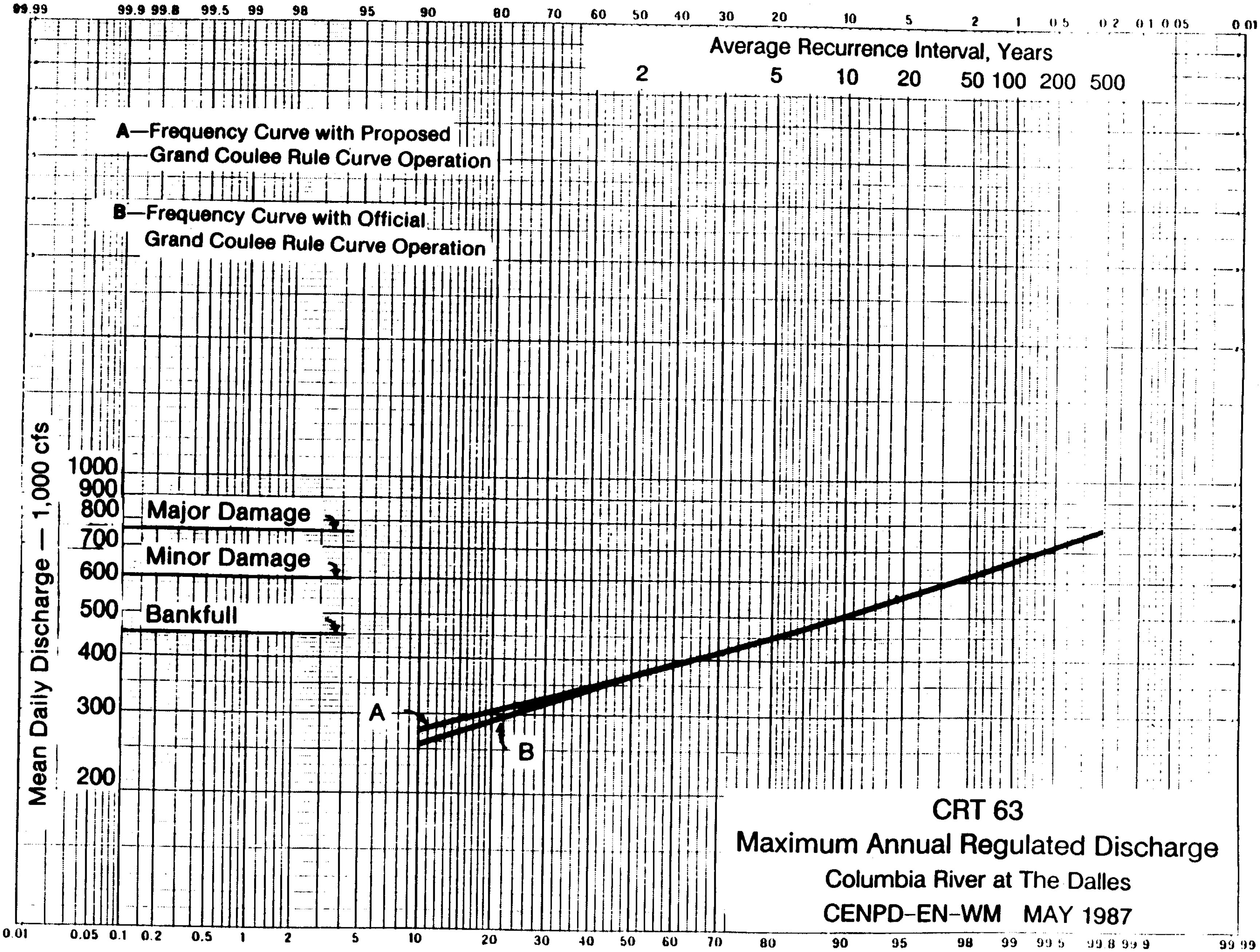


Figure 4-20. Maximum Annual Regulated Discharge Frequency Curve at The Dalles, Effects of Rule Changes

The proposed flood control rule curve shown previously on Figure 4-17 at the maximum draft point on 1 May is modified from the current interim operating curve along a broad range of forecast parameters. For forecasts below 100% of normal (normal corresponds to a flood control parameter of 70 to 75 million acre-feet depending on upstream reservoir space available) the proposed curve is raised to meet but not exceed the damage-frequency criteria given previously in Table 4-1 conditional on forecast level. For forecasts below approximately 80% of normal a minimum draft of 537,000 acre-feet is proposed because of the relative importance of Grand Coulee in regulating unforecasted flood events at Portland/Vancouver. For forecasts between approximately 100% and 120% of normal the proposed requirement was raised from the current interim curve to elevation 1220 feet without changing regulated flood peaks. The region of changes expressed in the proposed flood control rule curve corresponds well with the conclusions in the Interim Report in that the full range of Grand Coulee storage was investigated. Before the proposed rule curve is adopted officially additional analysis by the Corps and the Bureau of Reclamation will be used to refine the proposal.

Brownlee Project

The Brownlee project is owned and operated by the Idaho Power Company (IPC) for the generation of hydroelectric energy. The reservoir is also a recreational and economic resource for the area, and the company considers refill of the reservoir another important operating objective. The project's federal license, stipulates a flood control regulation that is specified by the Corps. Located in the middle reach of the Snake River downstream from the Boise, Owyhee, Weiser, and Payette tributaries, Brownlee storage of up to 1 million acre-feet can provide important river control where no other storage exists. The project is operated primarily as part of the system flood control for the lower Columbia River, but also can regulate for control of the lower Snake River if needed. The Federal Power Commission (now Federal Energy Regulatory Agency, FERC) license for the project stipulates that the reservoir will be at or below elevation 2034 by 1 March of each year to provide about 500,000 acre-feet of storage space. The license further provides that additional storage space of up to 500,000 acre-feet may be called for by the Corps after the 1 March fixed requirement. A formal flood control storage reservation diagram does not exist for Brownlee, primarily because of the fact that forecasts for the Snake River are relatively inaccurate compared with other basins. The variable space requirement has historically been determined primarily with internal guidance and ad-hoc analysis on a year-by-year basis. Table 4-2 summarizes the flood control requests made since 1970. It can be seen that in 1977 and other recent lower runoff years, the Corps waived the requirement for the full 500,000 acre-feet draft on 1 March and did not request additional storage, because it was deemed that a major flood threat did not exist.

In the current flood control study the flood control requirements for Brownlee were reexamined, with the objective of both relaxing the criteria where feasible and formalizing the seasonal operating rules. Since seasonal runoff volume forecast errors are so large (due to the inherent problem of spring rains and variations in irrigation requirements), the traditional drawdown curve having variable parameters was not utilized. Instead a tabular envelope approach was followed in which regions of forecast magnitude - both at The Dalles and at Brownlee - determine the extent of drawdown. This provides a more stable method than would be achieved by interpolating between parameter lines; and, it incorporates two forecast indices, both of which are important in the Brownlee regulation. Table 4-3 is a listing of the proposed requirement. As can be seen, the mandatory 500,000 acre-feet requirement for 1 March has been relaxed for part of the forecast region. The proposed Brownlee rule curves were tested with the SSARR watershed and river models, using both the simulations of historic floods and historic rainstorms. It is concluded that the proposed criteria is satisfactory from the flood control point of view; and, it will result in less stringent requirements for drawdown than are required by the FERC license on 1 March. Table 4-4 summarizes the new requirement for the 1970-1987 period, comparing it with theoretical and historic requirements requested in past operations. As can be seen, the proposed maximum drawdown is nearly the same as that requested in many past years, though for the lower runoff years the requirement has been reduced.

TABLE 4-2

HISTORIC BROWNLEE FLOOD CONTROL REQUIREMENTS

YEAR	1 FEBRUARY FORECAST KAF TDA	BRN	BRN SPACE - KAF REQUEST 1 MAR	ACTUAL 1 MAR	1 APRIL FORECAST KAF TDA	BRN	BRN SPACE - KAF REQUEST MAX	ACTUAL
1970	92.8	7.6	500	514	82.8	6.7	500	576
1971	119.3	8.7	500	502	120.6	10.9	980	984
1972	116.5	8.0	500	375	126.5	7.0	980	984
1973	81.6	5.0	500	507	69.6	3.6	500	515
1974	134.6	10.0	500	457*	138.0	11.0	980	776
1975	95.6	3.9	500	480*	105.4	7.1	800	734
1976	108.2	5.2	500	500	115.2	7.2	500	549
1977	57.2	2.2	200	196	55.6	2.0	200	303
1978	111.8	7.6	500	509	96.2	6.4	750	582
1979	73.2	4.0	500	503	81.5	4.4	250	250
1980	81.1	4.6	250	332	84.5	5.1	250	371
1981	85.5	4.2	250	249	77.5	3.4	150	328
1982	109.6	8.9	500	98	115.9	9.7	650	656
1983	95.1	6.0	500	246*	100.0	7.9	650	655
1984	88.9	6.3	500	468	84.0	8.4	500	468
1985	98.6	7.2	500	523	91.3	7.3	650	670
1986	83.3	5.2	400	92	83.9	6.3	400	412
1987	73.4	2.6	200	363	69.5	3.0	100	363

*** Draft to 500 KAF was delayed beyond 1 March.**

TABLE 4-3

PROPOSED BROWNLEE FLOOD CONTROL REQUIREMENTS

THE DALLES FORECAST APR - AUG, MAF	BROWNLEE FORECAST APR - JUL, MAF		SPACE REQUIRED, 1000, AF 28 FEB	31 MAR	15 APR	30 APR
< 60	<2.5		0	0	0	0
	>2.5	<3	100	50	0	0
	>3		200	100	50	0
> 60 < 70	<2.5		0	0	0	0
	>2.5	<3	100	50	0	0
	>3	<4	200	100	50	0
	>4		300	200	100	0
> 70 < 80	<2.5		200	100	0	0
	>2.5	<3	200	150	50	0
	>3	<5	300	200	100	50
	>5		400	350	250	150
> 80 < 90	<2.5		200	100	0	0
	>2.5	<3	200	150	50	0
	>3	<4	300	250	150	100
	>4	<5	300	350	400	400
	>5		400	450	500	500
> 90 <100	<2.5		200	100	50	0
	>2.5	<3	200	150	100	50
	>3	<4	300	300	250	200
	>4	<5	300	350	400	400
	>5	<6	400	450	500	500
	>6		400	500	550	600
>100 <110	<2.5		200	100	50	0
	>2.5	<3	300	200	150	100
	>3	<4	400	400	350	300
	>4	<5	400	450	500	500
	>5	<6	400	500	550	600
	>6		400	500	600	700
>110 <120	<2.5		200	100	50	0
	>2.5	<3	300	250	200	150
	>3	<4	400	400	400	400
	>4	<5	400	500	550	650
	>5	<6	400	650	750	850
	>6		500	750	850	980
>120 <130	<3		300	300	250	200
	>3	<4	400	500	550	600
	>4	<5	500	750	800	850
	>5		500	750	850	980
>130 <140	<3		500	400	300	200
	>3		500	750	850	980
>140 <160	<3		500	550	600	600
	>3		500	750	850	980
>160	ALL		500	750	850	980

Revised from 2 February 1983 Table

7/16/87 DDS

TABLE 4-4

COMPARISON OF PROPOSED AND
HISTORIC BROWNLEE FLOOD CONTROL REQUIREMENTS

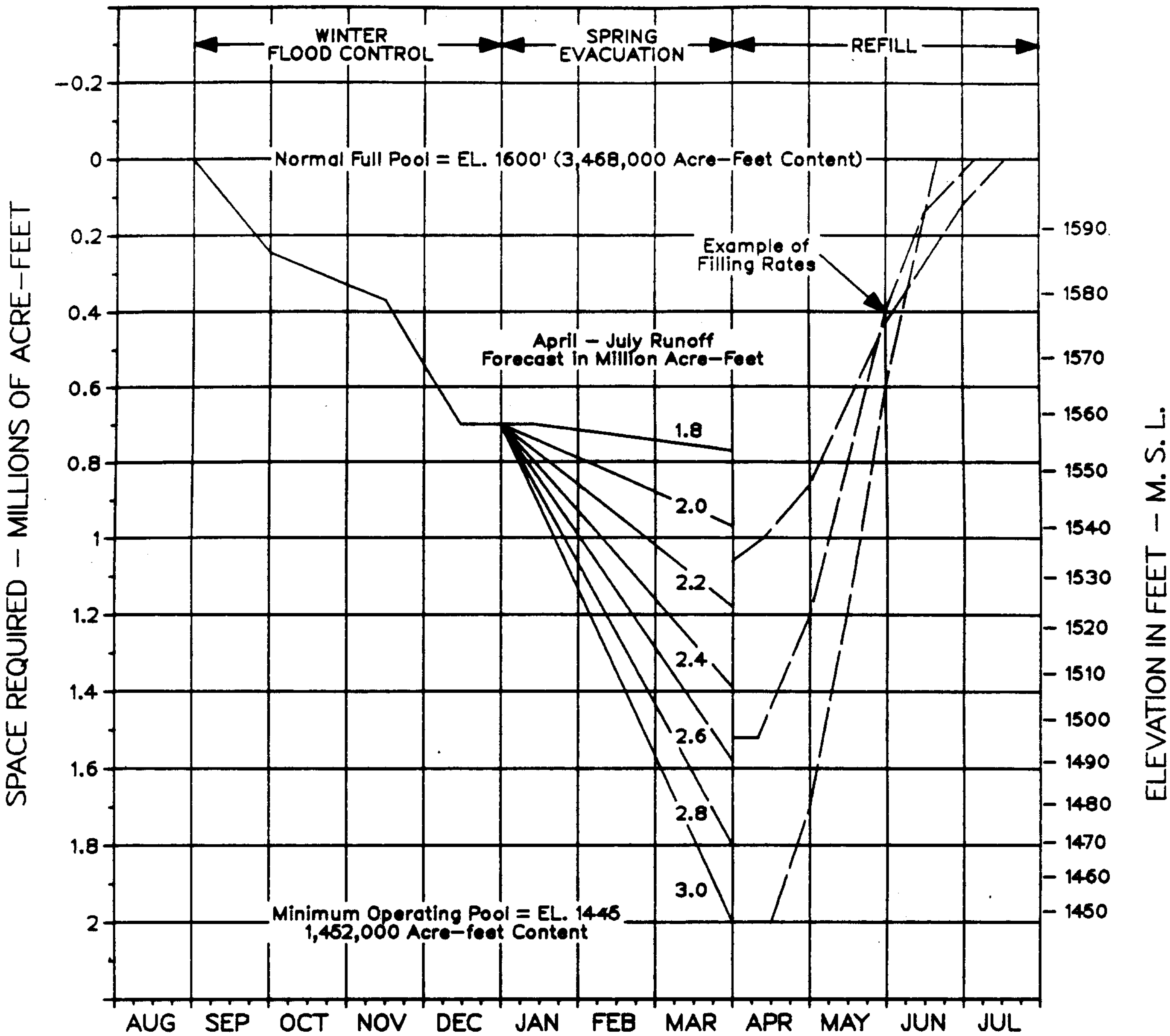
YEAR	1 FEBRUARY FORECAST KAF TDA	1 FEBRUARY FORECAST KAF BRN	BRN SPACE - KAF PROPOSED 1 MAR	BRN SPACE - KAF REQUEST 1 MAR	BRN SPACE - KAF ACTUAL 1 MAR	1 APRIL FORECAST KAF TDA	1 APRIL FORECAST KAF BRN	BRN SPACE - KAF PROPOSED MAX	BRN SPACE - KAF REQUEST MAX	BRN SPACE - KAF ACTUAL MAX
1970	92.8	7.6	400	500	514	82.8	6.7	600	500	576
1971	119.3	8.7	500	500	502	120.6	10.9	980	980	984
1972	116.5	8.0	500	500	375	126.5	7.0	980	980	984
1973	81.6	5.0	400	500	507	69.6	3.6	0	500	515
1974	134.6	10.0	500	500	457*	138.0	11.0	980	980	776
1975	95.6	3.9	300	500	480*	105.4	7.1	700	800	734
1976	108.2	5.2	400	500	500	115.2	7.2	980	500	549
1977	57.2	2.2	0	200	196	55.6	2.0	0	200	303
1978	111.8	7.6	500	500	509	96.2	6.4	600	750	582
1979	73.2	4.0	300	500	503	81.5	4.4	400	250	250
1980	81.1	4.6	300	250	332	84.5	5.1	500	250	371
1981	85.5	4.2	300	250	249	77.5	3.4	50	150	328
1982	109.6	8.9	400	500	98	115.9	9.7	980	650	656
1983	95.1	6.0	400	500	246*	100.0	7.9	700	650	655
1984	88.9	6.3	400	500	468	84.0	8.4	500	500	468
1985	98.6	7.2	400	500	523	91.3	7.3	600	650	670
1986	83.3	5.2	400	400	92	83.9	6.3	500	400	412
1987	73.4	2.6	200	200	363	69.5	3.0	0	100	363

* Draft to 500 KAF was delayed beyond 1 March

Dworshak Project

The Dworshak project is located in northern Idaho on the North Fork of the Clearwater River, the Clearwater being a tributary to the Snake River. The dam was constructed by the Corps beginning in 1968 and the project became fully operational in 1973. With 2.0 million acre-feet of storage, the reservoir provides flood control for the Clearwater River, for the City of Lewiston, Idaho on the Snake River; and, is part of the system flood control for the lower Columbia River (5% of the total system storage). The project is an integral part of the Columbia River Power System, having a generating capacity of 400 megawatts and providing stored water releases for generation at downstream Snake and Columbia River power plants. The reservoir also provides prime recreational opportunities for the people in the vicinity, and this is considered an important economic resource for the local communities. The fishery resource plays an important role in the operation of Dworshak project. A major hatchery, constructed as a mitigation project immediately downstream from the dam, has maintained a large and viable steelhead fishery in the Clearwater River, and during times of upstream migration the project is constrained in its operation to provide favorable river conditions for fishing. The reservoir is also a key to providing water for Water Budget flow augmentation in the lower Snake River during the period of fingerling outmigration. Since the Dworshak project is the only federal reservoir capable of significantly augmenting flow in the lower Snake, it has been looked to as the prime source of Water Budget storage (Brownlee reservoir being the other potential source) in the Snake basin. The Corps has agreed to provide up to 300,000 acre-feet of storage for this purpose, based upon a sliding-scale measure of need as determined by a forecast index at Lower Granite. The operation in 1987 was a good example of this water usage. During what proved to be an unusually low runoff, Dworshak released up to 25,000 cfs (15,000 cfs spill) to increase downstream flow during the outmigration of salmon and steelhead juvenile fish.

The current seasonal flood control operating criteria, Figure 4-21, were established in 1973 and are contained in the current Water Control Manual for the project (Reference 8). The curve differs from most other such curves for other projects in the basin in that a fixed winter requirement of up to 700,000



NOTES:

1. These curves are to be used with the forecast procedure developed by NPW.

2. Elevation reached on 1 April will be held until:

   a. Forecasts indicate a need to reduce outflow for flood control.

   b. Elevation becomes lower than the variable refill curve computed on a daily basis.

3. Release during flood control operation will be 4000 cfs unless forecasts indicate that significant spilling will result when the reservoir fills. In such a case, outflows may be increased to plant capacity. This rule applies only when the reservoir is above the variable refill curve.

4. The following minimum space must be retained when space is less than 700,000 AF, unless the reservoir is below the Variable Refill Curve:

Percent of Area Covered by Accumulated Winter Snowpack	Minimum Space 1,000 Acre-feet
100	700
80	540
60	385
40	230
20	80
10	0

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FEBRUARY 1973

Figure 4-21. Dworshak Project, Existing Flood Control Diagram.

acre-feet of space is required during the winter period. This space is needed to regulate unforecastable winter rain floods, which historically have exceeded the spring floods in magnitude. Additional drawdown for spring flood control begins in January, based upon forecasts of spring runoff, as is the case for other storage reservoirs in the basin. Another aspect of the flood control criteria which applies during spring and differs from most criteria for other projects is the snow-covered area limitation. When storage space left to fill is less than 700,000 acre-feet, the percentage of drainage area above Dworshak covered by snow is used as a parameter in the Table shown on Figure 4-21, which limits how much filling may take place. In some cases this limitation would override proposed rule curves, but it should apply infrequently for the range of forecasts where changes are recommended. Since the Dworshak project plays such an important role in the Water Budget operation for the Snake River, the possible conflict of flood control with conservation storage objectives was examined early in the flood control study and it was concluded that some modification of the rule curves could be made without detracting from overall flood control objectives. In fact, modified rule curves have been applied in actual operations, based upon early findings from the study.

As was done with rule curves for the other projects previously discussed, the analysis of the existing rule curve involved an examination from both the system and local flood control perspective. In the case of the system flood control requirement, the results of the envelope curve analysis is shown in Figure 4-22; the analysis procedure is described in Chapter III . . This shows that the existing flood control rule curve is providing adequate capacity, except in the most extreme floods where reservoir capacity is limited by the physical size of the project. In lower runoff years, however, the existing curve requires storage space in excess of what is needed to theoretically regulate inflow while flow at The Dalles is above the controlled flow objective. To account for this excess requirement a new curve was superimposed which would more closely match requirements throughout the range of forecasted runoff. This proposed curve (actually the result of several trials) is also shown on Figure 4-22.

The analysis of flood control requirements for the local flood control was handled somewhat differently in the case of the Dworshak than it was for the other projects, due to the employment of the Standard Project Flood (SPF) as a

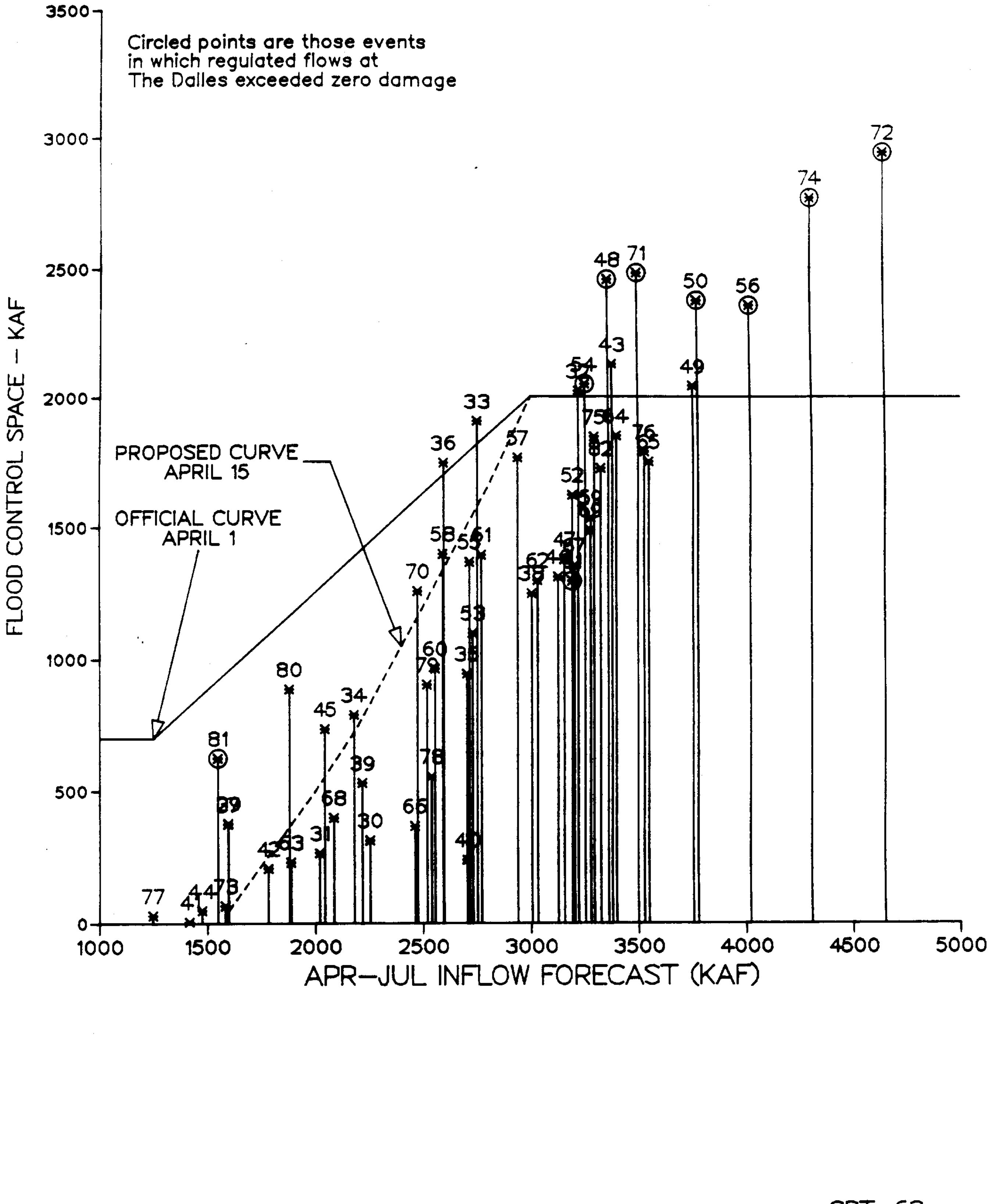

Figure 4-22. Dworshak Project, System Flood Control Requirement.

design standard at Lewiston. As part of the Lower Granite project, a major levee system was constructed around the City of Lewiston, thus enabling the reservoir to be held permanently above the level of the city. This levee required a very high degree of protection in its design since the risk of loss of life had to be reduced to near zero. Following Corps of Engineers policy for such situations, the SPF Flood was chosen as the basis for design. In the evaluation of the rule curves at Dworshak, then, the SPF became the main criteria to judge rule curve modifications. The Standard Project Flood is derived by applying a Standard Project Storm (SPS) to a river basin and computing the resulting flood, much in the same way that the synthetic floods were generated from rainstorms of specified frequency in this study. In the case of the SPS, however, the rainfall quantity and pattern is derived by meteorological analysis, by analyzing historical major storms for the region and employing storm transportation and maximization. For the Clearwater basin this analysis was performed through a contract with an expert formerly with the National Weather Service Hydrometeorological Branch. This study is published in a report, Reference 9. Once the SPS was derived, the resulting SPF can be calculated, given specified conditions of snowpack, soil moisture, etc. A reasonably severe combination of these conditions is used to determine the SPF for levee design. In this study, since there is this high design standard at Lewiston, the SPS was used as the standard in evaluating flood control storage requirement at Dworshak, instead of the 100-year storms used for other projects.

To evaluate the storage requirement needed to adequately regulate the SPS under varying forecast conditions, simulations were made with the SSARR model by the Corps' Walla Walla District, and resulting storage requirements calculated. Examples of SPS application to separate snowpack conditions are shown in Figures 4-23 and 4-24. Also shown are examples of simulated Dworshak regulation used in testing the proposed rule curves. Since storms in the Clearwater basin have a potential to occur throughout the winter period and into the spring, this analysis investigated the effects of seasonal variation of the timing of the storm and computed storage requirements as a function of date, as well as forecast magnitude. The resulting system of curves are shown on Figure 4-25. These indicate that the maximum drawdown requirement for Dworshak occurs prior to 1 April, unlike Libby and Hungry Horse projects. Since the local flood control requirement was determined as a function of time of year, a similar set

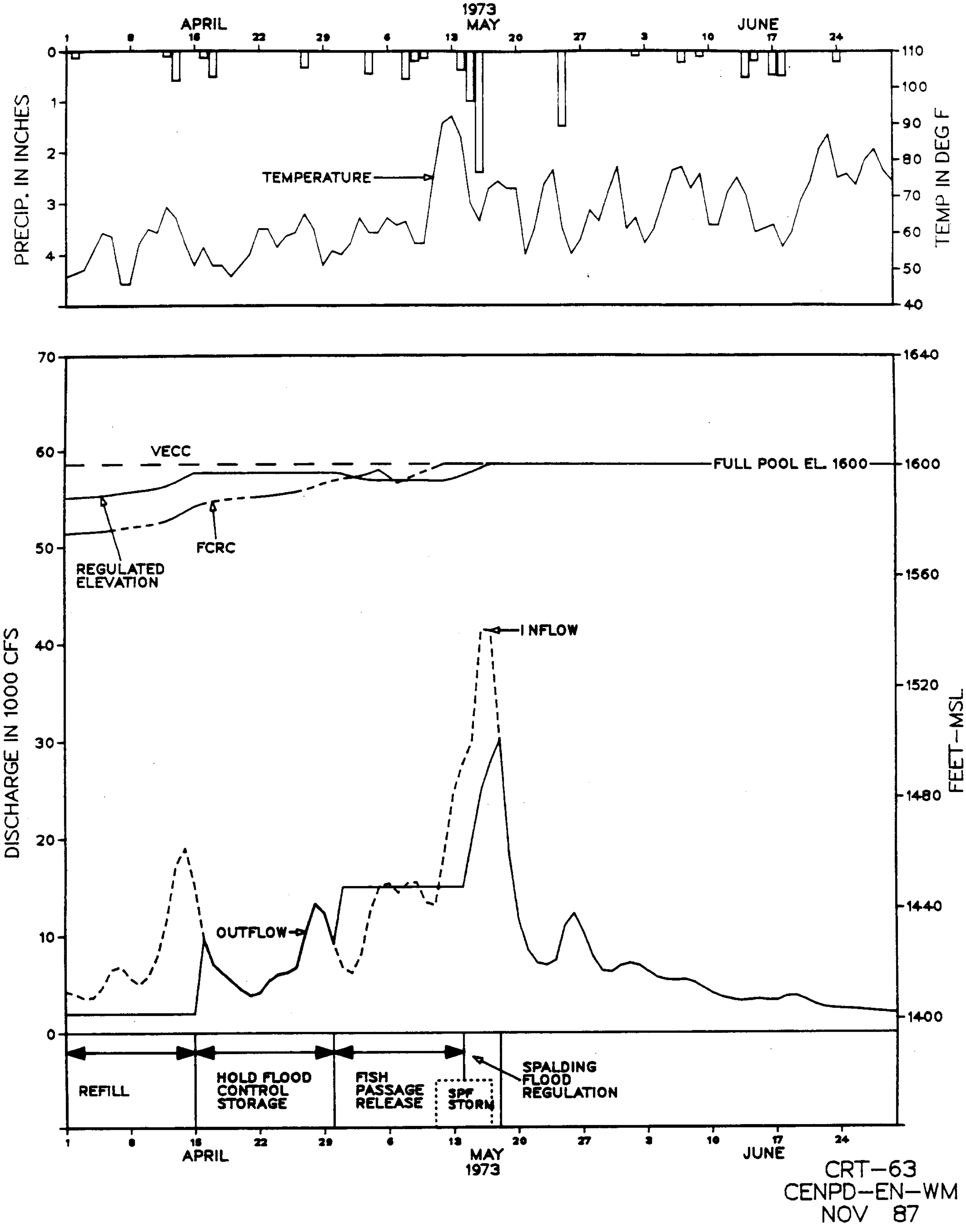

Figure 4-23. Dworshak Project, Example of Regulation to Proposed Rule Curve on a 'Low' Snowpack.

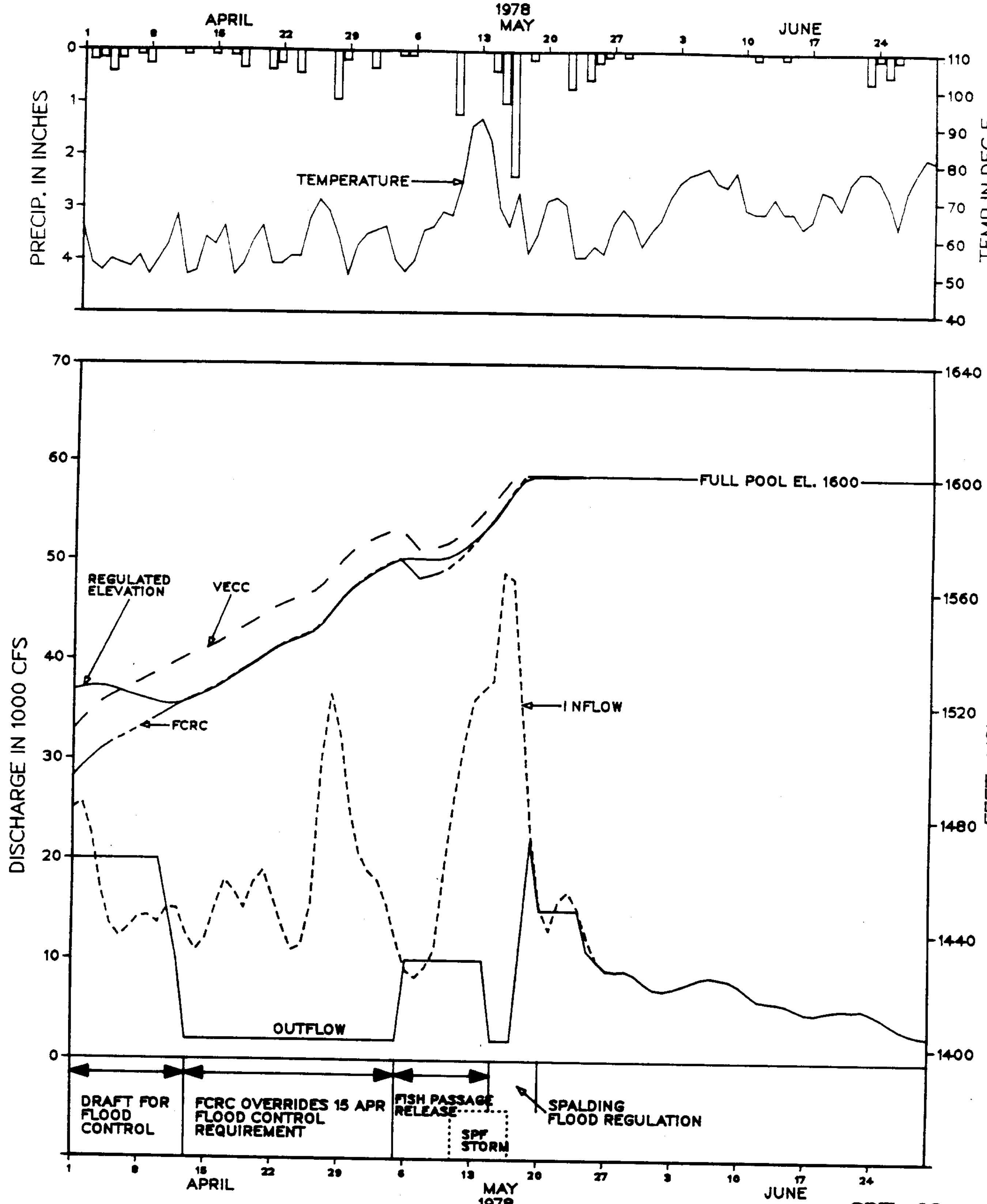

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Figure 4—24. Dworshak Project, Example of Regulation to Proposed Rule Curve on a 'Normal' Snowpack.

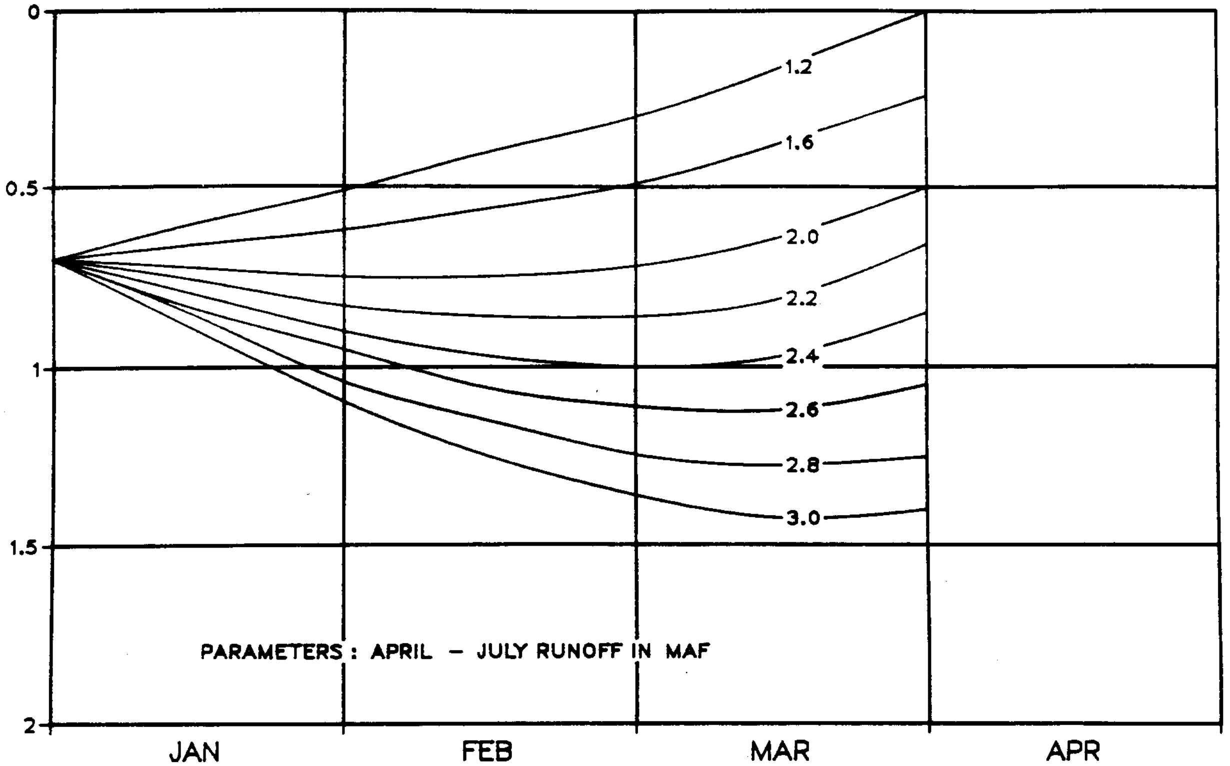

Figure 4–25. Dworshak Project, Local Regulation Curve.

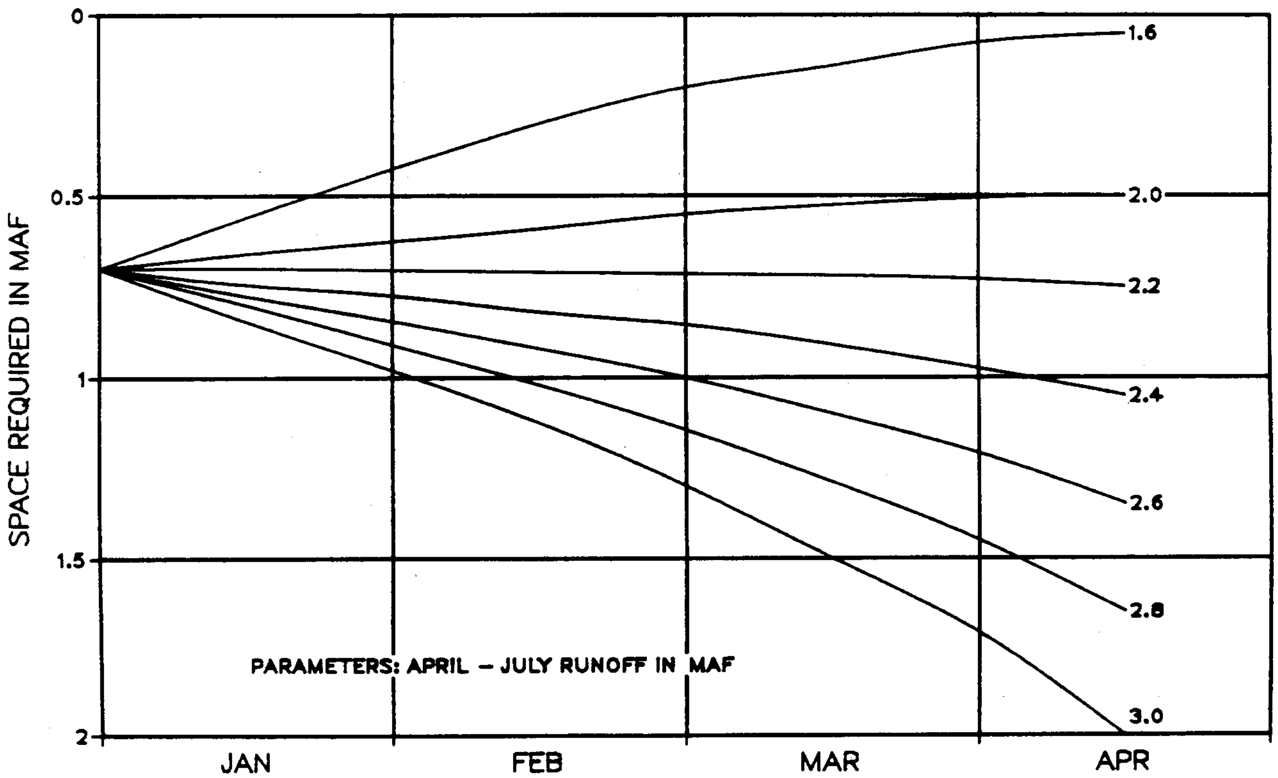

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Figure 4–26. Dworshak Project, System Regulation Curve.

of curves was constructed for the spring drawdown requirement for regulation at The Dalles. In this case, the ultimate goal is simply to have the reservoir drawn down prior to the beginning of the refill season, nominally mid-April. The shape of the drawdown curve was constructed such that a greater rate of draft was employed near the end of the drawdown period as shown in Figure 4-26. This is considered an advantage over a linear drawdown in case forecasts drop just prior to the runoff period. Maximum drawdown requirements for this curve are taken from Figure 4-22.

The final proposed flood control curve for Dworshak, shown on Figure 4-27, is a composite of Figure 4-25 and Figure 4-26. Superimposed on this drawing are the current official rule curves. As can be seen, the new curves require less storage space in the moderate to low forecast years, compared with the existing rule curves. Relative to the maximum flood control draft requirement, the region of modification from official rule curves to the proposed curves varies from no change at a 100% of normal forecast increasing to a maximum change at about a 50% of normal forecast. This region is larger in extent when to compared to preliminary conclusions reached in the Interim Report where the region of acceptable modifications was concluded to be a 75% of normal or less runoff forecast. Further modifications shown on Figure 4-27 are the general shape of the rule curves and the delay of maximum draft to 15 April. These features of the rule curves have not been thoroughly investigated such that they require further study and possible refinement.

Effects of Rule Curve Changes

From the standpoint of local and system flood control, the proposed rule curves will have relatively insignificant impact on the current capability of meeting flood control objectives. As has been pointed out previously, the rule curve changes have been constructed with the goal of not worsening the overall flood control objectives.

From the standpoint of other water uses, the proposed flood control changes can most easily be demonstrated by comparing the flood control criteria and other rule curves that would be called for in each year of the 50-year study period, 1929-1978, used for system power planning in the Pacific Northwest. This provides a sampling of the effects of year-to-year natural runoff variability,

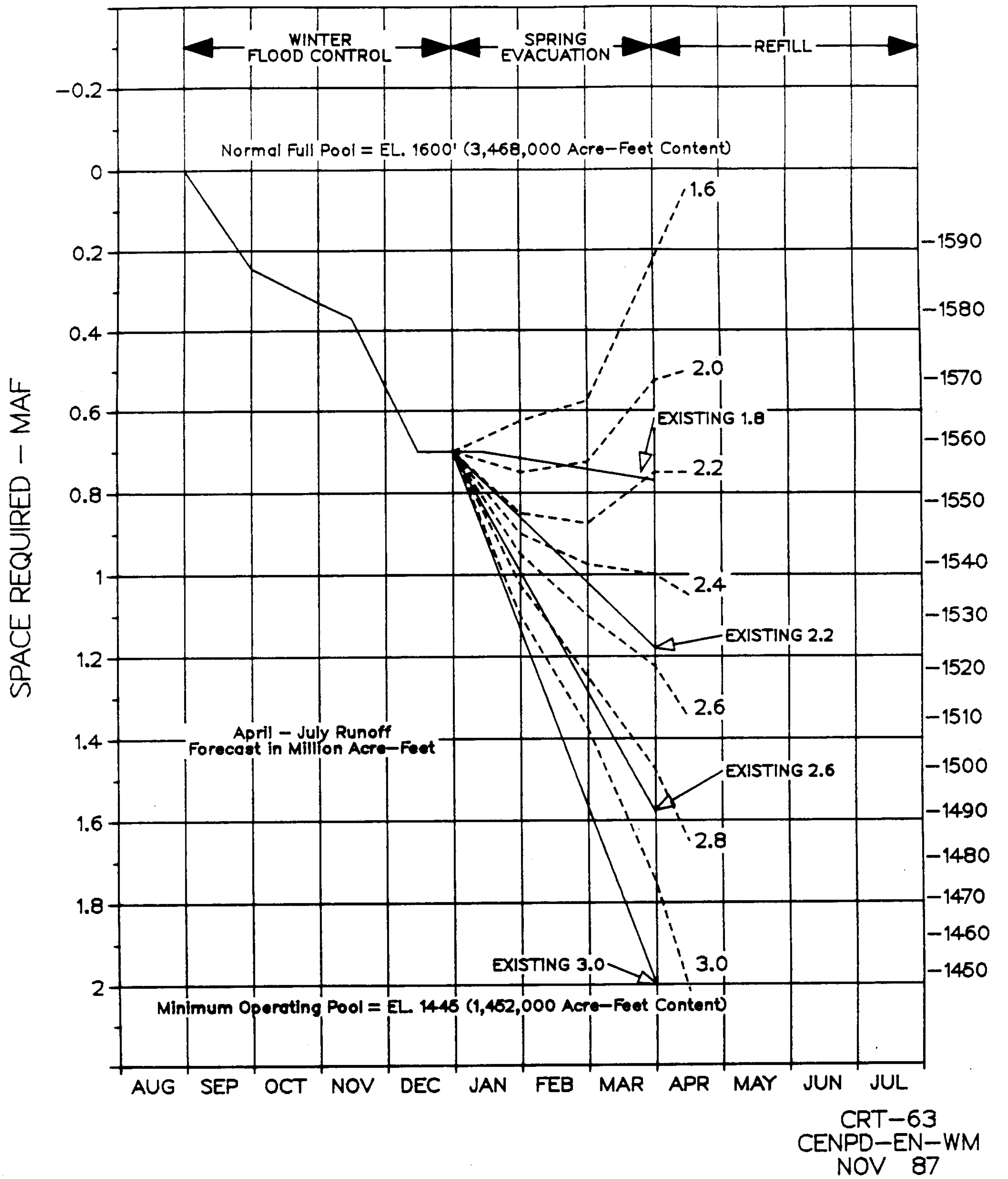
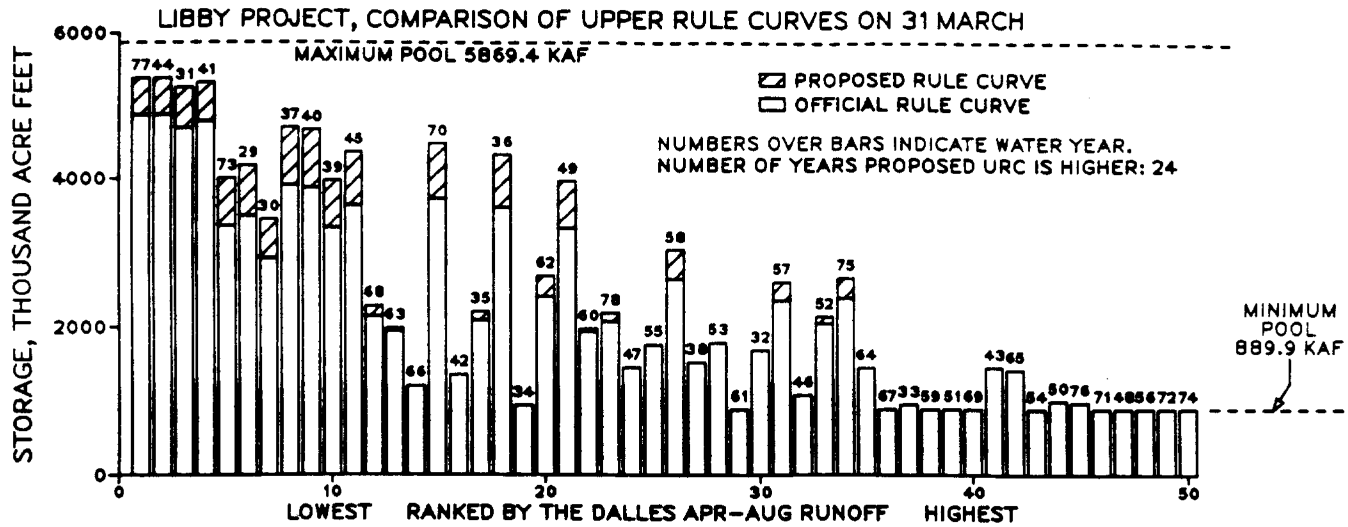


Figure 4—27. Dworshak Project, Comparison of Existing and Proposed Flood Control Diagrams.

in that both the flood control and other rule curve requirements can be based upon the runoff for that year. There are four figures described below, one for each of the four projects studied, which represent the results of two system planning simulations using the HYSSR model. The two simulations differ only by the change in flood control requirements at the Libby, Hungry Horse, Grand Coulee, and Dworshak projects. In these simulations the system was operated to meet May Water Budget objectives (134,000 cfs at Priest Rapids and 85,000 cfs at Lower Granite) as well as serve system power loads. Alternative Water Budget objectives were not examined. Each of the four figures discussed below has two or three bar charts each having the same horizontal axis of study years ranked by The Dalles April through August runoff with years of lowest runoff beginning on the left progressing to highest on the right; each study year is indicated by a number above each vertical bar. The top bar chart of each figure shows the difference in flood control rule curves (termed Upper Rule Curves in power planning studies or URC's) for each year on the date of maximum required draft for the proposed URC. The date of maximum draft for flood control varies for each project as a function of the unique hydrology of each surrounding watershed. The second chart compares the system simulations resulting from use of the different flood control curves as of 30 April to give an indication of any additional storage available immediately prior to Water Budget operations. In the case of Grand Coulee and Dworshak, a third chart is also presented, showing the effects of the simulations for the month of May at downstream points used to reference the Water Budget operation.

For Libby project the existing and proposed flood control requirement for the 50-year study period is represented on the top bar chart of Figure 4-28. The crosshatch on the bars indicate the amount of increased storage allowed by the proposed flood control rule curves relative to the existing flood control rule curve. As can be seen, the greatest changes in flood control requirement occur in the years having lowest runoff, while no changes occur in the highest years. Twenty-four years out of the 50-year period 1929 to 1978 show a change in flood control requirement. The lower chart on Figure 4-28 demonstrates the effect proposed flood control rule curves have on Libby project 30 April reservoir storage. The crosshatch area on each bar of this chart represents the amount of increased storage as a result of changing from existing to proposed flood control rule curves. Twelve years have increased storage, with only the four largest increases (1935, 1957, 1973, and 1975 in the range of 208,000 to 205,000



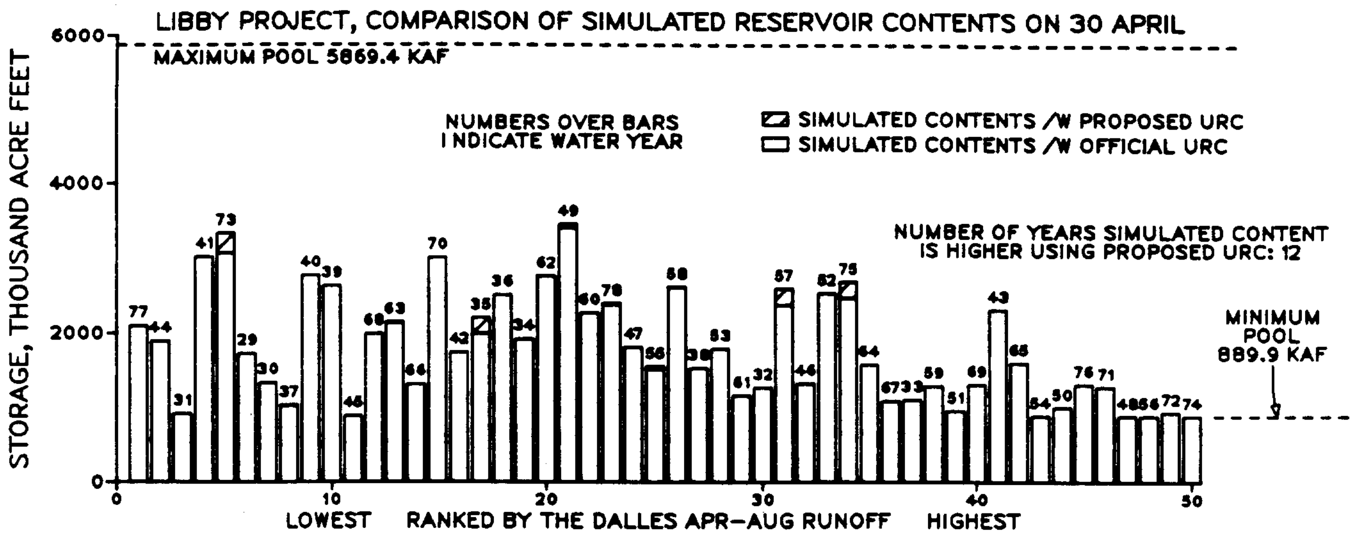


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Figure 4–28. Libby Project, Effects Of Proposed Flood Control Rule Curves In Simulated System Operations.

acre-feet visible in Figure 4-28. Comparing both charts on Figure 4-28 reveals that changing flood control requirements has relatively small effect on the operation at Libby project. The system simulations also indicate that 31 July Libby reservoir contents, not shown here, are insignificantly affected by proposed flood control rule curves, with refill to full pool accomplished in 1963 and 1970 by additional storage amounts of 265,000 and 94,000 acre-feet.

Figure 4-29 is similar to Figure 4-28 but represents the effects of proposed flood control changes at Hungry Horse project. The crosshatch areas of the bars on the top chart of Figure 4-29 show that only three years have a significant proposed change in 30 April flood control requirement. The changes are proposed only for inflows forecasted to be 60% of normal or lower, due to limited channel capacity and significant uncontrolled flow below the project. The crosshatch areas on the bars of the lower chart on Figure 4-29 show the increased reservoir storage on 30 April. These increases in storage are all relatively small (less than 215,000 acre-feet). When both charts of Figure 4-29 are compared the years of flood control change at Hungry Horse do not correspond with years of increased storage; these increases are interpreted as incidental effects of proposed flood control changes at the three other projects. The years with proposed changes at Hungry Horse project have no effect on operation because of low water supply in those years.

Figure 4-30 for Grand Coulee project is similar to the two previous Figures 4-28 and 4-29 with the addition of a third chart at the bottom for Priest Rapids flows. Referring to the top chart of Figure 4-30, the crosshatch area again represents the increased storage potentially allowed by the proposed criteria, when compared with current 30 April maximum draft for flood control. Thirty-seven years out of the 50-year study period show a change in the flood control requirement extending over a wide range of runoff possibilities. In the center chart, crosshatch areas indicate the simulated increase in storage due to changed flood control requirements. Seventeen of the years show an increase in storage due to a relaxation of flood control requirement. Note that in this comparison storage is not increased for the years ranked 35 through 46 which are large runoff years. In these years operating rules other than flood control require draft to minimum pool. The bottom chart of Figure 4-30 represents the May average flow of each of the study years at the Priest Rapids project. These flows are shown only to illustrate the potential effect of changing flood control

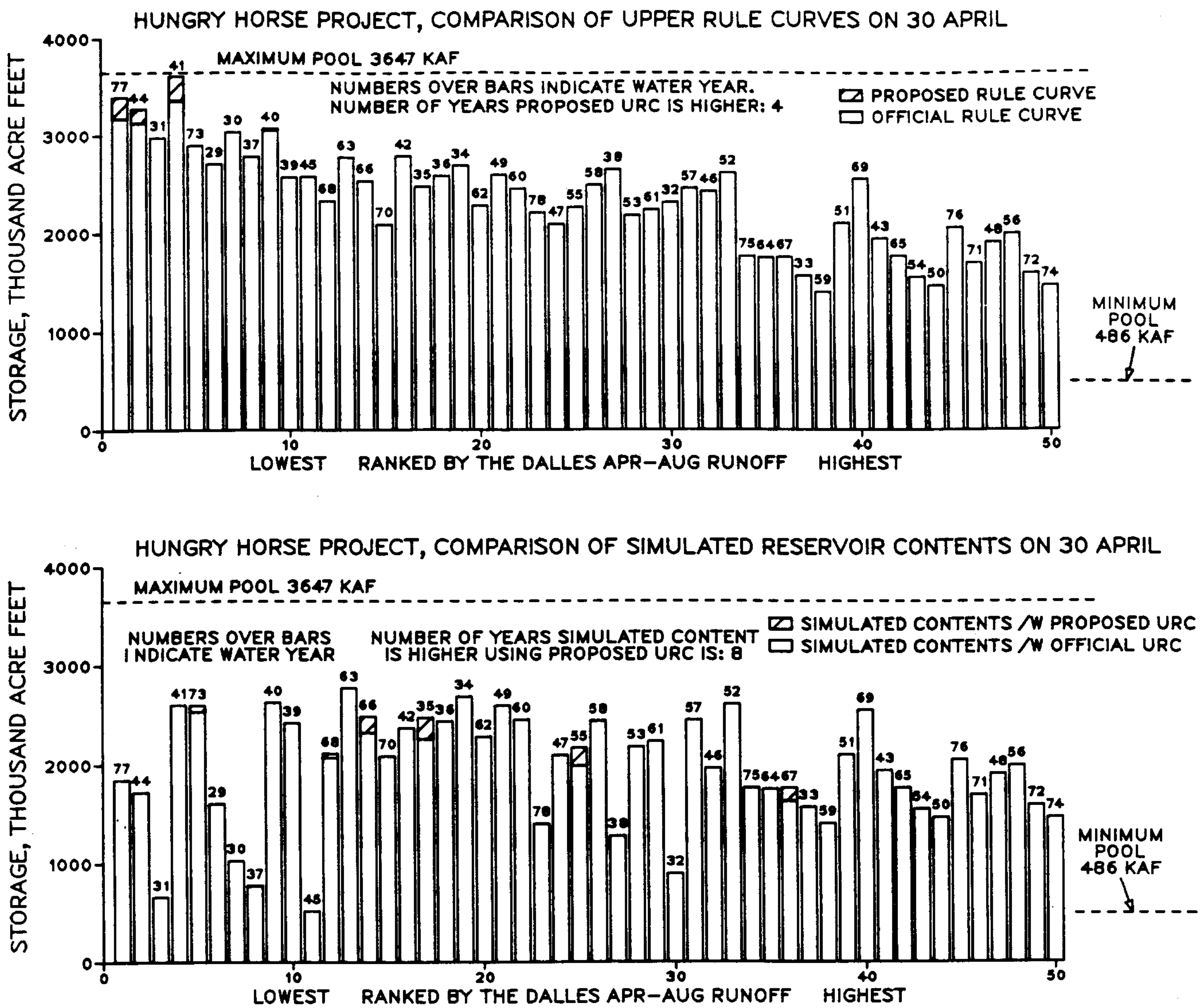

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Figure 4–29. Hungry Horse Project, Effects Of Proposed Flood Control Rule Curves In Simulated System Operations.

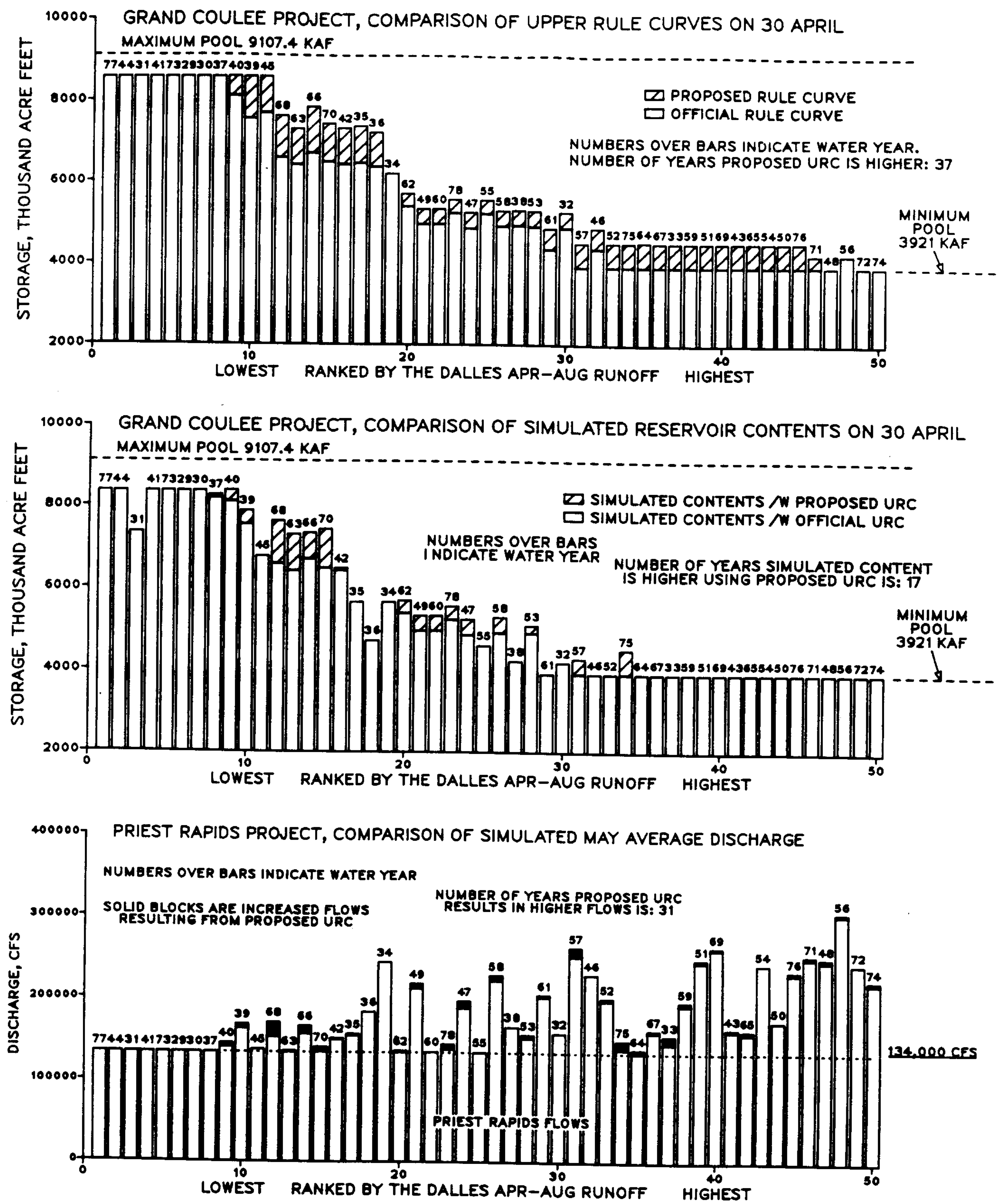

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Figure 4-30. Grand Coulee Project, Effects of Proposed Flood Control Rule Curves in Simulated System Operations.

requirements. The flows shown here would change with a differing set of assumptions regarding power loads and system restrictions. With regard to flood control, the solid blocks on the bars of the bottom chart in Figure 4-30 show the flow increase simulated as a result of changing from current to proposed flood control requirements. Thirty-one of the years show these increases over a broad spectrum of runoff volumes. The flow increases generally result when the URC limits storage in May. A relaxed requirement at the first of May and an unchanged requirement for flood control at the end of May results in less storage during the month, with corresponding increased flow downstream. Conversely when a storage increase is available on the first of May and no flow increase is observed, then the URC did not limit storage during May; this is the case in two of the years. In years where no increased storage is simulated at Grand Coulee, but flows at Priest Rapids increase, an indirect effect of relaxed flood requirement at Grand Coulee causes upstream projects to release more water; the largest of these years is 1933 with an increase at Priest Rapids of 9000 cfs. Maintaining a minimum target flow of 134,000 cfs in May for juvenile fish passage was an objective of the simulations which was met in every year with existing criteria. With proposed flood control criteria, this objective was again met and as shown in Figure 4-30, additional flow was added, mostly in higher runoff years.

The information in Figure 4-30 is also included in Table 4-5 as counts of the crosshatch or solid portions of the chart bars. Table 4-5 lists the number of occurrences out of the 50 study years when Grand Coulee URC or storage, or Priest Rapids period average discharge is simulated to be greater as a result of the proposed flood control rule curves. Table 4-5 shows that in addition to the 31 years in May where flows were increased at Priest Rapids, 18 years in June were increased. The footnotes for this table also indicate that the simulations do result in reduced flows at Priest Rapids is some years (only 3 years in May). This is due to the simulation model taking advantage of the changed URC to regulate to the benefit of power when no other operating constraint is controlling the regulation goal.

TABLE 4-5

GRAND COULEE PROJECT

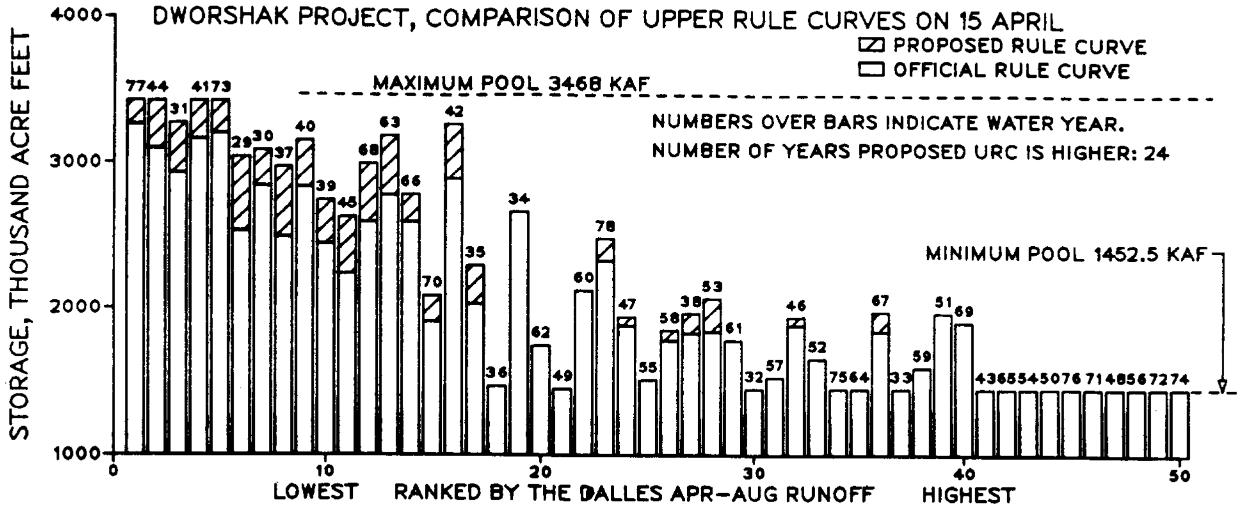
RESULTS OF COMPARATIVE SYSTEM SIMULATIONS

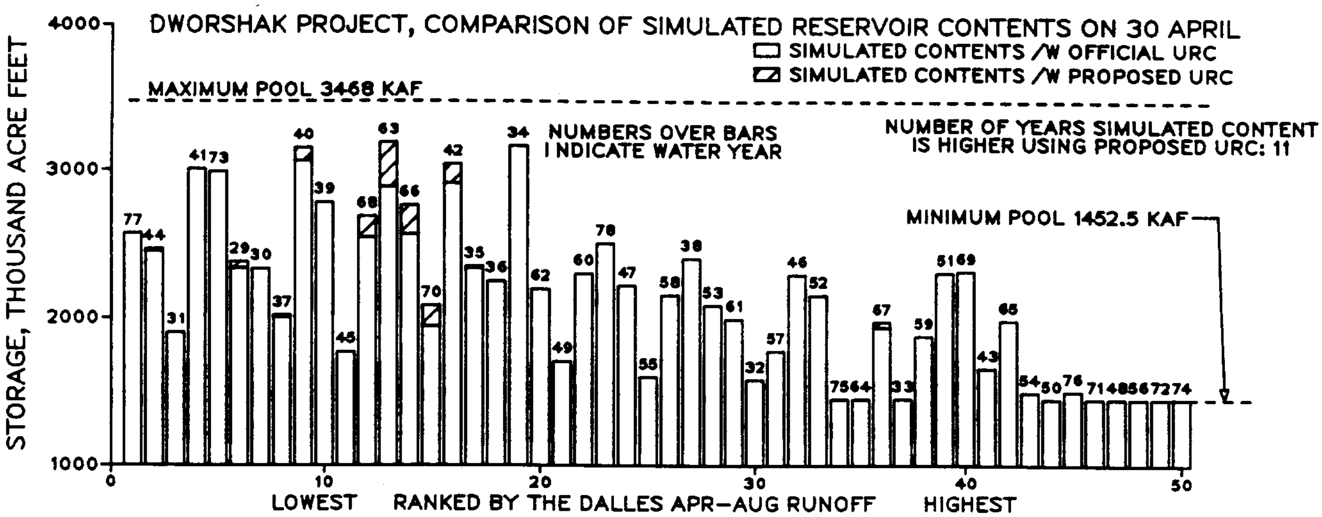
Number of Years out of 50 years (1929 to 1978)
Proposed URC is higher or
results in greater Grand Coulee storage or
results in higher Priest Rapids (PRD) flow.

	31 March	15 April	30 April	31 May	30 June	31 July
URC	32	41	37	7	0	0
STORAGE	1	4	17	7	1	1
PRD FLOW 1/	2 2/	6 3/	15 4/	31 5/	18 6/	8 5/

1/ Counts for average of period ending as column heading (month or 15-day average.)
2/ Flow was reduced in 30 years.
3/ Flow was reduced in 22 years.
4/ Flow was reduced in 18 years.
5/ Flow was reduced in 3 years.
6/ Flow was reduced in 7 years.

For Dworshak project the top bar chart of Figure 4-31 shows with crosshatch areas the difference in flood control rule curves (URC's) for each year on April 15, the maximum draft point of the proposed URC. Twenty-four of the years show that proposed URC's potentially allow storage of as much as 500,000 additional acre-feet. The center bar chart compares the simulated Dworshak reservoir contents on April 30 with the crosshatch portion of the bars indicating additional storage available immediately prior to a Water Budget operation. A comparison of the amount of additional storage actually available on April 30 in the center chart with the amount of additional storage which might potentially be allowed in consideration of flood control in the top chart shows that the actual additional storage is much less. This is due to a number of factors including water supply, power loads, and refill considerations. In the middle chart eleven years of the simulation show additional storage on 30 April ranging from 9,400 to 301,000 acre-feet representing the increase in storage due to relaxation of flood control requirements. Examining Figure 4-31 further, the bottom bar chart compares May average outflows from Dworshak and May average discharges at Lower Granite. The solid portions on the vertical bars indicate increase in both Dworshak and Lower Granite flows as a result of the proposed rule curves. Note that in eleven years there is additional storage available on 30 April, but only 4 of these result in increased flow at Lower Granite in May. Note further that in those eleven





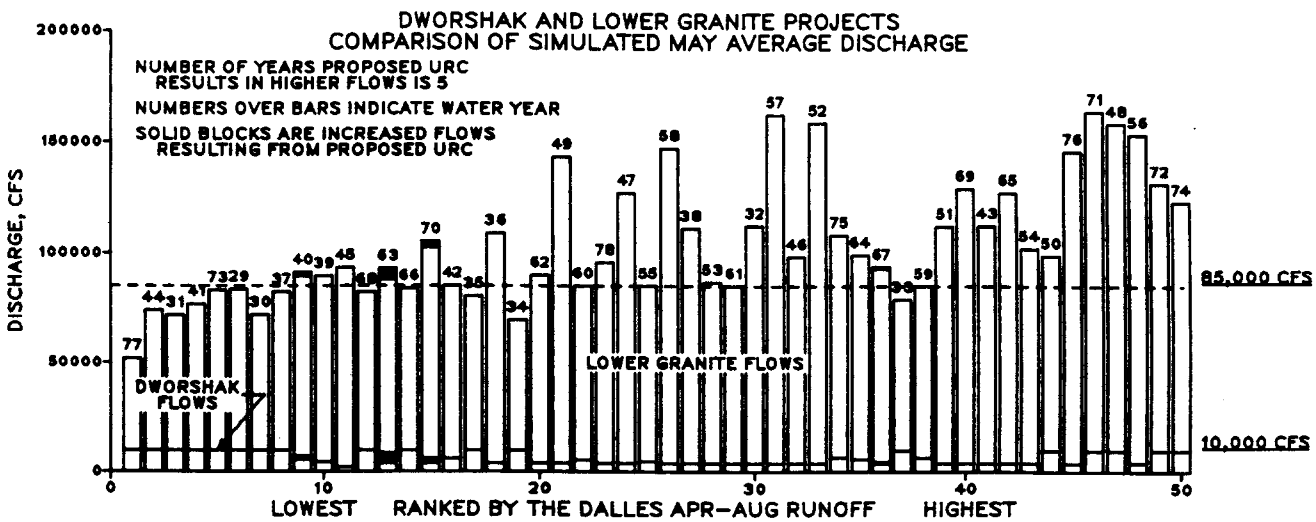


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Figure 4–31. Dworshak Project, Effects of Proposed Flood Control Rule Curves in Simulated System Operations.

years in which additional storage is available on April 30, the minimum fish passage flow at Lower Granite of 85,000 cfs is already being met or Dworshak is already releasing a monthly average 10,000 cfs. The results shown in Figure 4-31 suggest that the proposed flood control rules are of some benefit to juvenile fish passage by providing some flow in excess of Water Budget requirements.

Further information on the power planning study simulations relating to Dworshak project is listed in Table 4-6. The information from Figure 4-31 is included in Table 4-6 as counts of the crosshatch or solid portions of the chart bars. Table 4-6 lists the number of occurrences out of the 50 study years when the Dworshak upper rule curve or storage, or Lower Granite discharge is simulated to be greater as a result of proposed flood control rule curves.

TABLE 4-6

DWORSHAK PROJECT
RESULTS OF COMPARATIVE SYSTEM SIMULATIONS

Number of Years out of 50 Years (1929 to 1978) Proposed URC is higher or results in greater Dworshak storage or results in higher Lower Granite (LWG) flow.

	31 March	15 April	30 April	31 May	30 June	31 July
URC	35	24	15	0	0	0
STORAGE	27	18	11	7	6	6
LWG FLOW 1/	0 2/	22 3/	12 4/	4	0	1

1/ Counts for average of period ending as column heading (month or 15-day).
2/ Flow was reduced in 25 years.
3/ Flow was reduced in 6 years.
4/ Flow was reduced in 1 year.

In 6 years out of the 50 study years, Dworshak has increased storage on 31 July due to proposed flood control rules. In one of these years, 1942 Dworshak completely refills with an additional 55 thousand acre-feet, while meeting other project commitments. In the other five years Dworshak storage is increased by amounts ranging from 6 to 196 thousand acre-feet but fails to refill. Even though the simulations did not incorporate any changed Water Budget objectives, the raised flood control curves resulted in increased flows at Lower Granite in April, May, and June as shown in Table 4-6. This would be generally beneficial to the fisheries migration on the Snake River.

Recent actual operations have also demonstrated the benefit of adjusted rule curves. This can be shown at Dworshak with the regulation of the 1987 runoff, which for the Clearwater drainage was one of the lowest runoff volumes of record. During the actual operation in 1987 a partial adjustment in the flood control rule curve had been made based upon an early assessment of the flood control study results. Subsequently, simulations were run to compare (1) the actual operation with what would have occurred if (2) the official flood control rule curve had been used; or (3) the fully adjusted curve proposed in this report had been used. The results of these simulations are shown on Figure 4-32, in which both elevation and outflow are plotted for the three cases. These simulations utilize the outflow requested by the Fish Passage Center for increased flows at Lower Granite during the Water Budget accounting. Outside of this period, outflows were based upon refill objectives and operating constraints. Potentially, approximately 450,000 acre-feet of storage would have been gained on 1 April by using the new curve instead of the official curve; however, snow-covered area requirements (see Figure 4-21) would have limited this gain to 300,000 acre-feet. In the actual (observed) operation 130,000 acre-feet were gained over the official rule curve requirements. It was possible to take advantage of the relaxed flood control requirement and achieve this gain in storage largely because Bonneville Power Administration had no market for Dworshak power during this period. As it turned out, this assured refill of the reservoir, since the simulation based on the official rule does not refill by 31 July, leaving 29,000 acre-feet (1.5 feet) unfilled. The simulation with the newly proposed rule curve also results in outflow in the latter half of April of 10,000 cfs, compared to minimum release for the other two cases.

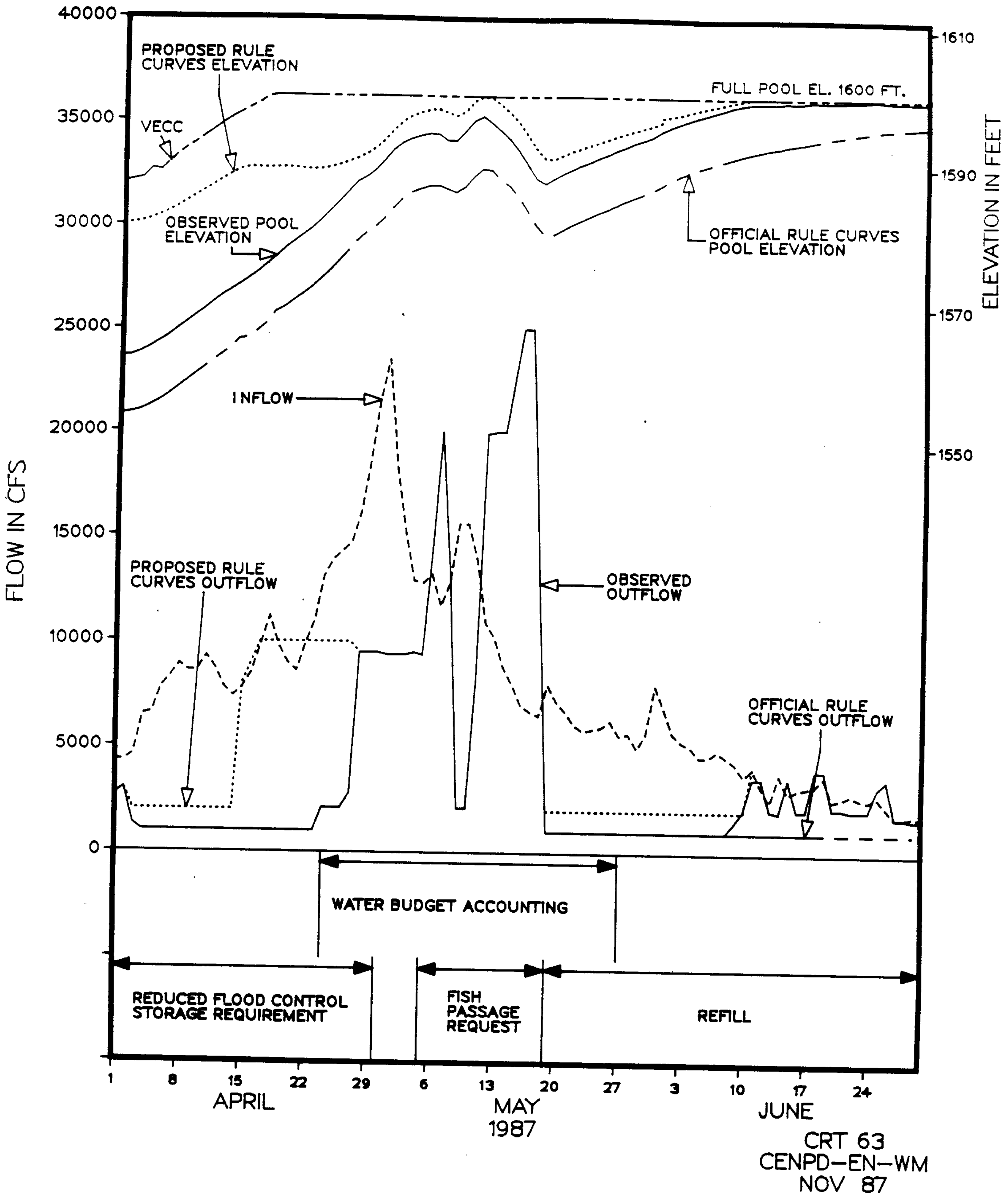

Figure 4–32. Dworshak Project, Simulated vs Observed Regulation of 1987 Runoff.

V. SYSTEM FLOOD CONTROL CAPABILITY STUDIES

Objective of Studies

One of the findings of the early phase of the study, described in the Preliminary Report, was that existing assessments of design flood magnitude for the lower Columbia River and for other damage centers in the Columbia needed updating. These flood assessments were made in flood studies conducted in the mid-1960's and since that time operating experience has revealed a number of deficiencies in the assumptions reflected in those studies. The Preliminary Report contained cursory reevaluations of two important floods, the Standard Project Flood and the 1948 Flood, showing that the new study resulted in higher peaks at The Dalles than had been previously used. Since the SPF may be a direct levee design criteria and the 1948 flood significantly affects the flood frequency curve that also gives levee design criteria, it can be concluded that these criteria would correspondingly be increased. Given that several of the major drainage districts in the lower Columbia River have levees that are marginal in capability when judged against these design floods, a further investigation of the lower Columbia flood control capability appears warranted. Specifically, a new flood frequency curve for The Dalles had to be developed for the spring flood period which reflected up-to-date regulation principles and policies.

The Preliminary Report also described the fact that, in the Portland-Vancouver area, two sources of flood aggravate the flood capability assessment. In addition to the spring snowmelt floods emanating from the upper Columbia and Snake Rivers, a significant source of flooding also occurs from winter rain floods originating in the Willamette River and in tributaries to the lower Columbia and Snake Rivers. Any flood control assessment must consider the combined probability of both of these types of floods. A winter flood analysis, including both a refinement of the winter flood frequency curves and an estimate of the winter Standard Project Flood, was therefore, a second objective of this study. A third objective of the study was to improve the hydraulic relationships in the lower Columbia River, for the purposes of finding river heights that correspond to discharges which have been derived by the hydrologic analyses.

Summary of Methodology

The methodology employed for the flood capability study was much the same as that used for the rule curve evaluations, and in fact incorporated the findings of that study. For the determination of the spring frequency curve at The Dalles, the historic flood simulations provided the annual peak flows for several important years of record to use to estimate and updated curve. These incorporated all the new regulation procedures, including proposed changes to the curves. Most of the effort in this study, however, was the winter flood analysis. This was because the winter flooding was a greater uncertainty in developing design floods for the lower Columbia. For this analysis, watershed models were developed for the tributaries subject to winter rainstorms, and synthetic rainfall patterns were employed to produce design flood alternatives. Model results provided data which, when combined with historical stage data for the lower Columbia, were used to derive stage frequency curves and a winter Standard Project Flood. Water surface profiles were then determined by applying discharges to a hydraulic model of the lower river.

Hydrologic Models, Winter Floods

A study of historic winter flooding in the lower Columbia shows that the Willamette River and portions of the lower Columbia and Snake Rivers basins are the main source of flood waters. Referring to the Columbia basin map, (Figure 2-1), the areas which contribute most significantly to winter floods are the areas west of the Cascade Range and the areas tributary to the Snake River downstream from Boise, Idaho. The eastern slope of the Cascade Range, and the upper Columbia and upper Snake drainages contribute less to winter floods due to a combination of lesser precipitation amounts and lower temperatures. The first facet of the winter flood study was to construct hydrologic models of the drainage area subject to winter flooding, using the SSARR program. For the upper Columbia, this involved using the same model that was used for the rule curve analysis, with relatively minor adjustments. Most of the effort went into developing new models for the Willamette basin and smaller tributaries to the lower Columbia. Figure 3-3, 5-1, and 5-2 show schematic diagrams of the winter watershed model that was developed. Note that this model includes the entire

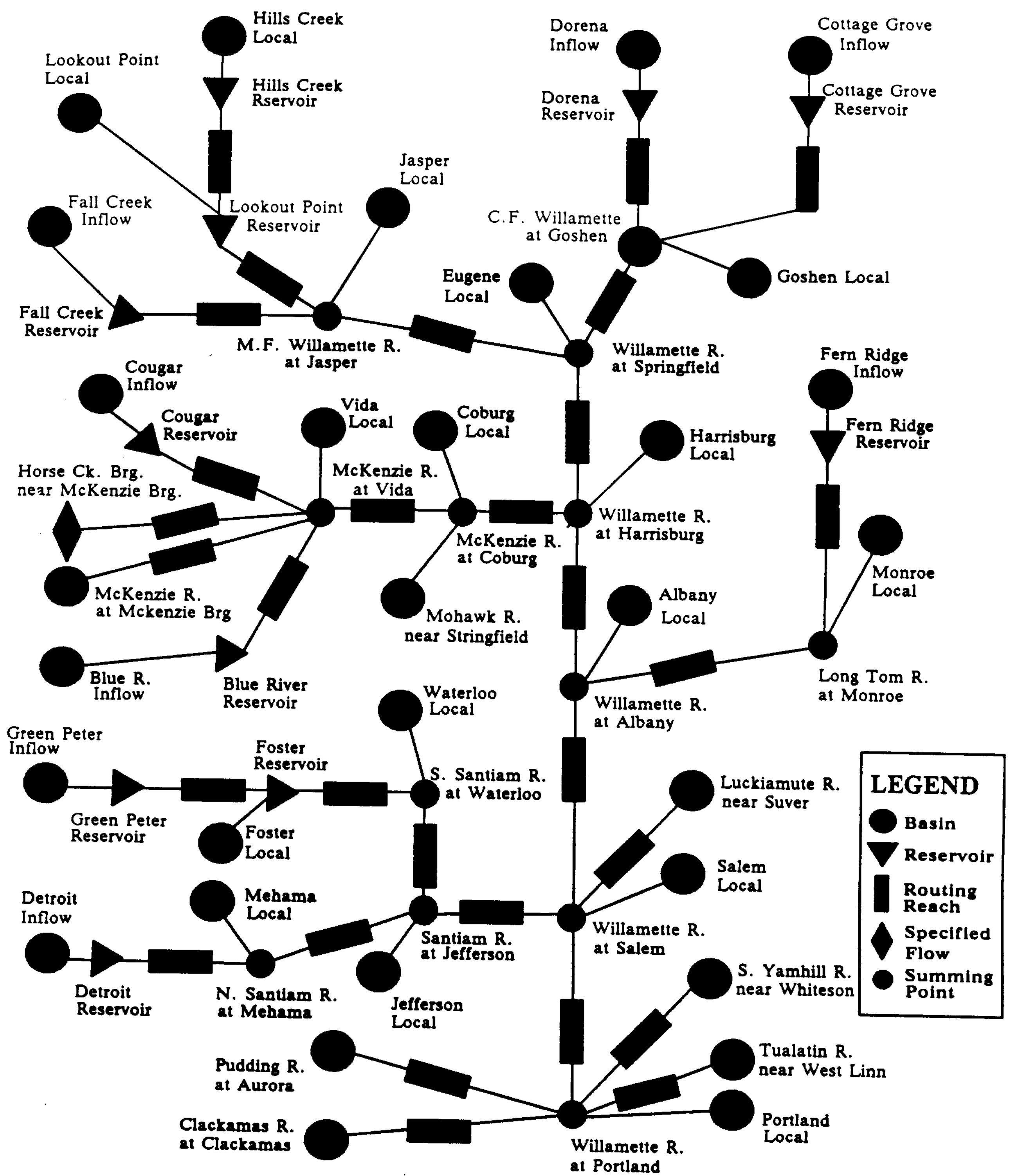

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Figure 5-1. **SSARR Hydrologic Model, Willamette River Basin Schematic**

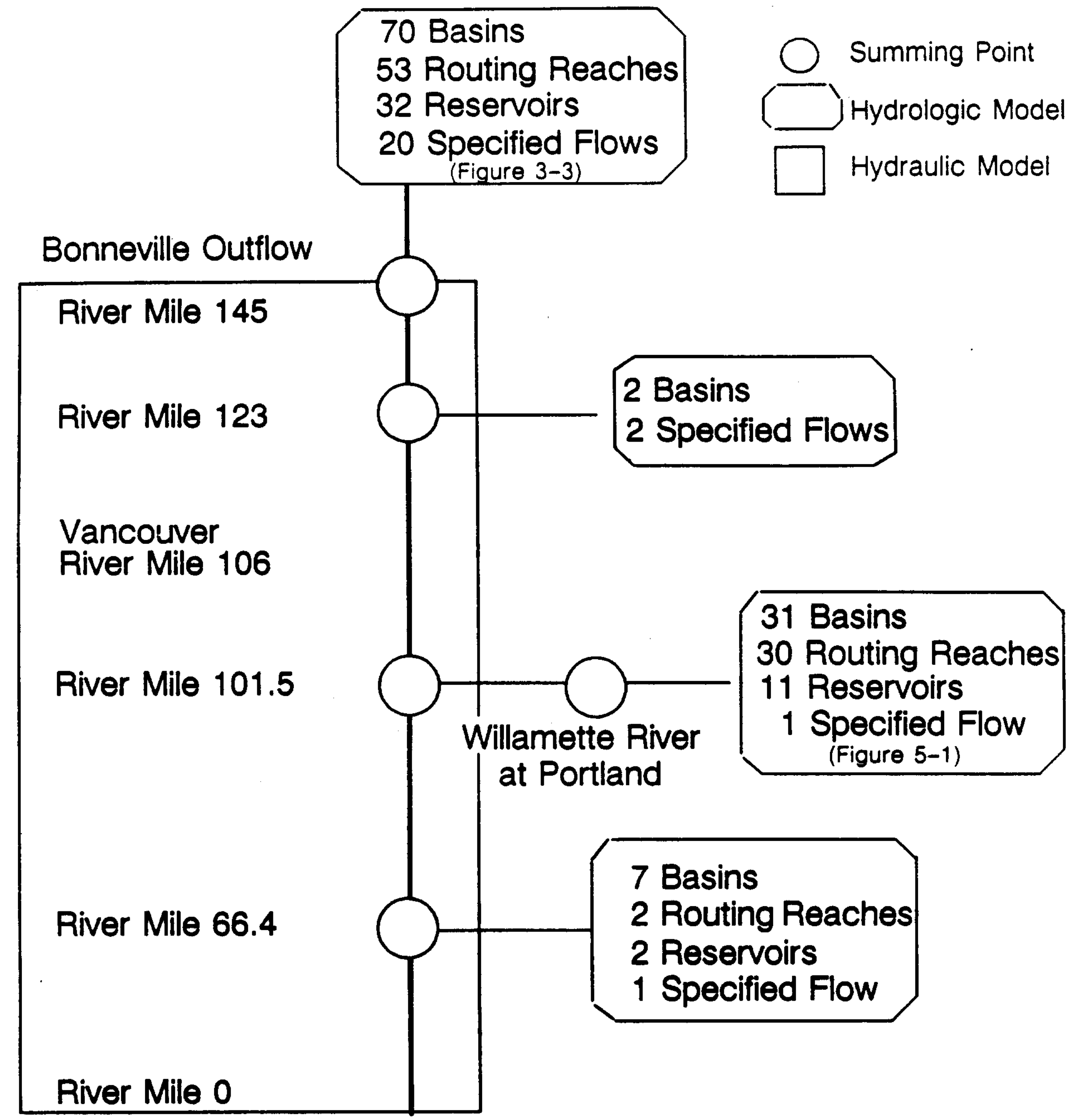

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Figure 5-2. **DWOPER Hydraulic Model**

Columbia basin even though portions of the basin have not contributed significantly to flooding in the winter. This was done to be sure that the model was complete, and to permit the study of hypothetical flood situations that went beyond observed events in terms of their temperature and precipitation.

Calibration of Winter Models

The overall model was set up and calibrated, basin by basin, using historic floods. Since a winter flood is a much faster rising and shorter duration event when compared with a spring snowmelt flood, a shorter time period - 6 hours - was used for calibration in small watersheds. The model was eventually converted to a daily time step for the production simulations.

The calibration study was a major effort in itself, in which several historic floods were used to develop and check the parameters used in the model. As shown on Figure 5-2, the model involved a total of 110 watersheds as well as many channel reaches and hydraulic simulation of water surface profiles in the lower Columbia River. For the smaller tributaries the model was verified using complete hydrographs of flow. In the lower Columbia River, however, the absence of good flow records precluded the accurate assessment of the time variation of discharge and calibration was based substantially on the ability to reproduce peak flows. Table 5-1 is a tabulation of peak flow comparisons for the Columbia River at The Dalles.

Winter flood runoff is very sensitive to antecedent conditions, precipitation amounts, and particularly, temperature, which means that to accurately compute runoff from all the watersheds would require much more data than is currently available. The one major adjustment in the calibration process which was required for the Columbia basin above The Dalles was to compute elevation-temperature relationships (lapse rates) on a daily basis using high and low elevation temperature station data. It is characteristic of large winter storms coming from the Pacific Ocean to have an overall temperature rise and a decrease of temperature with elevation much lower than normal for several days due to the influx of relatively warm marine air. This results in precipitation falling as rain instead of snow at higher elevations.

TABLE 5-1

COLUMBIA RIVER AT THE DALLES
Comparison of Observed and Computed Unregulated Maximum Daily Flows

Flow in kcfs

Date	Observed Unregulated	Watershed Computation (Lapse Rate - 3.3 °F/1000 ft)	(Variable Lapse Rate)	(3)/(1)
	(1)	(2)	(3)	(4)
Dec 55	335	199	322	.96
Dec 64	465	323	445	.96
Jan 70	239	138	389	1.63
Jan 74	450	306	366	.81

The flows in Column 2 of Table 5-1 were computed with the fixed temperature lapse rate which normally applies during the spring snowmelt season and as can be readily seen computed flows are approximately two-thirds of what they should be. Using a temperature lapse rate computed daily from high and low elevation station data produced the flows shown in Column 3. The 1970 event illustrates the sensitivity of runoff to temperature as the variable lapse rate almost tripled the maximum runoff. There was obviously adequate precipitation to produce high runoff so the magnitude of flow was dependent upon whether precipitation fell as snow or rain. Reference 11 provides a discussion of this subject.

Table 5-2 compares the overall results of calibration for the Willamette River at Salem, the largest tributary to the Columbia in the lower river basins. Willamette River flows are about the same magnitude as Columbia River flows but much easier to compute because the basin is generally below the freezing level elevation during the time of maximum precipitation intensities. The adjustment in lapse rate was, therefore, not as critical and was not made in the calibration.

TABLE 5-2

WILLAMETTE RIVER AT SALEM
Comparison of Unregulated and Computed (Unregulated Peak Flows)

Flow in kcfs

Date	Unregulated	Computed	(2)/(1)
	(1)	(2)	(3)
Dec 55	304	315	1.08
Dec 64	472	379	.80
Jan 72	282	277	.98

Synthetic Storms

As was done with the rule curve studies, synthetic storms were developed to apply to the model to generate synthetic floods of given magnitude. In the winter flood analysis, however, the intent of the application was slightly different in that one of the main objectives was to investigate a range of storm patterns that could occur, as opposed to concentrating on the possible combinations of snow and storm magnitude as was done in the rule curve study. The concern is an operational one, relating to the regulation of reservoirs to control winter flooding in the Portland-Vancouver area. Since the source of flooding at this point is from two widely disparate areas, the timing of one as compared to the other is conceivably more important than the magnitude of the contributing flow. For this reason the intention of the study was to evaluate several possible patterns and timing of winter rainstorms.

The database of precipitation records was reviewed and several historic events were decided upon as patterns for the synthetic storm derivations. The scope of the region upon which the analysis was based included the entire Columbia and Snake basins, including the Willamette River, above the confluence of the Willamette and Columbia Rivers. As was done with the spring storm study, an index was derived for this drainage, representing the composite of precipitation stations to be used in the analysis. In this case there were 102 stations, of which 88 were in the Columbia/Snake drainages, and 14 were in the Willamette drainage. Once the composite index was derived then a frequency curve of the index could be computed. A given probability event could be then derived by finding the index value, and determining the corresponding station amount associated with the index value and the storm pattern selected. Figure 5-3 is an example of four alternative historical storm patterns for the overall basin, along with a summary of the precipitation quantities involved. As it turned out, the historic precipitation record did not reveal any significantly unusual storm patterns that might result in a critical reservoir regulation problem if they were to occur.

Hydraulic Studies

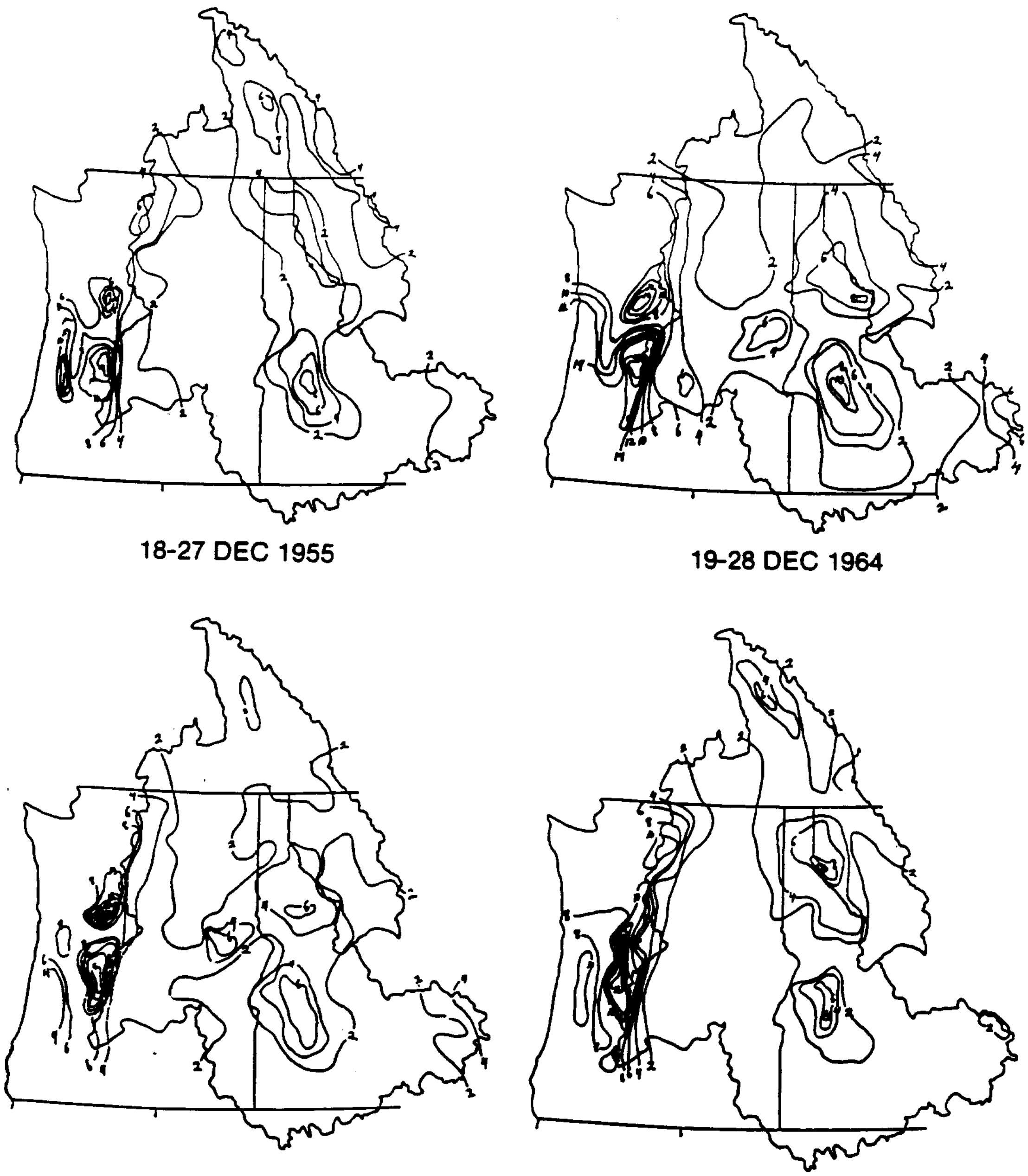
Since the evaluation of the levee system in the lower Columbia must ultimately be in terms of river elevation, a means of converting flood discharges to flood heights must be employed. In the past, various methods have been used, including the extrapolation of historic water surface profiles and computational methods using steady-state backwater programs. It was decided that the previous procedures were lacking in various ways, and that a new hydraulic study should be undertaken. This was a major effort that is described in detail in Reference 6, and is summarized in the following paragraphs.

The decision was made at an early stage to use an unsteady flow model DWOPER for the lower river hydraulic study. This model, developed by the National Weather Service, offers several advantages over the previously used, standard-step backwater programs:

- It provides the capability to model the river hydraulics as a function of time, thereby considering more thoroughly the time-dependent interaction of the two rivers in the vicinity of their junction.

- Previous work had been done with this model by the NWS and the Corps, so that cross-section data and other input factors were already available and calibration had already been done for certain ranges of flow.

- Once calibrated for this study the model would serve a more flexible and useful purpose for future applications in the lower river.



18-27 DEC 1955

19-28 DEC 1964

18-27 JAN 1970

12-21 JAN 1974

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Figure 5-3. **Isohyetal Maps, Precipitation in Inches**

The calibration process with the DWOPER program involves setting up the cross-sections necessary for accurate and stable computation, and the establishment of Manning's "n" values that result in reproduction of observed river profiles. The layout of the model that was eventually employed is included on Figure 5-2, along with the hydrologic model. The basis for this model was the original work done by the NWS; however, this work was set up only for low-flow forecasting and considerable additional work had to be done to extend the characteristics to include the higher flood conditions that would be encountered in this study. Some difficulties were experienced in the region of flow wherein the river begins to flow into overbank areas or overtop levees, and special consideration had to be given to handling these situations. Figure 5-4 is an example of the calibration results for one summer flood and one winter flood. In general, accuracy was within +/- 2 feet, which is not untypical of such studies, although not exceptionally precise. One major factor in undertaking such reconstitutions is that of not knowing the discharges associated with the event, i.e., the input into the model, since there are no streamgages in the near vicinity and flow must be estimated from upstream gages.

Flood Frequency Curves

Flood frequency is expressed as discharge-frequency at The Dalles and as stage-frequency at Vancouver. The backwater effects created by the Willamette River preclude a simple stage-discharge relationship and therefore, a record of river discharge at Vancouver. However, during spring-summer freshets on the Columbia River, Willamette River flows are relatively low so that discharges from The Dalles and Vancouver stage are reasonably correlated. There are over one hundred years of data available for flood frequency analysis at both The Dalles and Vancouver. Ordinarily this amount of data would be considered as adequate to establish a reasonably sound flood frequency curve at either location. In this study, however, some modification was made to the frequency curves of maximum annual summer events at each location to make The Dalles and Vancouver curves consistent with each other.

Flood frequency curves at both locations are based on data which has been adjusted to simulate 1985 level of irrigation depletions, and the curves of regulated discharge and stage reflect 1987 system development and regulation

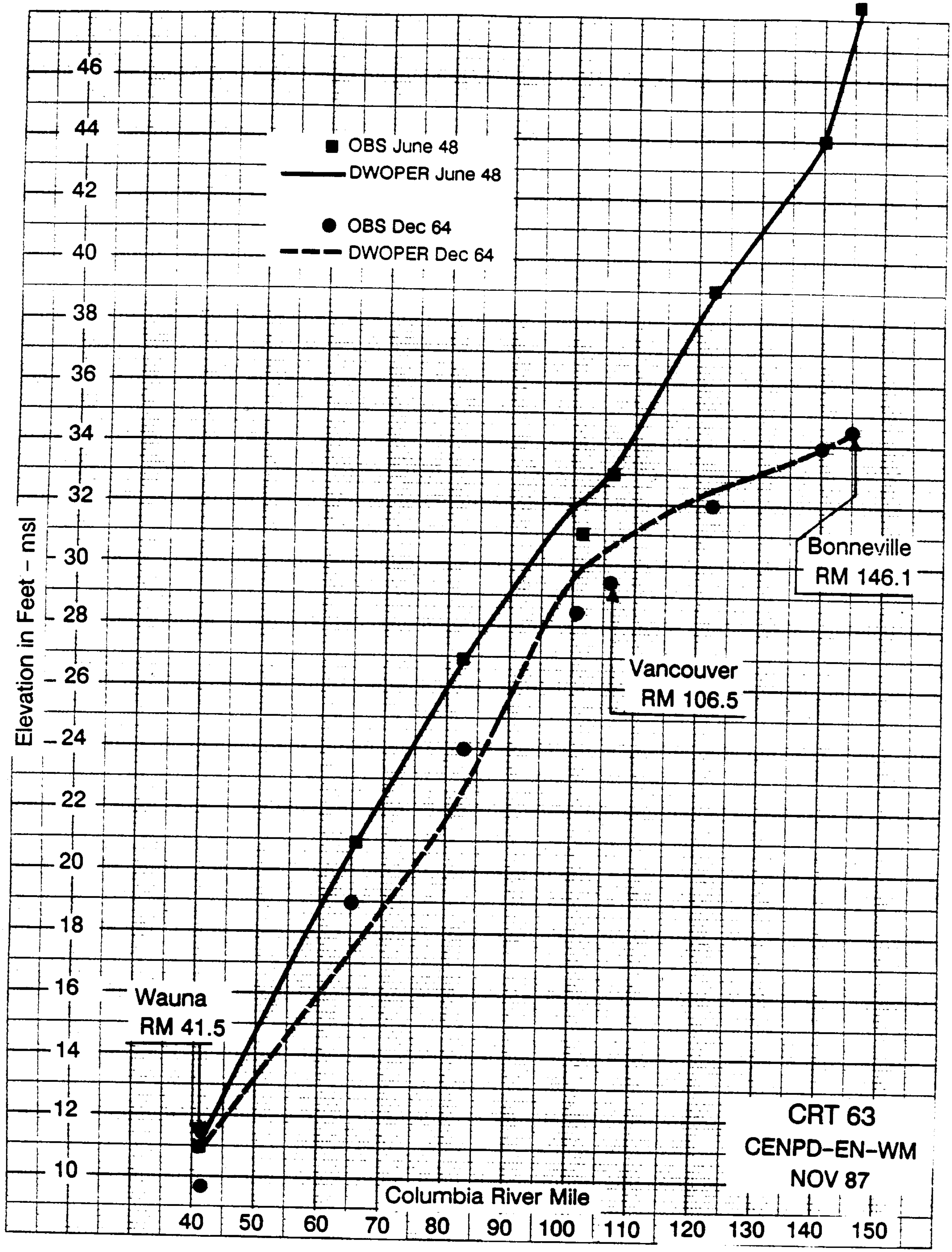

Figure 5-4. **Water Surface Profiles for 1948 & 1964 Storms**

rain events, frequency curves must be calculated considering each season separately and then calculating the combined probability curve which represents annual flood probability.

The Dalles discharge-frequency curves for the Columbia River at The Dalles unregulated events were computed with the HECWRC model which employs the current Water Resources Council Guidelines for flood frequency analysis. For maximum annual spring-summer events the period of record is 1858 through 1985. The computed curve was ultimately adjusted upward so that a 0.3% event is equivalent of 1,195,000 cfs (the 1894 flood). This adjustment was made to assure consistency with the stage-frequency curve of spring-summer events at Vancouver. For the winter unregulated curve computation data from the period 1879 through 1939 were used, this period ending before major regulation was introduced in the basin. The computed curve was then adjusted to account for the 3 large events which have occurred since 1939, 1965, 1974, and 1982). Unregulated estimates of these events are the highest in the period 1879 through 1982. The unregulated frequency curves for The Dalles are shown on Figure 5-5.

A discharge-frequency curves of maximum annual spring-summer regulated events for The Dalles was constructed from the unregulated curve and a relationship between regulated and unregulated peak discharges. This relationship was derived from regulation of historic floods in the current study and therefore considers current regulation policies, irrigation depletions, etc. Figure 5-6 is a plot of this curve, compared with the curve currently in use. The discharge-frequency curve of maximum annual winter regulated events was derived from analysis of 1940 through 1982 data, together with adjustments to compensate for (a) the assumption that 1965, 1974, and 1982 floods are highest since at least 1879 and (b) system regulation which has increased the winter average and below regulated peaks over those experienced in the past. This discharge-frequency curve is also shown on Figure 5-6.

The combined probability frequency curves for The Dalles (maximum annual discharge-frequency) are essentially equivalent to spring-summer unregulated and regulated discharge-frequency curves. The probability of a winter event occurrence compared with the probability for spring event of the same magnitude is so small that it does not appreciably effect the combined probability curve.

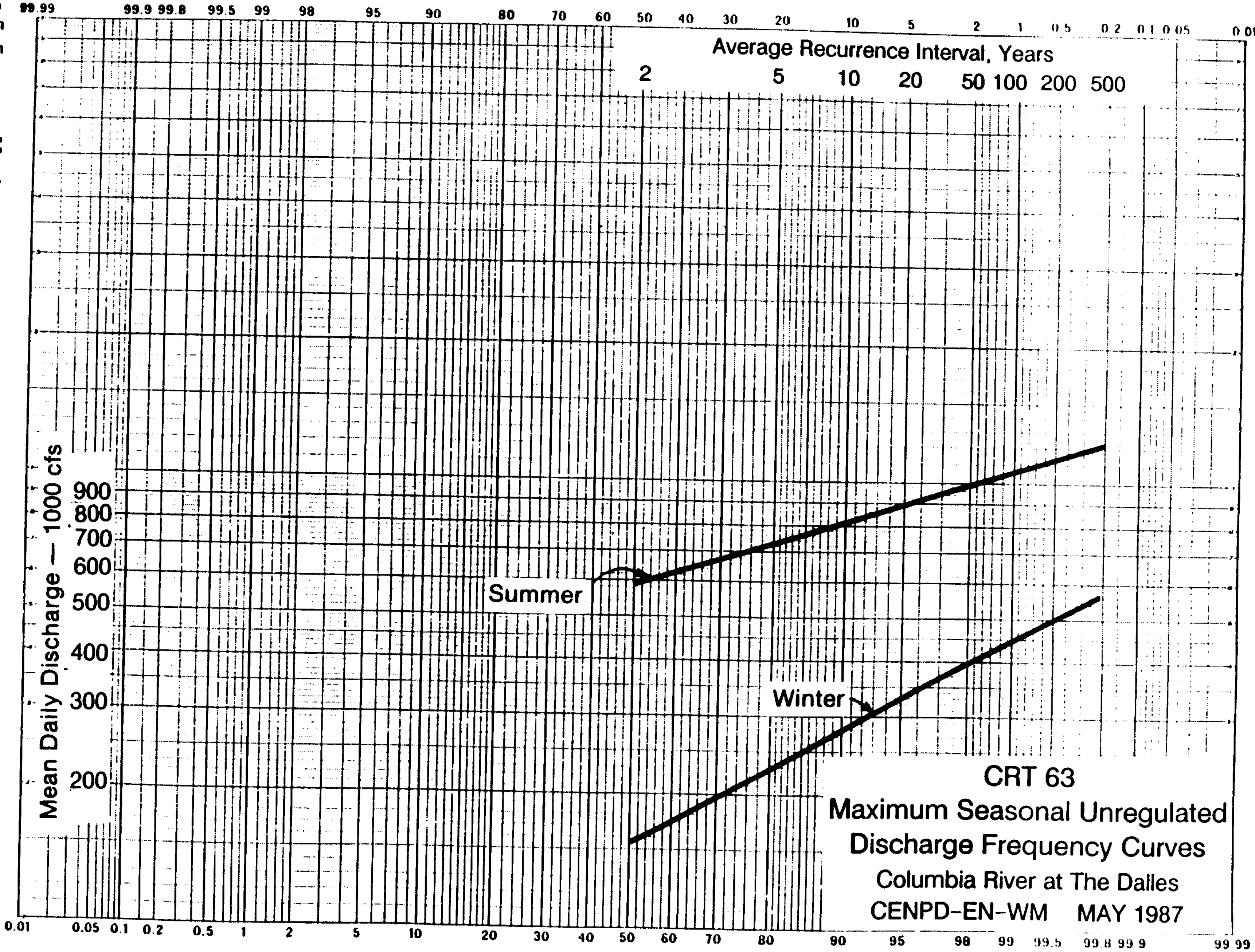

Figure 5-5. Maximum Seasonal Unregulated Discharge Frequency Curves at The Dalles

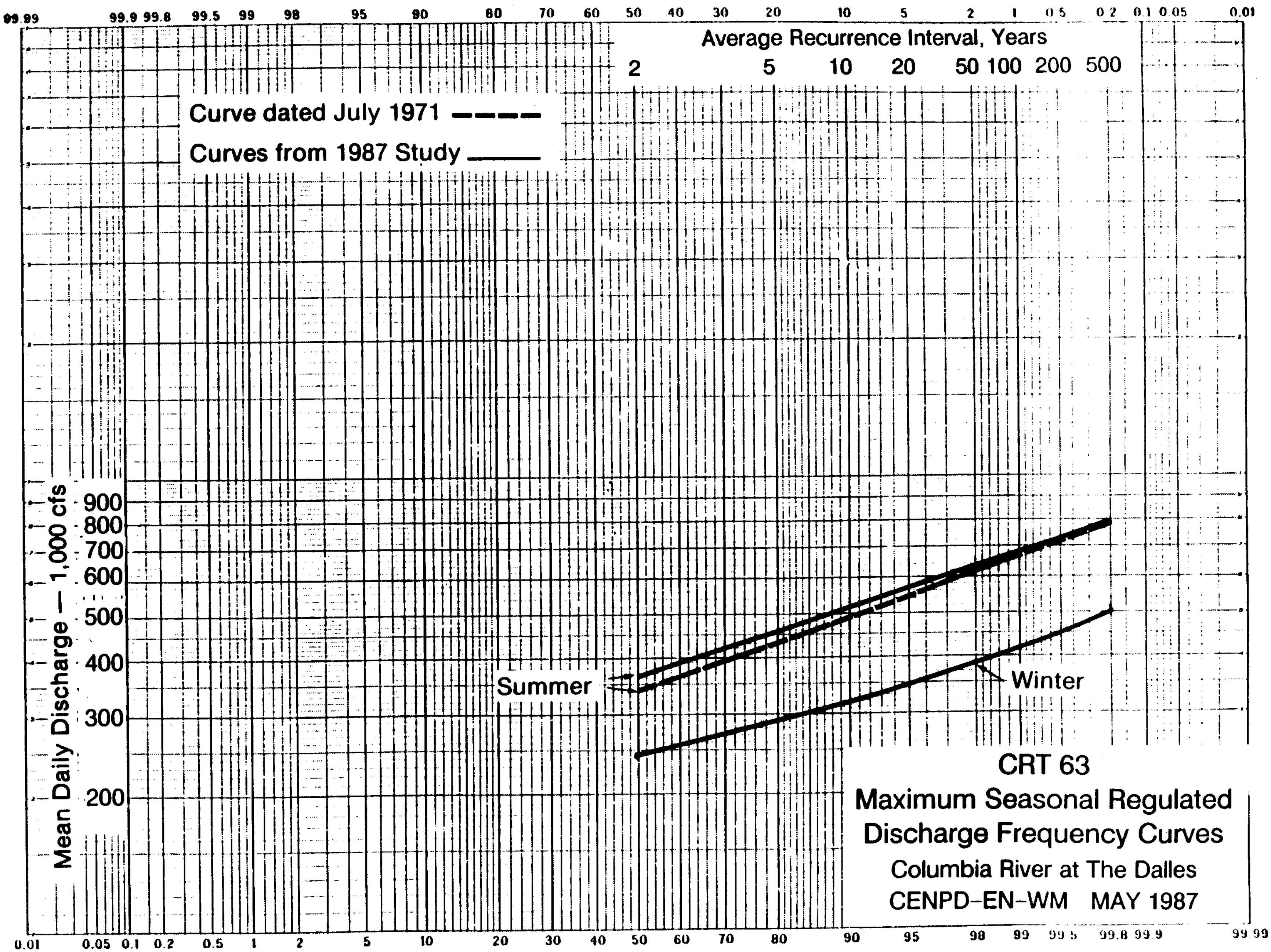

Figure 5-6. Maximum Seasonal Regulated Discharge Frequency Curves at The Dalles

Vancouver stage-frequency curves of maximum annual spring-summer and winter unregulated events were derived from data observed prior to regulation. For the spring-summer events this was from the period 1876 through 1939 with an adjustment to the curve so that a 0.3% event is equivalent to an elevation of 35.2 feet NGVD (the 1984 flood) at Vancouver. This adjustment was made to assume consistency with the discharge-frequency curve at The Dalles. Data from the period of record 1880 through 1939 and estimates of unregulated 1965 and 1974 events were used to derive the winter unregulated curve. The latter two events are the highest in the period 1880-1984. Unregulated spring-summer and winter stage frequency curves for Vancouver are shown on Figure 5-7.

The regulated stage-frequency curve of spring-summer events was constructed from the unregulated curve and a relationship between regulated and unregulated elevations. This relationship was determined from the regulation effects imposed during the period 1973 through 1985. The stage-frequency curve of winter regulated events was derived from an analysis of 1940 through 1984 data and adjustments to compensate for (a) the assumption that 1965, 1974, 1890 and 1939 events were the highest since 1880 and (b) system regulation which has increased the winter average and below regulated peak over those experienced in the past. Stage-frequency curves developed for regulated conditions at Vancouver are shown on Figure 5-8. The combined probability stage frequency curve for regulated conditions developed in this study is shown on Figure 5-9. This curve is compared with a similar curve computed in previous studies.

Water Surface Profiles

Profiles of river elevation corresponding to specified frequencies and to the Standard Project Flood are needed to judge the adequacy of levees in the lower Columbia River. Existing water surface profiles had been developed in 1979; however, these profiles do not reflect the latest in reservoir operating policy and other factors that have changed the frequency curves. As discussed previously the water surface profiles were based upon runs made with the program DWOPER, although it will be seen that the ultimate results were melded in with stage frequency curves already developed.

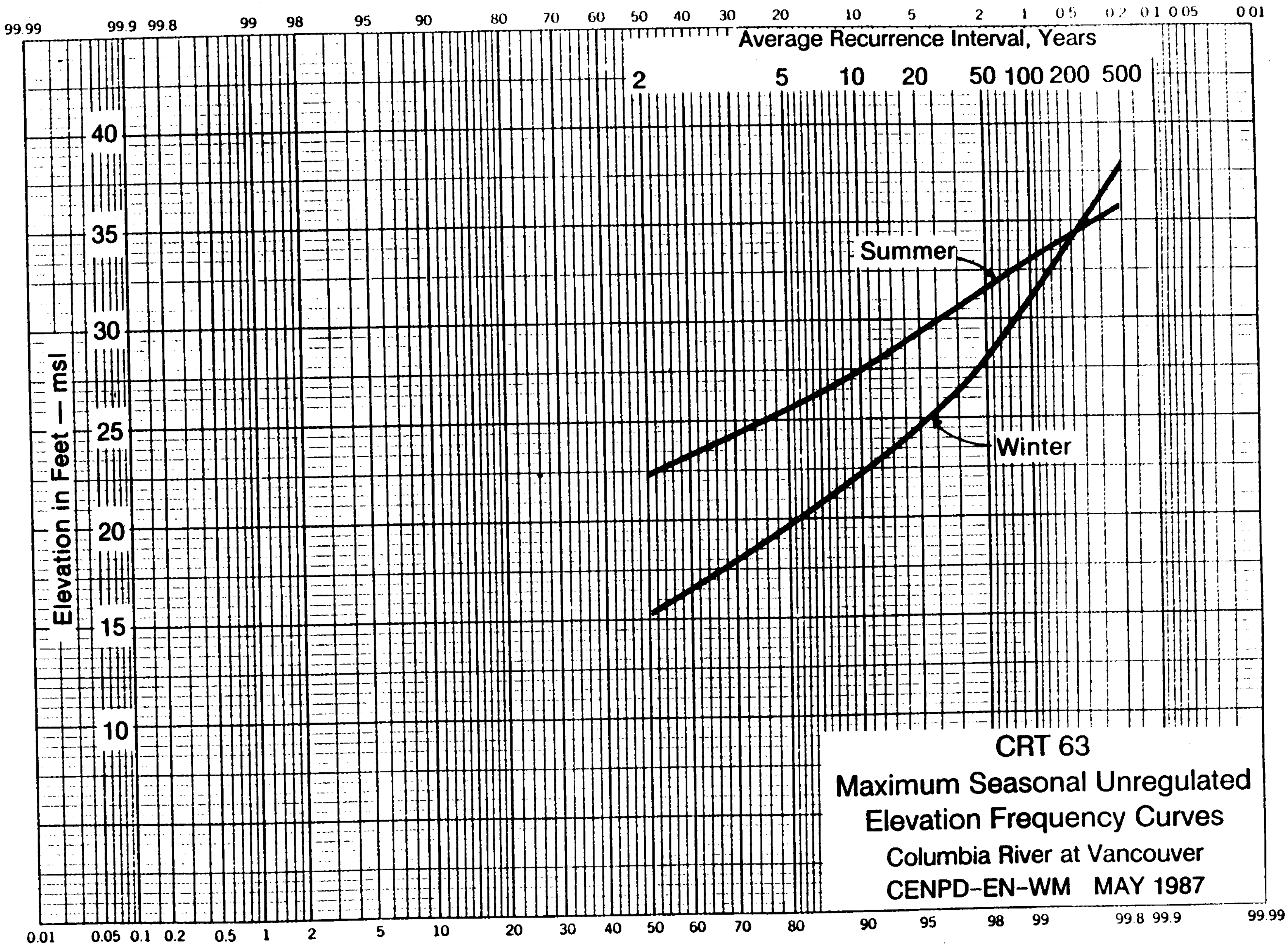

Figure 5-7. Maximum Seasonal Unregulated Elevation Frequency Curves at Vancouver

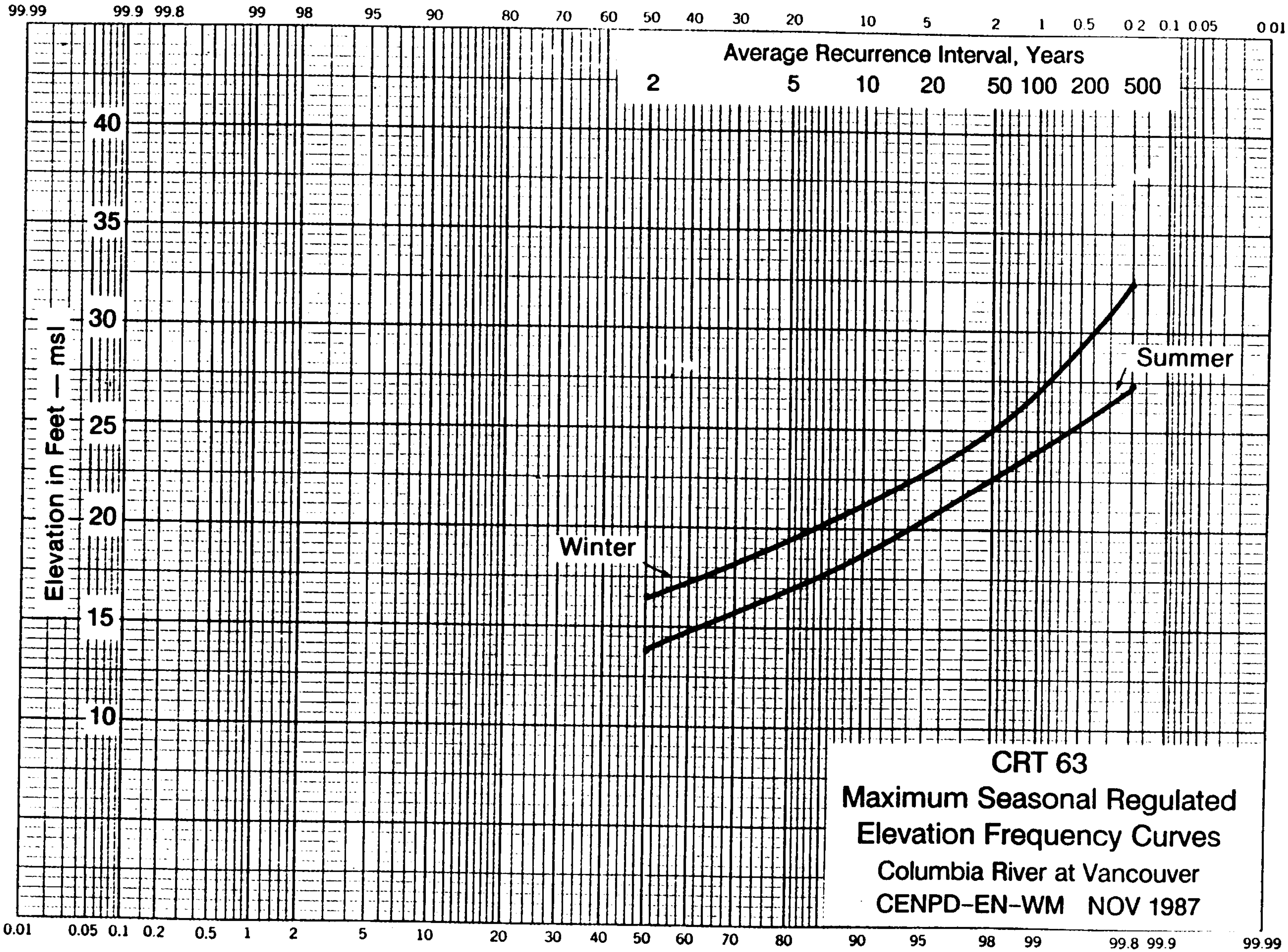

Figure 5-8. Maximum Seasonal Regulated Elevation Frequency Curves at Vancouver

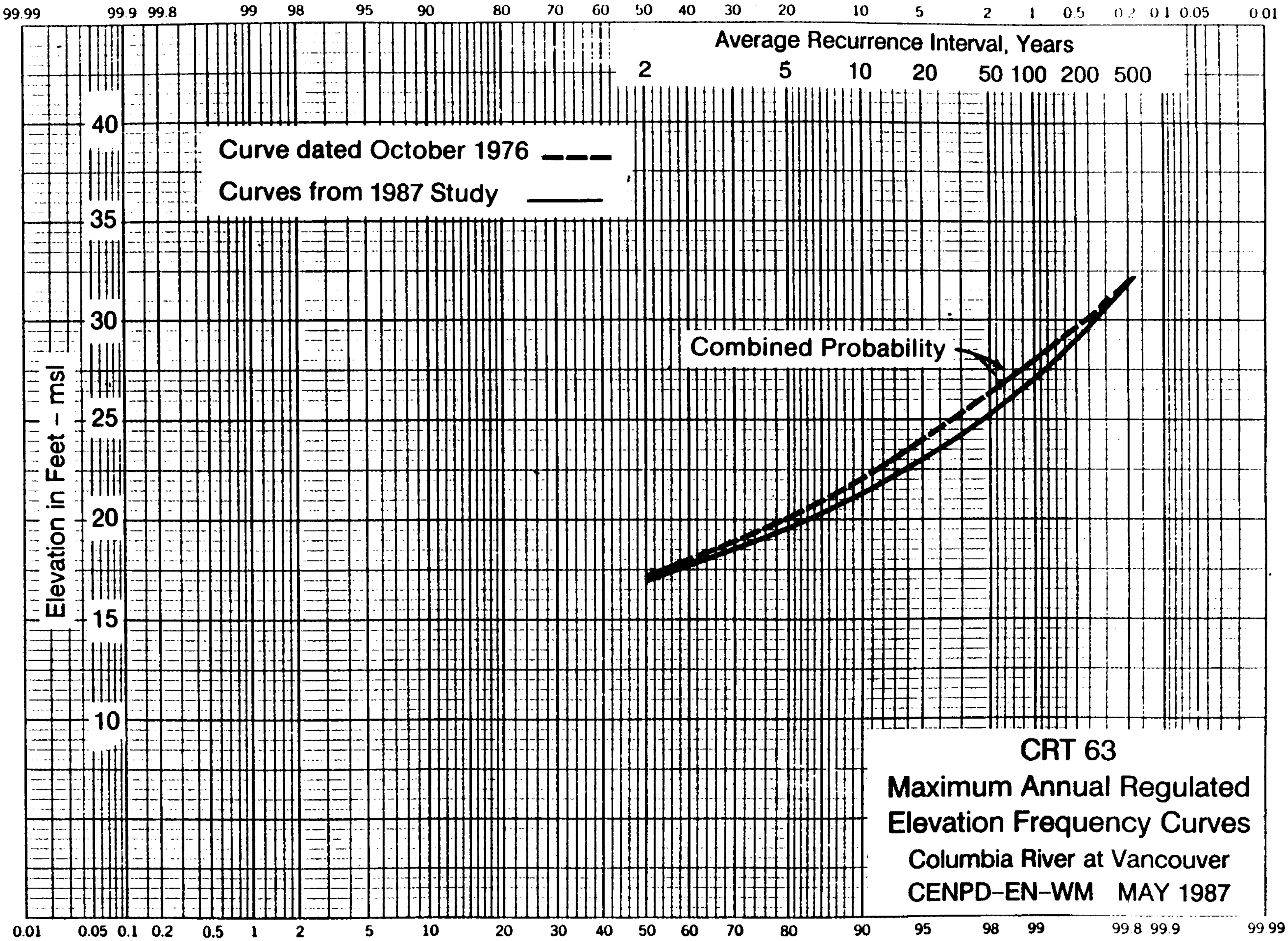

Figure 5-9. Maximum Annual Regulated Elevation Frequency Curves at Vancouver

There are three locations in the lower Columbia where stage-frequency could be established. These are:

- Bonneville tailwater (river mile 145) where discharge-frequency can be transposed from The Dalles and stage-discharge can be taken from DWOPER to derive stage-frequency.

- Vancouver (river mile 106) where a long record of stage data has been acquired. The analysis of this data is discussed in this report and the curve is presented in Figures 5-8 and 5-9.

- Wauna (river mile 42) where data from a previous study were available. At this location tidal effects are dominant and basically establish water surface elevations rather than the rate of flow in the Columbia River. Frequency curves for river elevation at each of these locations became "anchor points" for the water surface profiles under the assumption that historic observed data at site is more representative than elevation/frequency relationships developed through the use of hydrologic and hydraulic models.

Given the frequency curves at the three locations in the lower Columbia, the theoretical water surface profiles were computed with DWOPER, using hypothetical flows developed from watershed modeling. Winter and summer profiles were computed for the reach from river mile 42 (Wauna) to river mile 145 (Bonneville Dam). These profiles based on hypothetical (computed) and historical streamflow were not representative of any given frequency for the total reach, but do approximate water surface elevation for discharges input to the model. Given that elevation-frequency was defined at the three anchor points these profiles were used to define the shape of profiles of specific frequency between the three points. The above analysis is considered quite cursory in its depth of study, yet is felt to be an improvement over simply extrapolating stage or discharge frequency curves in the lower Columbia River. Profiles derived in this study should, therefore, be considered adequate for reconnaissance type evaluation. For investigations carried beyond the reconnaissance level, site-specific evaluation should be made.

The 100-year and 500-year winter and summer and combined probability profiles are shown on Figure 5-10 and 5-11. In both figures for the Columbia River immediately below Bonneville the profile of regulated summer runoff is higher than the profile of regulated winter events, as expected with high Columbia River flows and low Willamette River flows. Downstream of river mile 120 to 130 winter floods produce higher stages than summer floods due primarily to Willamette River inflows. The combined probability profiles illustrate elevation probability on an annual basis.

Standard Project Flood Profiles

The Standard Project Flood (SPF) is a design standard used primarily in levied areas, where loss of life could occur if the levee were overtopped or failed. It represents a flood "reasonably possible" for the region, and can be thought of as equivalent to the greatest historic floods that have been experienced in a relatively broad geographic region. The Standard Project Flood typically has a recurrence interval on the order to 500 to 1000 years. Since the derivation of the SPF is by way of meteorological methodology, the probability is usually not stated. The SPF may or may not be used as a basis for design of a levee, depending upon economic analysis, assessment of risk of failure, etc. However, for purposes of this report it is a useful reference to use in describing levee capability in the lower Columbia River.

The summer SPF was developed with traditional meteorological methodology which is discussed in Reference 3. The source of runoff for the summer SPF is primarily snowmelt from the Columbia River system upstream of The Dalles, Oregon. Tributaries in the lower Columbia River such as the Willamette River are generally in a low flow regime compared to winter conditions and therefore, have a relatively minor effect on the summer SPF profile. The summer SPF profile shown on Figure 5-12, is regulated by flood control storage in system reservoirs to a much greater extent than occurs winter events due to the system flood control plan calling for draft of reservoirs in the early spring before snowmelt begins.

In this study the derivation of the winter Standard Project Flood for Vancouver by the formal, meteorological method was impossible due to the extremely large

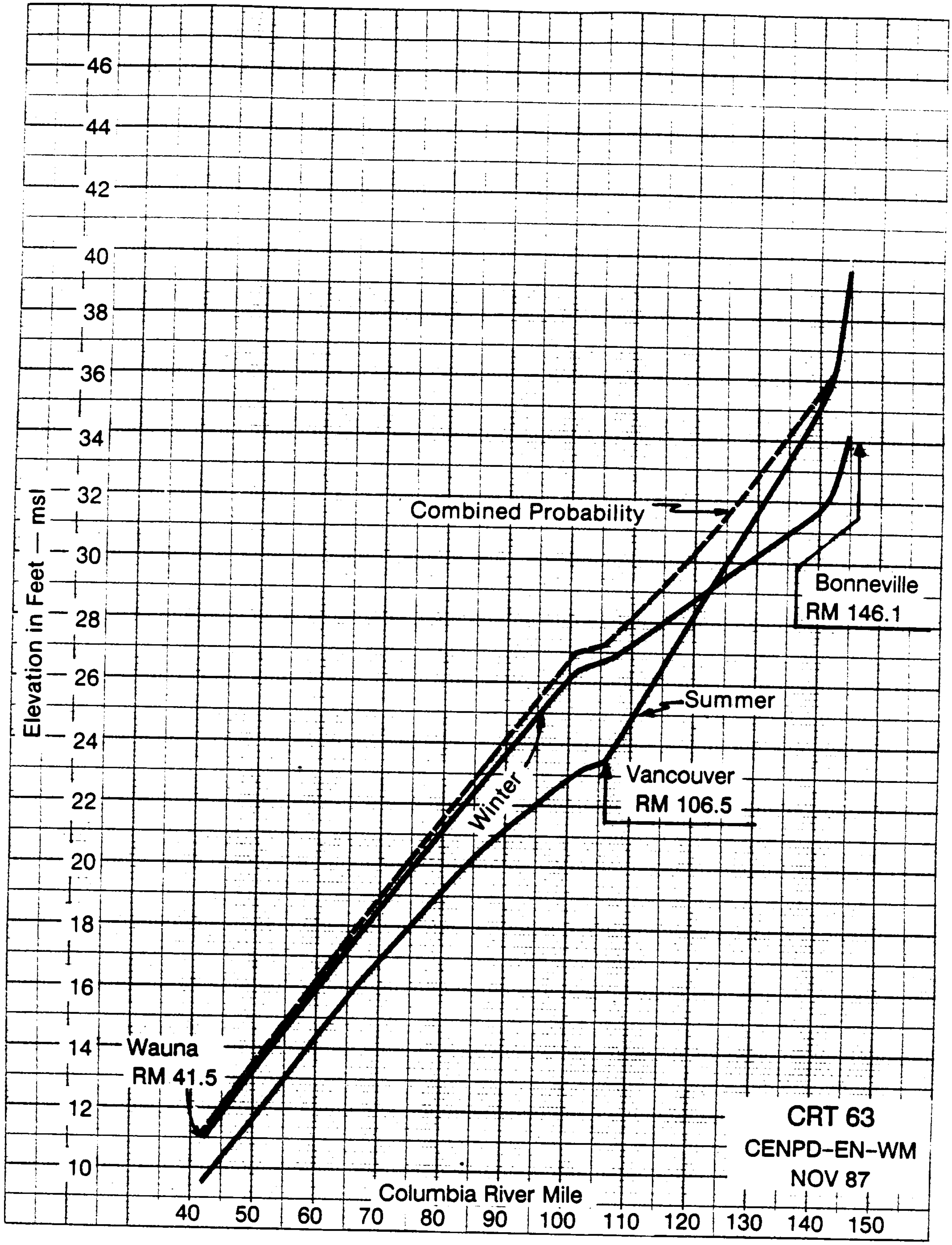

Figure 5-10. **Columbia River 100-year Regulated Water Surface Profiles**

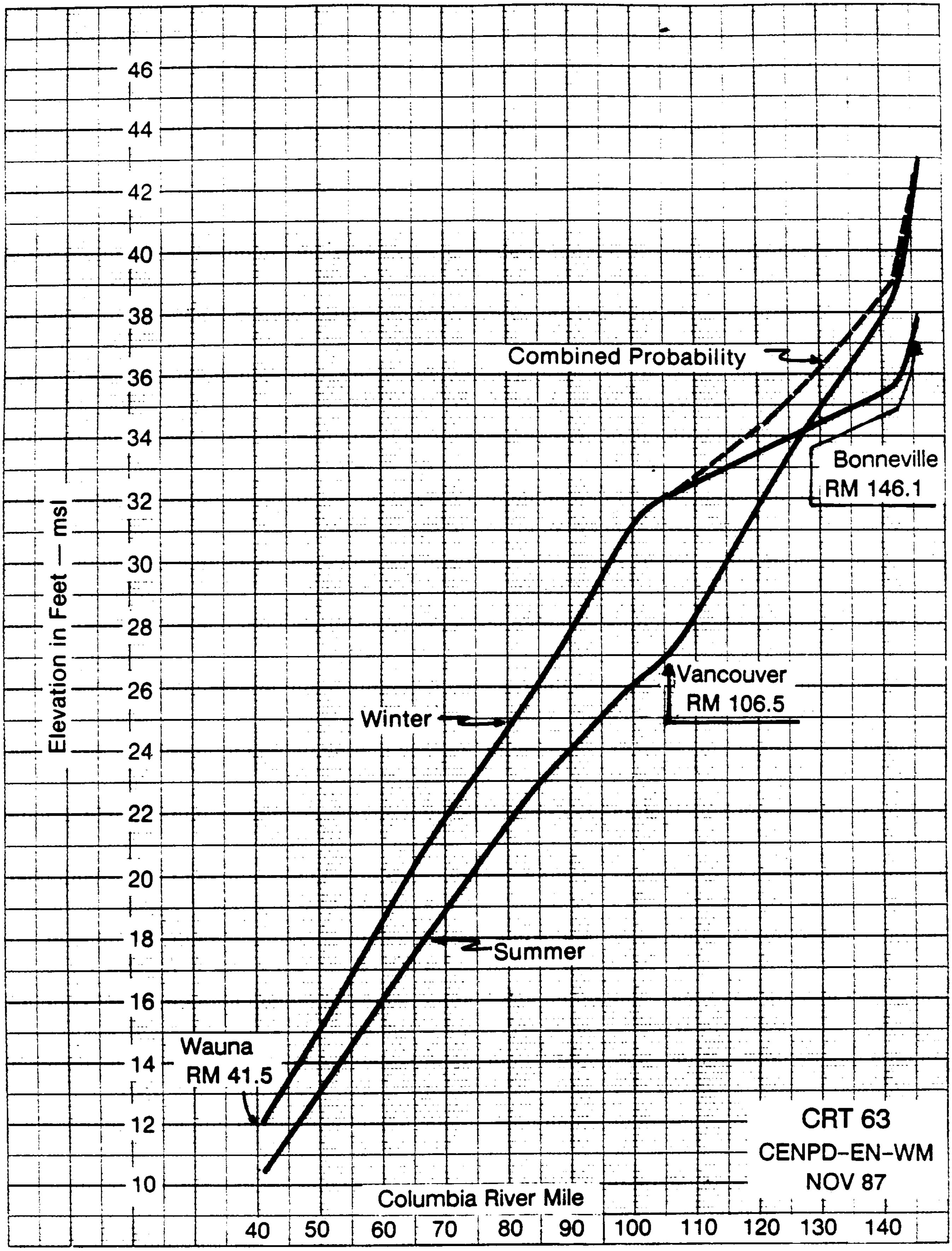

Figure 5-11 **Columbia River 500-year Regulated Water Surface Profiles**

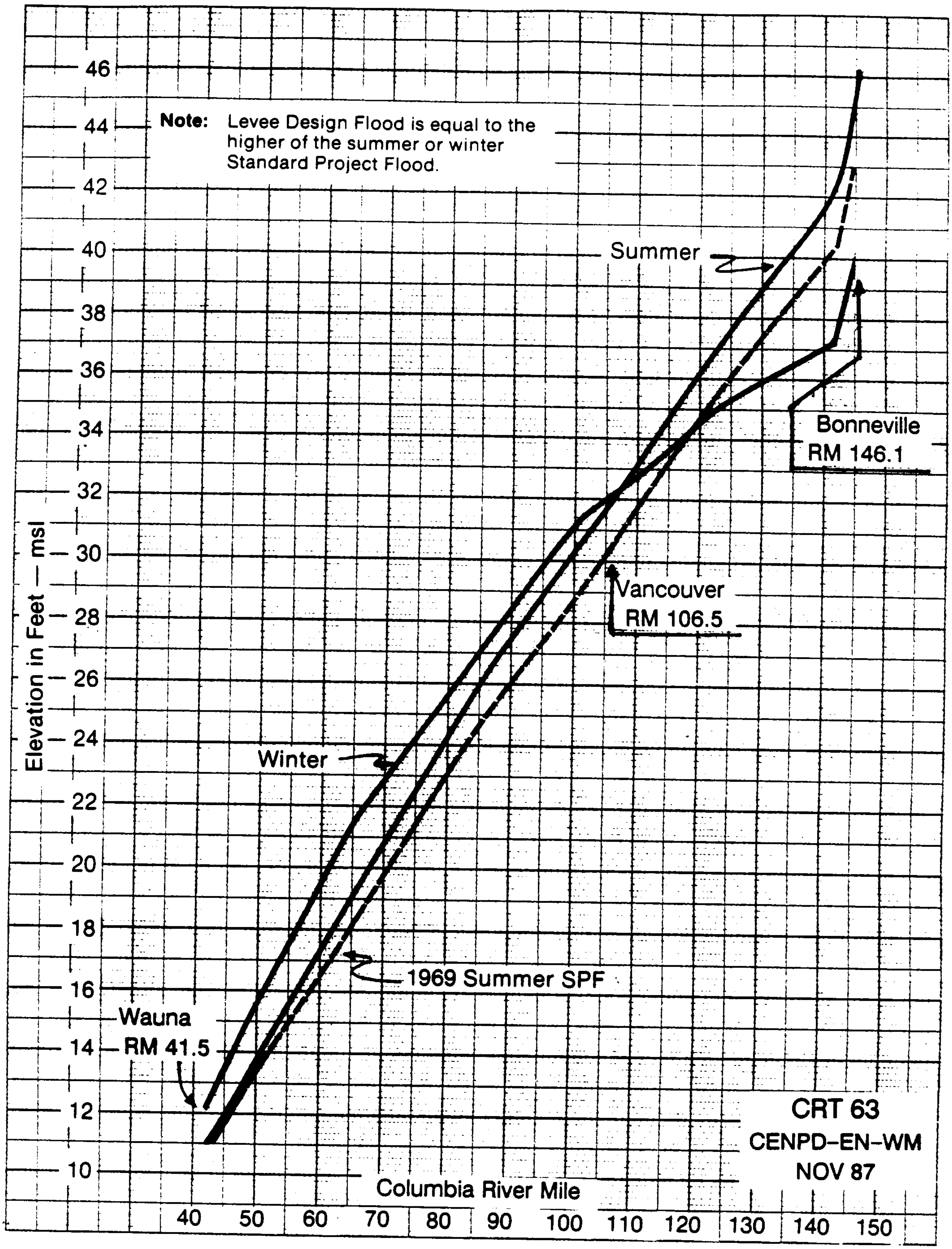

Figure 5-12. **Columbia River Regulated Standard Project Flood Profile**

areal extent involved. This deviation would have required a special meteorological analysis involving at least 2 man-years of work. Since this was impossible in the time-frame given, and since there were no meteorological specialists available who would be capable of undertaking such an analysis, an alternative approach was used.

The method used involved simulating large magnitude winter storms using the winter basin model described earlier in this chapter. Synthetic basin-wide storms of 500 year magnitude were developed using three storms patterns, 1964, 1970, and 1974. These were run through the model shown in Figure 5-1 to produce resulting flows and river elevations on the lower Columbia River. A winter SPF was then estimated by enveloping the high points on the water surface profiles produced by the simulated 500 year storms. This Standard Project Flood profile is shown on Figure 5-12.

As has been pointed out in previous discussions of the winter flooding conditions on the lower Columbia, factors such as storm distribution and temperature are considered to be as critical to determining the stage in the Portland-Vancouver harbor area, as are precipitation quantities falling over the basin. It has been pointed out that temperature alone was an extremely sensitive parameter, as evidenced by sensitivity tests which show that if temperatures above The Dalles were just 3 degrees greater during the occurrence of the December 1964 flood, the flood would have had a crest elevation at Vancouver that was 2 to 3 feet higher than actually observed. Temperatures rose approximately 20 to 40 degrees in the mid-Columbia and lower Snake areas respectively in a 5-day period associated with this storm. Storm pattern, along with the temperature, also effects the relative contribution of the flood and determines whether it is concentrated in one region of the basin versus another. Because of these factors, the enveloping technique was used to assure that temperature and distribution factors were being accounted for in estimating the SPF. As it turned out, the 1970 storm and temperature pattern produced the most critical conditions in the lower river when the 500 year precipitation was applied.

As a check on the reasonableness of this approach the discharge at The Dalles as generated by the model in the most critical storm pattern was checked against the flood frequency curves for this station; and, stages at Vancouver were checked against the stage-frequency curve at that point. The resulting discharge is between a 500-year and a 1000-year event at The Dalles and the stage at Vancouver is very close to a 500-year event.

It is concluded that additional analysis would be clearly desirable if the SPF is used further, beyond the reconnaissance phase of planning investigations. Temperature effects need to be studied further, and timing of Columbia and Willamette River flows need to be examined. For example, in the events analyzed, the Willamette generally peaks before the Columbia by several days. It is entirely possible that meteorological conditions can produce coincident timing of major peak flows with resultant higher stages. Increased temperatures and optimum timing are not reflected in the current winter SPF due largely to the fact that the estimated discharges and stages are within range of anticipated probabilities as reflected by frequency curves. Considering the importance of the areas subject to flooding a more rigorous analysis is considered desirable.

Comparison of Water Surface Profiles With Levees

In the Preliminary Report, tables were presented which compared the estimates of river height along the lower Columbia with levee conditions. In that report the river elevations were based upon water surface profiles developed in 1979; however, elevations were adjusted somewhat subjectively to account for likely changes in the discharges-frequency relationships due to regulation changes and other factors. These were considered rough estimates of elevations to be used for a qualitative identification of potential problems, to be used until the more detailed study described herein could be completed. The updated versions of these tables are Tables 5-3, 5-4, and 5-5, representing spring-summer, fall-winter, and combined frequency conditions, respectively.

The tables list levee capacity in terms of "Safe Levee Height" (SLH) and Top of Levee (TOL). These data are taken from a 1978 Portland District Corps of Engineers report (Reference 5). Levee and channel capacities in the lower Columbia River are highly variable, since flood prone areas are protected by a system of independently constructed levees extending over a 75 mile reach of the river. The SLH was subjectively determined based upon structural factors, levee height, and maintenance performance. This standard represents a level at which the levee could fail if no emergency remedial measures were undertaken during the course of a flood to combat any levee deficiencies.

TABLE 5-3 LOWER COLUMBIA RIVER LEVEES AND SPRING FLOOD CONDITIONS

RIVER MILE	DRAINAGE DISTRICT, DEVELOPMENT		LEVEE ELEVATIONS		FLOOD ELEVATIONS(Ft NGVD)		
			TOP 1/	SLH 1/	20-YR	100-YR	SPF
122.5 - 128.0	WASHOUGAL AREA	a,b,c,d,e	43.0	36.7	28.1	31.3	38.4*
119.0 - 121.5	SANDY	b,c,d,e	45.0	34.9	25.8	29.2	36.6*
108.2 - 119.0	MULTNOMAH COUNTY NO. 1	c,d,e,h	44.0	34.4	24.9	28.3	35.8*
106.5 - 108.2	PENINSULA NO. 2	b,c,d,h	35.8	18.0	20.8*	24.3*	32.4*
105.6 - 106.5	PENINSULA NO. 1	c,d,h	35.3	22.0	20.1	23.6*	31.8*
93.9 - 102.6	CLARK COUNTY NO. 14	c,e,f	31.5	16.0	19.8*	23.2*	31.0*
98.3 - 101.5	SAUVIE ISLAND	b,c,h	33.5	29.3	19.8	23.2	30.7*
92.2 - 96.8	COLUMBIA NO. 1	b,f,i	27.5	20.0	19.1	22.4*	29.6**
90.3 - 97.0	SCAPPOOSE	b,c,d,e	30.8	27.4	19.1	22.4	29.6*
89.5 - 92.2	LAKE RIVER DELTA	i	25.4	16.0	18.5*	21.5*	29.6**
87.9 - 91.4	BACHELOR ISLAND AREA	e,f,i	25.8	20.0	18.4	21.5*	28.5**
86.4 - 88.2	LEWIS RIVER AREA	f,g	23.0	15.0	17.9*	20.8*	28.3**
80.6 - 86.3	COWLITZ COUNTY NO. 2	a,b,d,e,f	28.2	25.2	17.6	20.3	27.5*
75.8 - 82.3	DEER ISLAND	f,g	29.9	16.0	17.0*	19.6*	27.0*
68.3	COWLITZ COUNTY PUD # 3	b,d,e	26.2	18.5	13.8	15.8	25.8*
60.3 - 68.3	COWLITZ COUNTY PUD # 1	a,c	28.9	18.4	14.2	16.2	20.0*
62.2 - 66.8	RAINIER	b,e,f	23.0	18.3	13.8	15.8	19.4*
57.1 - 60.0	COWLITZ COUNTY NO. 15	e,f	19.9	15.7	12.4	14.1	17.0*
55.5 - 56.5	JOHN	a,f	14.0	10.0	11.7*	13.2*	15.8**
49.7 - 55.4	BEAVER	c,e,f	17.5	10.6	11.5*	13.0*	15.4*

DEVELOPMENT CODES

a. Urban
b. Residential
c. Industrial
d. Commercial
e. Agriculture
f. Pasture
g. Wooded
h. Recreation
i. Wildlife Refuse or Game Preserve

NOTES

1/ From "Drainage District Condition Survey on Safe Water Surface Levels", Corps of Engineers, Portland District, May 1978
Upstream Elevation Shown in Feet, NGVD
SLH: Safe Levee Height

* Equals or Exceeds Safe Levee Height
** Equals or Exceeds Top of Levee

TABLE 5-4 LOWER COLUMBIA RIVER LEVEES AND WINTER FLOOD CONDITIONS

RIVER MILE	DRAINAGE DISTRICT, DEVELOPMENT		LEVEE ELEVATIONS TOP 1/	LEVEE ELEVATIONS SLH 1/	FLOOD ELEVATIONS (Ft NGVD) 20-YR	FLOOD ELEVATIONS (Ft NGVD) 100-YR	FLOOD ELEVATIONS (Ft NGVD) SPF
122.5 - 128.0	WASHOUGAL AREA	a,b,c,d,e	43.0	36.7	26.4	30.0	35.6
119.0 - 121.5	SANDY	b,c,d,e	45.0	34.9	25.2	29.0	34.7
108.2 - 119.0	MULTNOMAH COUNTY NO. 1	c,d,e,h	44.0	34.4	24.8	28.6	34.3
106.5 - 108.2	PENINSULA NO. 2	b,c,d,h	35.8	18.0	22.9*	27.0*	32.4*
105.6 - 106.5	PENINSULA NO. 1	c,d,h	35.3	22.0	22.6*	26.7*	32.1*
93.9 - 102.6	CLARK COUNTY NO. 14	c,e,f	31.5	16.0	22.4*	26.6*	31.7**
98.3 - 101.5	SAUVIE ISLAND	b,c,h	33.5	29.3	22.3	26.6	31.6*
92.2 - 96.8	COLUMBIA NO. 1	b,f,i	27.5	20.0	21.3*	25.4*	30.2**
90.3 - 97.0	SCAPPOOSE	b,c,d,e	30.8	27.4	21.3	25.4	30.2*
89.5 - 92.2	LAKE RIVER DELTA	i	25.4	16.0	20.3*	24.2*	28.9**
87.9 - 91.4	BACHELOR ISLAND AREA	e,f,i	25.8	20.0	20.1*	24.0*	28.6**
86.4 - 88.2	LEWIS RIVER AREA	f,g	23.0	15.0	19.6*	23.3**	27.7**
80.6 - 86.3	COWLITZ COUNTY NO. 2	a,b,d,e,f	28.2	25.2	19.1	22.9	26.0*
75.8 - 82.3	DEER ISLAND	f,g	29.9	16.0	18.2*	21.9*	24.8*
68.3	COWLITZ COUNTY PUD # 3	b,d,e	26.2	18.5	15.6	18.1	22.3*
60.3 - 68.3	COWLITZ COUNTY PUD # 1	a,c	28.9	18.4	15.6	18.1	22.3*
62.2 - 66.8	RAINIER	b,e,f	23.0	18.3	15.3	17.7	21.8*
57.1 - 60.0	COWLITZ COUNTY NO. 15	e,f	19.9	15.7	13.9	15.8*	19.3*
55.5 - 56.5	JOHN	a,f	14.0	10.0	13.2*	14.9**	17.9**
49.7 - 55.4	BEAVER	c,e,f	17.5	10.6	12.9*	14.6*	17.4*
Willamette 12.8	PORTLAND	a,b,c,d	33.9	33.9	23.1	25.3	33.6

DEVELOPMENT CODES

a. Urban
b. Residential
c. Industrial
d. Commercial
e. Agriculture
f. Pasture
g. Wooded
h. Recreation
i. Wildlife Refuse or Game Preserve

NOTES

1/ From "Drainage District Condition Survey on Safe Water Surface Levels", Corps of Engineers, Portland District, May 1978
Upstream Elevation Shown in Feet, NGVD
SLH: Safe Levee Height

* Equals or Exceeds Safe Levee Height
** Equals of Exceeds Top of Levee

TABLE 5-5 LOWER COLUMBIA RIVER LEVEES AND SPRING/WINTER FLOOD CONDITIONS

RIVER MILE	DRAINAGE DISTRICT, DEVELOPMENT		LEVEE ELEVATIONS		FLOOD ELEVATIONS 2/		
			TOP 1/	SLH 1/	20-YR	100-YR	LDF 3/
122.5 - 128.0	WASHOUGAL AREA	a,b,c,d,e	43.0	36.7	29.0	32.3	38.4*
119.0 - 121.5	SANDY	b,c,d,e	45.0	34.9	27.2	30.7	36.6*
108.2 - 119.0	MULTNOMAH COUNTY NO. 1	c,d,e,h	44.0	34.4	26.6	30.1	35.9*
106.5 - 108.2	PENINSULA NO. 2	b,c,d,h	35.8	18.0	23.8*	27.7*	32.6*
105.6 - 106.5	PENINSULA NO. 1	c,d,h	35.3	22.0	23.3*	27.3*	32.1*
93.9 - 102.6	CLARK COUNTY NO. 14	c,e,f	31.5	16.0	23.0*	27.0*	31.7**
98.3 - 101.5	SAUVIE ISLAND	b,c,h	33.5	29.3	23.0	26.9	31.6*
92.2 - 96.8	COLUMBIA NO. 1	b,f,i	27.5	20.0	22.0*	25.7*	30.2**
90.3 - 97.0	SCAPPOOSE	b,c,d,e	30.8	27.4	22.0	25.7	30.2*
89.5 - 92.2	LAKE RIVER DELTA	i	25.4	16.0	21.1*	24.6*	28.9**
87.9 - 91.4	BACHELOR ISLAND AREA	e,f,i	25.8	20.0	20.9*	24.4*	28.6**
86.4 - 88.2	LEWIS RIVER AREA	f,g	23.0	15.0	20.3*	23.7**	27.7**
80.6 - 86.3	COWLITZ COUNTY NO. 2	a,b,d,e,f	28.2	25.2	19.9	23.2	27.1*
75.8 - 82.3	DEER ISLAND	f,g	29.9	16.0	19.1*	22.2*	26.0*
68.3	COWLITZ COUNTY PUD # 3	b,d,e	26.2	18.5	16.1	18.3	22.3*
60.3 - 68.3	COWLITZ COUNTY PUD # 1	a,c	28.9	18.4	16.1	18.3	22.3*
62.2 - 66.8	RAINIER	b,e,f	23.0	18.3	15.8	17.9	21.8*
57.1 - 60.0	COWLITZ COUNTY NO. 15	e,f	19.9	15.7	14.2	16.0*	19.3*
55.5 - 56.5	JOHN	a,f	14.0	10.0	13.4*	15.0**	17.9**
49.7 - 55.4	BEAVER	c,e,f	17.5	10.6	13.1*	14.7*	17.4*
Willamette 12.8	PORTLAND	a,b,c,d	33.9	33.9	23.7	25.7	33.6

DEVELOPMENT CODES

a. Urban
b. Residential
c. Industrial
d. Commercial
e. Agriculture
f. Pasture
g. Wooded
h. Recreation
i. Wildlife Refuse or Game Preserve

NOTES

1/ From "Drainage District Condition Survey on Safe Water Surface Levels", Corps of Engineers, Portland District, May 1978
Upstream Elevation Shown in Feet, NGVD
SLH: Safe Levee Height
2/ Flood Elevations in Feet, NGVD Reflect: Combined Probability of Spring and Winter Flooding
3/ LDF - Levee Design Flood
* Equals or Exceeds Safe Levee Height
** Equals or Exceeds Top of Levee

The tables show that the combined probability Levee Design Flood would exceed SLH for all drainage districts, and that the top of levee would be exceeded in several districts. For the occurrence of the 100-year flood, the SLH would have been exceeded in nine districts and two would experience overtopping. Compared to the tabulations contained in the Preliminary Report these results indicate a lowering of the number of exceedances due to a reduction in the estimates of river elevation in most areas. In some areas, particularly the furthest downstream reaches of the Columbia, the revised estimates are higher than those contained in the Preliminary Report.

VI. SUMMARY AND CONCLUSIONS

Summary

This report documents the overall results of a major hydrologic and reservoir system analysis study that has been underway since 1984, and which were partially documented in two previous interim reports, "Preliminary Review of Flood Control, Columbia River Basin", and "Interim Report on Flood Control, Columbia River Basin". The study can be considered as two separate and somewhat independent topics: (1) a review of flood control criteria for major reservoirs; and, (2) an assessment of system flood control capability. These two facets of the study are relatively independent from each other, although any investigation of changing flood control criteria at reservoir projects must consider what the capability of the project is in meeting current flood control objectives.

The study involved the following study tools, most of which were newly developed and are of benefit for future general application:

1. Development of a hydrologic and meteorological database consisting of data records for most stations in the Columbia Basin for the period of record.

2. Development of several computer models for simulating basin hydrologic conditions, reservoir operations, and hydraulic conditions in the lower Columbia River. The SSARR hydrologic model, HEC-5 Hydrologic Model, and DWOPER hydraulic model were used.

3. Comprehensive storm study for the Columbia River basin, including a database and statistical routines that can be applied to future studies.

4. Extensive watershed simulations using hypothetical storms combined with varying levels of snowpack.

5. A database of historic adjusted river flows and tributary "local inflows" complete for the 1929 to 1984 period of record. These are used for simulating the historic operations on a daily basis.

6. A new analysis of winter flooding in the lower Columbia, including the development of an estimated winter Standard Project Flood.

7. A new frequency analysis of flooding in the lower Columbia.

The above study tools were employed to evaluate flood control rule curves, and to perform an assessment of flood control capability. The former involved testing existing and proposed alternative rule curves against various combinations of forecasted runoff (a function of the spring snowpack) and storm precipitation, to check whether a modification in the criteria was feasible. In the capability studies, new estimates of design floods, reflecting current reservoir operating policy and procedures, could be checked against levee heights in the lower Columbia to assess their capability.

Conclusions, Rule Curve Analysis

In Chapter IV proposed new rule curves are presented for Libby, Hungry Horse, Grand Coulee, Dworshak, and Brownlee projects. These reflect raised elevations (a decreased flood control requirement) for low runoff years, but a need to maintain existing requirements for high years. The degree of change varies from project to project. For instance, the change at Hungry Horse is relatively small - affecting only the lowest few runoff years in the 50 year study period - while that at Dworshak is more significant. In the case of Hungry Horse a restricted downstream channel capacity precludes extensive change. Perhaps the most significant change, in terms of potential flood control impacts, is for Grand Coulee project. As with the other projects, the criteria in the lowest years has been raised as compared to the existing official rule curves. Additionally, the rule curve has been proposed for change in certain intermediate years, to reduce conflicts with requirements for pumping into Banks Lake. These changes reflect one major assumption: that the Columbia River Treaty projects (Mica, Arrow, and Duncan) will continue to be operated according to the criteria established in the Treaty Flood Control Operating Plan. If this criteria were to be reduced, the Grand Coulee flood control rule curves would have to be lowered, to compensate accordingly. Another assumption reflected in all the rule curve modifications is that strict rules for operating during the refill period would be followed. Since the reservoir would be operating with relatively low amounts of storage space during a time when storm conditions could create a critical situation, rate of filling becomes an important concern. New internal operating guidance should be formulated if the rule curves are adopted.

The rule curve modifications proposed are to be considered of preliminary status, and subject to future revision. In the case of Grand Coulee and Hungry Horse projects, the curves are subject to further joint study and approval by the Bureau of Reclamation and Corps of Engineers before being adopted as official operating criteria under Section 7 of the Flood Control Act of 1944. Similarly, the Libby and Dworshak rule curves will require review and concurrence by the District offices responsible for project operations. It is conceivable that in the process of further analysis of these curves some changes may be made to what has been presented in this report. In the meantime, the curves proposed will be used as interim guidance for reservoir operations, subject to modifications deemed necessary during the actual operations.

The bar charts represented in Chapter IV demonstrate the benefits of the proposed rule curve modifications. In general, the flood control requirement is raised in the lower runoff years, thus reducing incidences when flood control criteria govern operation of the reservoir. However, it is noted that, even with the proposed changes, the operation may not change in the lowest years, since the reservoir may likely be operated to serve system firm power loads, out of the influence of the flood control requirement.

Conclusions, System Capability Study

The system flood control capability studies described in Chapter V represent the first major effort in more than 20 years to assess the status of the levee-reservoir system in the Columbia basin. With the study directed primarily at the levee system in the lower Columbia, several new tools described above provided an updated comparison between design floods of various magnitudes and the assessment of levee capacity within the 20 drainage districts studied.

Results of the study have been tabulated to compare river elevation for the 100-year and Levee Design Flood (LDF). This comparison shows that an occurrence of the LDF would exceed the Safe Levee Height in all drainage districts, and would overtop the levees in some districts. This indicates that the flood control capability of the combined reservoir-levee system is not overly conservative and is perhaps inadequate in some instances.

The results of this determination will be reflected in another study now being performed by the Portland District office under the Columbia River and Tributaries program, in which the damage potential of the lower Columbia area will be updated, and conclusions will be drawn about the need for further studies of this problem, and the need for levee improvements.

Future Studies

The Flood Control Study will now enter a third phase which will address the finalization of the rule curve changes proposed in this report. These studies will be coordinated closely with, and may directly involve, Bureau of Reclamation personnel, since two of the five projects involved are USBR projects. The goal in these cases will be to formalize the new rule curves according to the provisions of Section 7 of the 1944 Flood Control Act.

Future studies will be of a similar nature to those described in this report. Basic data and models will remain the same, although the historic daily flow database will have been expanded to include more historic years. The new studies will be directed more at the shape and timing of the flood control drawdown, as opposed to the quantification of the maximum drawdown; although, in the case of the latter, the results of this report will continue to be subject to future scrutiny in future studies. It is quite likely that new flood control operating guidance will be formulated, to be used in the application of the new rule curves. The goal is to finalize the rule curves within the next two years, with priority being given to Dworshak and Grand Coulee projects.

Future studies will also lead to refinement of downstream frequency curves and other such reference tools that will reflect the latest operating rule curves, operating methodology, and up-to-date hydrologic data.

VII. REFERENCES

1. Nelson, M. L. and Rockwood, D. M., "Flood Regulation by Columbia Treaty Projects," ASCE Journal of the Hydraulics Division, January 1971.

2. U.S. Army Corps of Engineers, North Pacific Division, Columbia River Treaty Flood Control Operating Plan, October 1972.

3. U.S. Army Corps of Engineers, North Pacific Division, Lower Columbia Probable Maximum and Standard Project Flood, September 1969.

4. U.S. Army Corps of Engineers, North Pacific Division, User Manual, SSARR Model, April 1986.

5. U.S. Army Corps of Engineers, Portland District, Drainage District Condition Survey on Safe Water Surface Levels, May 1978.

6. U.S. Army Corps of Engineers, Portland District, Description of 1987 Hydraulic Studies, Lower Columbia River, July 1987.

7. U.S. Army Corps of Engineers, Seattle District; Libby Dam and Lake Koocanusa Water Control Manual, July 1984.

8. U.S. Army Corps of Engineers, Walla Walla District, Water Control Manual for Dworshak Dam and Reservoir, North Fork Clearwater River, Idaho, November 1986.

9. U.S. Department of Commerce, NOAA-NWS, Standard Project Storm Precipitation and Snowmelt Temperature Criteria for the 9570-Square Mile Clearwater River Drainage Above Spalding, Idaho, NOAA Technical Memorandum NWS HYDRO 42, September 1986.

10. Wortman, R. T., "Synthetic Design Storms for the Columbia River Basin," EOS - Transaction, American Geophysical Union (Abstract) Vol. 66, No. 46, November 12, 1985; Paper presented at AGU Fall Meeting - December 1985.

11. Barcellos, D. J. and Holmes, G. D., "Impact of Temperature on Columbia River Winter Floods," Proceedings of the ASCE Engineering Hydrology Symposium, August 3-7, 1987.

12. Speers, D. D., "Calibrating and Applying a Hydrologic Model of the Columbia River Basin," Corps of Engineers Hydrologic Engineering Workshop, October 1988.

APPENDIX TO CRT-63

AGENCY COMMENTS ON DRAFT REPORT

AND

RESPONSES TO THOSE COMMENTS

Corps of Engineers, North Pacific Division

February 1989

APPENDIX TO CRT-63

AGENCY COMMENTS ON DRAFT REPORT AND RESPONSES TO THOSE COMMENTS

A draft copy of this report, dated November, 1987, was circulated to agencies involved with the Columbia River for their comment. This appendix contains letter that were received from these agencies, followed by our response to those letters. In many cases the text and figures contained in this final version of the report reflect the comments made in the agency review.

The following is a listing of the agencies involved in the review, along with the responses received:

Bonneville Power Administration	Comments made
Bureau of Indian Affairs	Comments made
Bureau of Reclamation	Verbal comments made
Columbia Basin Fish and Wildlife Authority	Comments made
Fish Passage Center	Commented with CBFWA
Idaho Department of Water Resources	No comments
Idaho Power Company	Comments made
Mid-Columbia Public Utility Districts	Discussed in meeting
Montana Dept. of Fish, Wildlife and Parks	Comments made
National Weather Service, NWRFC	No comments
National Weather Service, Western Region	No comments
Northwest Power Planning Council	Comments made
Northwest Power Pool	No reply received

In addition to the above, the draft report received review by the Corps of Engineers' District offices with jurisdiction in the Columbia River, and by the staff in the North Pacific Division office.

The Corps of Engineers appreciates the review and comments that were made, and hopes that the changes that were made to the report and the discussions that follow were responsive to the reviewer's comments.

Department of Energy
Bonneville Power Administration
P.O. Box 3621
Portland, Oregon 97208-3621

November 24, 1987

In reply refer to: SJ

Colonel James R. Fry
Deputy Division Engineer
North Pacific Division
U.S. Army Corps of Engineers
P.O. Box 2870
Portland, Oregon 97208-2870

Dear Colonel Fry:

Bonneville Power Administration (BPA) has reviewed the draft copy of the report titled "Review of Flood Control Columbia River Basin," and we submit the following comments for your consideration.

1. In paragraph 2, page 34, it is stated that the Columbia River Treaty projects have not been included in the analysis. Yet Table 2-1, page 5, shows that the Treaty projects control about 51 percent of the total flood control space; with such a large volume it would seem that they should be considered for re-evaluation in this analysis. The Mica and Arrow projects also indirectly provide fish augmentation water to Grand Coulee. Therefore, it would seem natural that the total combination would need to be investigated in the Grand Coulee flood control plan. Any alternate plan for optimizing this combination could then be used during the re-negotiations for the Columbia River Treaty at some later date.

2. Our second comment concerns the Libby (LIB) project. In light of the changes in agricultural conditions since the 1938 International Joint Commission Agreement and the revisions to the channel at the Narrows, shouldn't an alternate flood control analysis be done to see if any appreciable reduction should be made in the flood control draft? Information from such a study would eventually be used during future Treaty negotiations.

3. In using the envelope curve analysis, was a comparison made of the forecasted volumes versus the observed volumes? For example, in the Libby project (Figure 4-9) the 1948 water year shows a simulated forecast of approximately 6300 kaf whereas the observed volume was about 8454 kaf. If enough of these deviations were to occur, would they bias the results? If this was already investigated, it would be helpful to include an explanation in the Final Report.

4. In Figure 4-9, we believe that the dotted line above the 5800 kaf point should coincide with the solid line. We belive that the dotted line as drawn gives too much weight to the one year, 1948. We think the reservoir space represented by the difference between the two lines would be better used for power purposes.

5. Referring to Figure 4-17, will BPA be able to continue to use the maximum rate of drawdown (1.5 feet per day) to meet the proposed drawdown curve?

6. Referring to Figure 4-21, variable refill curves are not always used in actual practice to govern the operation of Dworshak during the refill period, and the inclusion of Notes 2b and 4 on Figure 4-21 is therefore misleading. We would prefer that the practice indicated in these Notes actually be followed, or that some other appropriate firm constraint be developed and followed, so that BPA would have a consistent basis on which to plan and operate.

Thank you for the opportunity to review the draft copy of the report. If you have any questions on the above comments, please call Mr. Mark Maher, of BPA's Hydrometeorology Branch, at (206) 690-2103 (FTS 425-2103).

Sincerely,

Anthony R. Morrell
Assistant to the Administrator for
Environment

COMMENTS ON LETTER FROM THE BONNEVILLE POWER ADMINISTRATION, 24 NOVEMBER 1987.

Paragraph 1 - The Columbia River Treaty projects should have been included in the analysis.

Refer to page 160, paragraph no. 5, of our comments to the letter from the Northwest Power Planning Council on the same subject. For several reasons stated in that response, the inclusion of the Treaty projects in the analysis was considered beyond the scope of this report.

Paragraph 2 - Influence of Kootenay Lake IJC rules on the Libby rule curves.

An analysis of the Kootenay Lake IJC Rule Curve is proposed for a future phase of this study, as discussed in the revised report (see page 44.)

Paragraph 3 - Using observed versus forecasted runoff in the envelop curve analysis.

Both observed and forecasted data were examined in the analysis and results from each were similar. We prefer to use the forecasted value (actually simulated forecasts), since that is more representative of real-life conditions.

Paragraph 4 - Proposed increase in flood control storage for Libby in Figure 4-9 (and 4-8).

This proposed change has been eliminated in the final version of the report because the flood control benefit gained was very small.

Paragraph 5 - Rate of drawdown for Grand Coulee, Figure 4-17.

The maximum rate of drawdown for Grand Coulee has not been changed.

Paragraph 6 - Comments on figure 4-21, Dworshak operation.

This plot and its description (beginning on page 68, 73) have been clarified in the final version of the report.

IN REPLY REFER TO:
Branch of Fisheries

United States Department of the Interior

BUREAU OF INDIAN AFFAIRS
PORTLAND AREA OFFICE
POST OFFICE BOX 3785
PORTLAND, OREGON 97208

- 3 1987

Colonel James Fry
Deputy Division Engineer
U.S. Department of the Army
North Pacific Division, Corps of Engineers
Post Office Box 2870
Portland, Oregon 97208-2870

Dear Colonel Fry:

I have review your draft report, "Review of Flood Control, Columbia River Basin, and have concerns that relate to treaty Indian fishing rights.

In the introduction you cite that one objective of the study is to evaluate the feasibility of improving fish flows throughout the Columbia River Basin as recommended in the Northwest Power Planning Council's Fish and Wildlife Program. Yet little discussion occurs regarding impacts to resident or anadromous fisheries as a result of changes in flood control operational role curves.

As trustee for the tribes, I am concerned that you take into account all fishery needs within the basin as it relates to the new proposed flood operation procedures. Significant strides have been made at the local, national and international level to improve all fish stocks. Any potential infringement on these efforts must be carefully evaluated and related to United States obligations to fulfill treaty Indian rights while providing the necessary conservation needs for the fisheries.

Thank you for the opportunity to comment.

Sincerely,

Acting Portland Area Director

COMMENTS ON LETTER FROM THE BUREAU OF INDIAN AFFAIRS, 3 NOVEMBER 1987

Comment concerning a lack of discussion on the impacts to resident or anadromous fisheries as a result of changes in the flood control rule curves.

Reference is made to our responses to a similar comment from the Columbia Basin Fish and Wildlife Authority (see page 143, paragraph 1). As discussed in those responses we believe that proposed changes benefit the fisheries.

COLUMBIA BASIN FISH AND WILDLIFE AUTHORITY
METRO CENTER • SUITE 170
2000 S.W. FIRST AVENUE
PORTLAND, OREGON 97201

(503) 294-7031
FTS 423-7031

OFFICE OF
EXECUTIVE SECRETARY

November 24, 1987

Colonel James Fry
Corps of Engineers
P.O. Box 2870
Portland, OR 97208

Dear ~~Colonel Fry~~ Jim:

We have reviewed the draft final report "Review of Flood Control, Columbia River Basin", and offer the following comments for your consideration.

Language from the Northwest Power Planning Council Fish and Wildlife Program, relating to provision of flows for fish in the Columbia Basin, is cited as part of the basis for this review of flood control. However, beyond the introduction to the report, there is no mention of potential increased flows for fish from modifications of flood control criteria. There is no mention of reservoir requirements for resident fish. It would be helpful to understand the affects of the proposed modifications of flood control, if the resulting flows or operations were described in the report. A description of the relative benefits of flood control modifications to power operations, fishery flows, and resident fish should be added. A description of potential fish flow benefits should be presented. As an example, on page 84 the report indicates that neither Grand Coulee nor Brownlee are addressed relative to URC/VECC comparisons "since the VECC for these projects is not as meaningful..." Yet these projects are critical in providing for fish flows. Perhaps this example could be used as a possible area to begin to address potential fish benefits.

The report indicates (page 90) that by modification of the official flood control rule curve in 1987, 130,000 acre-feet of water were gained at Dworshak Reservoir. This gain ensured refill, yet no additional water was provided for the Water Budget in the Snake River. Three-hundred thousand acre-feet could have been gained by full use of the new rule curve. Incorporation of the new rule curve should provide for an increased Water Budget, not just an improved chance of refill.

The study concludes that in high runoff forecast years, flood control rule curves should not be modified. The earlier preliminary reports indicated that forecast error was historically greater on high forecast years. In this case, if substantial forecast error occurred, flood control operations could preclude the provision of fishery flows above minimum levels. In terms of provision of fishery flows, runoff error in high forecast years could be important, because it could preclude provision of optimum fishery flows even in a good runoff year.

In the section addressing the effects of the rule curve changes, controlling system operations are addressed. With the new rule curve changes, power operations control reservoir operations in most years, except for high forecast years. Fishery flows in the study are limited to current Water Budget requirements. At present, the Water Budget is smaller than needed due to other operational constraints, and a long-term re-evaluation of these constraints, one of which is flood control regulation, should address whether changes could be made to allow full fishery flow requirements to be met. The "experimental procedures" language in Water Budget measures of the Fish and Wildlife Program would support this approach.

The report should address whether or not additional years would occur where the VECC and URC conflict, if fishery flow requirements were increased. In this comparison, it would be helpful if the actual VECC were noted, to illustrate the operation between the VECC and the URC.

Table 2-1 in the report could be clarified to show that the volumes committed for flood control on the upper Snake and Boise river are combined for more than one project.

We appreciate the opportunity to review this report, and found it very informative. We belive that fish flow requirements and their potential enhancement through modification of flood control operations should be more directly addressed in this report.

Sincerely,

John R. Donaldson
Executive Secretary

777.87/±

COMMENTS ON LETTER FROM COLUMBIA BASIN FISH AND WILDLIFE AUTHORITY, 24 NOVEMBER 1987

Paragraph 1 - No discussion of increased flows for fish and effects on resident fishery; relative benefits to power, fish flows, and resident fish.

The report scope was purposely limited to flood control considerations, and to expressing the magnitude and frequency of occurrence of any storage increases associated with the flood control modifications. The increases were deliberately expressed in generic terms, since their allocation is based on numerous policies, technical considerations, and economic factors not related to flood control. We believe that, in general terms, the changes described in the report will benefit the anadromous fishery by relaxing one barrier that can limit the amount of water stored in reservoirs in some years. This benefit has already been demonstrated, as in the operation of Dworshak in 1986 and 1987. However, we cannot guarantee that water gained from a flood control change will always benefit the fishery, since, in a given year, so many other factors need to be considered.

In considering the potential benefit to the fisheries it would be well to review the results of the 50-year analysis shown in Figures 4-29 through 4-32 and discussed the section beginning on page 81. This analysis shows that in very few years will there be added storage in the reservoirs, resulting from the rule curve changes. At Libby and Hungry Horse essentially no change occurs; at Grand Coulee, 37 mostly larger runoff years have added storage; at Dworshak, 11 years have an increase. Thus, even if this water were entirely allocated to downstream fisheries, the overall benefit from the flood control changes would be very small. Furthermore, the benefit does not occur in the lowest runoff years when the fishery would need water the most. The above statistics reflect the projected system operation based on policy during the time of this study.

The effect of the flood control modifications on the resident fishery has not been discussed; however, the changes will tend to reduce the magnitudes of spring drawdown and increase summer pools levels. Presumably this is a benefit to the resident fish.

Paragraph 2 - Change in the rule curve for Dworshak should be designated for Water Budget.

See response to paragraph 1, above.

Paragraph 3 - Concern about large forecast errors in years with high runoff forecast impacting fisheries operation.

The reference to high forecast errors in larger runoff years was related to the concern for underforecasts - in which actual runoff exceeds the forecast. As shown by Figure 15 in the Preliminary Report, cases of overforecast - which would impact fishery, refill, etc. - have not been significantly greater in higher runoff years than in moderate to low years. Although it is possible that a major forecast error in a large water year could impact the fishery operations, most likely adequate water would nevertheless exist. On the other hand, the impact of an underforecast would be very severe, and thus the existing flood control capability in large years must be retained.

Paragraph 4 - Long-term re-evaluation of operational constraints needed to address whether greater fishery flows can be provided.

This topic is considered outside the scope of this flood control report, as per previous response to paragraph 1.

Paragraph 5 - Report should address whether or not additional years would occur where the VECC and URC conflict, if fishery flows were increased.

The revised URC's determined by this study represent the theoretical upper limit that can be achieved without reducing project and system flood control capability. Thus, under the hypothetical scenario of increased Water Budget allocation, two options would be left with regard to flood control: (1) accept the limiting influence of flood control in regulation, even in dry years and reduce refill; (2) modify flood control storage space even more, thereby requiring compensating actions such as raising levees.

Paragraph 6 - Clarify Table 2-1

This table has been corrected in the final version of the report.

State of Idaho

DEPARTMENT OF WATER RESOURCES

STATE OFFICE, 450 W. State Street, Boise, Idaho

CECIL D. ANDRUS
Governor

R. KEITH HIGGINSON
Director

Mailing address:
Statehouse
Boise, Idaho 83720
(208) 334-4440

November 6, 1987

Colonel James R. Fry
Corps of Engineers
P. O. Box 2870
Portland, OR 97208-2870

Dear Colonel Fry:

Thank you for providing us a draft copy of the final Report, "Review of Flood Control, Columbia River Basin" for review and comment.

We find the draft report to be acceptable.

Sincerely,

R. KEITH HIGGINSON
Director

RKH:alw

SNAKE RIVER
HYDRO POWER

IDAHO POWER COMPANY

BOX 70 · BOISE, IDAHO 83707

CLIFFORD E. BISSELL
Vice President
Power Plant Construction
and Operations

Phone (208) 383-2421

December 31, 1987

Colonel James R Fry
Deputy Division Engineer
Department of Army
North Pacific Division, Corps of Engineers
Box 2870
Portland, OR 97208-2870

Dear Colonel Fry:

We have received your draft Final Report, "Review of Flood Control, Columbia River Basin", and reviewed it as you requested. We have the following comments concerning the draft report which are specific to our Brownlee project:

- We feel the recreational opportunities and economic importance to the area should be mentioned similar to your discussion of the Dworshak project. A full Brownlee Reservoir is very important to several communities in the local area, especially for the Fourth of July and early summer.

- Specific to the "Proposed Brownlee Flood Control Requirements" table, we believe the space required on April 30th should be based on a May-July volume forecast. This would take into account an early April runoff which is common to the Snake River Basin. By not recognizing the early runoff, the flood control requirements can keep Brownlee drafted into May, thereby hindering refill opportunities and water budget contributions.

We wish these comments could have been forwarded to you at an earlier date; however, we did not receive the draft report until December 11, 1987.

If there is any future correspondence concerning flood control or reservoir operations, please address them to Mr J M (Jim) Collingwood, our manager of power operations, (208) 383-2425.

Sincerely,

C. E. Bissell

C E Bissell

CEB:bvh

c: J W Marshall
J M Collingwood

COMMENTS ON LETTER FROM IDAHO POWER COMPANY, 31 DECEMBER 1987

Paragraph 1 - Report should mention the recreational usage of the Brownlee Reservoir.

The text has been revised accordingly; see page 68.

Paragraph 2 - Space requirement for April 30th should be based upon a May-July forecast.

In actual operations the April 30th required space is determined by a forecast made shortly after April 1st without knowledge of the actual April runoff; therefore, a May-July parameter would not add increased information about potential runoff. During the month of April as more data becomes available the April-July runoff forecast can be adjusted to influence the April 30th flood control storage target. If a May-July parameter were used during the month of April, it too would in the same fashion be adjusted as new data becomes available in the month of April. Further we feel that the flood control space requirement related to the April-July parameter already accounts for the Snake River's runoff timing characteristics.

MID-COLUMBIA PUBLIC UTILITY DISTRICTS
CHELAN, DOUGLAS, GRANT COUNTIES, WASHINGTON
REGIONAL COORDINATION OFFICE

520 S.W. SIXTH AVENUE, SUITE 1100
PORTLAND, OREGON 97204 (503) 222-3317

November 17, 1987

Colonel James R. Fry
Corps of Engineers
North Pacific Division
220 N.W. Eighth Avenue
P.O. Box 2870
Portland, Oregon 97208-2870

Dear Colonel Fry:

The included comments are in response to the Draft Copy of the "Review of Flood Control - Columbia River Basin, Columbia River and Tributaries Study, CRT-63." The draft copy is dated November of 1987.

After review by the Mid-Columbia PUDs, there was a general feeling that this document shows movement in the right direction and is an effort that was needed for quite some time. It was also felt that clarification would help us to obtain a better and more thorough understanding of some of the areas that were discussed in the document. For example, we were unclear as to the effect this would have on system operations.

Accordingly, in order to obtain clarification, we propose having a meeting with you and your staff to discuss this in more detail. Perhaps, at your convenience, you could contact me directly and we could discuss this.

Sincerely,

Dennis Rohr/dp

Dennis E. Rohr
Regional Coordinator

DR101
cc: CPUD
DPUD
GPUD
CLAN
NPPC Members
Al Wright, PNUCC

Montana Department
of
Fish, Wildlife & Parks

1420 East Sixth Avenue
Helena, MT 59620
January 4, 1988

Douglas Speers
Department of the Army
North Pacific Division, Corps of Engineers
P.O. Box 2870
Portland, OR 97208-2870

Dear Mr. Speers:

Thank you for the opportunity to comment on the draft final report "Review of Flood Control - Columbia River Basin." The following represents our comments for your consideration.

In this report, it is proposed to relax the flood control drafting requirements during low water years on Hungry Horse and Libby reservoirs. While we welcome these changes, it seems doubtful that they will be of any benefit to the reservoir fisheries. Quoting from the above document: "actual drawdown in any year will likely exceed the flood control requirement in the lowest runoff years, due to having to release water to meet system power loads. Therefore, it is quite possible that the proposed revisions would not actually affect operations in any given year." In fact, drafting for power production and overestimates of spring runoff have resulted in emergency reductions in Kootenai River discharges between April 1 and August 31 to assure reservoir refill. These reduced spring flows are below the minimum recommended outflow (4,000 cfs) and have deleterious effects on river fish, food organisms, and habitat.

The ACOE study proposes greater flood storage capacity at Libby during years with forecasted runoff between 6.0 and 7.5 maf, April to August. Earlier preliminary reports indicated that forecast error was greater during runoff years of similar or greater magnitude. If substantial forecast error continues to occur, this could prevent provision of higher reservoir levels during normal water years. Also, more stringent drafting requirements will increase the potential to exceed recommended maximum drawdown limits during normal water years.

The ACCE analysis used a hypothetical system flood which exceeds a 100-year occurrence probability (approximately 333 years plus). It also incorporates the more conservative of the two flood control curves for each basin, regional vs. Columbia system-wide. Admittedly these provide an extra margin of safety but, if considered cumulatively for the storage basins in the system, it seems overly conservative. We question the appropriateness of using the system-wide flood control rule curve for the headwater reservoirs. Using the hydrologic component of the quantitative fisheries model we are currently developing, we calculated maximum drawdown at Libby Reservoir could be less than 90 feet and still safely control 7.5 maf runoff (April-August) for the region (maintaining safe stage levels at Bonners Ferry and Kootenai Lake). Flood storage requirements at Hungry Horse are also more moderate if calculated on a regional basis. It would be helpful if the report provided all developed flood control rule curves for each reservoir in the system.

As indicated above, MDFWP is currently developing (through BPA funding) a fisheries component model of Libby and Hungry Horse reservoirs. Recommendations for dam operations which incorporate fishery rule curves will be forthcoming in July 1988. It would be beneficial to reevaluate flood control criteria when this information is available.

Again, thank you for the opportunity to review this report. If you have any questions or require further information, please contact me at (406) 444-3183.

Sincerely,

Larry G. Peterman

Larry G. Peterman
Bureau Chief
Research and Special Projects

LGP/IC/BLM/fs

COMMENTS ON LETTER FROM MONTANA DEPARTMENT OF FISH, WILDLIFE AND PARKS, 4 JANUARY, 1988

Paragraph 1 - Comment to the effect that the proposed rule curve changes will not benefit the resident fisheries.

We concur that the proposed changes will have little or no benefit to the reservoir fisheries, particularly at Libby and Hungry Horse reservoirs where the changes are relatively small. The revised rule curves will also have virtually no effect on the need to reduce Libby outflows below 4,000 cfs to enhance refill.

Paragraph 2 - Increase in flood control storage for forecast parameters between 6.0 and 7.5 maf.

This proposal was eliminated in the final version of the report because the gain in flood control was very minor.

Paragraph 3 - Concern about system versus local flood control considerations in developing revised rule curves.

It is true that in the existing - and proposed - rule curves the requirements for system flood control are generally more stringent than local flood control requirements for a given flood event. However, given that Libby storage is an important part of the Columbia basin flood control system and that flood control benefits for Libby were predicated on operating for system protection, the system flood control criteria cannot be eliminated nor substantially reduced. The same holds true for the Hungry Horse project.

The analysis did not actually "accumulate" conservative criteria at each project to find the criteria appropriate for control at The Dalles. Instead, independent design floods were developed reflecting appropriate contributions from tributary points to produce a given magnitude flood at The Dalles.

Regarding the storage requirement for flood control at Bonners Ferry, there have been several floods exceeding a 7.5 maf runoff, the largest being greater than 9 maf. If storage space were reduced to a 90-foot draft, there would be a decrease in the current level of protection at Bonners Ferry from the 0.5 percent

(200 year) capability shown on Figure 4.2 in the report. The system flood control capability would, of course, also be reduced.

Reference is made to Appendix B of the Preliminary Report for flood control rule curves for all flood control projects in the basin.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE
Forecast Office
5420 N. E. Marine Drive
Portland, OR 97218-1089

November 6, 1987

Mr. James R. Fry
Colonel, Corps of Engineers
Deputy Division Engineer
Water Management Branch
P. O. Box 2870
Portland, Oregon 97208

Dear Colonel Fry:

We certainly do appreciate receiving a copy of, "Review of Flood Control Columbia River Basin." The information contained within it will be informative in carrying out our hydrologic mission.

There is nothing that we can add to the report at this time.

Thanks again for sending us a copy.

Sincerely,

George R. Miller
Area Manager/Meteorologist in Charge

cc:
Clint Stiger

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service Western Region
P. O. Box 11188 Federal Building
Salt Lake City, Utah 84147

November 3, 1987

Colonel James R. Fry
Deputy Division Engineer
U.S. Army Corps of Engineers
North Pacific Division
P.O. Box 2870
Portland, Oregon 97208-2870

Dear Colonel Fry:

Personnel in my Hydrologic Services Division at the Regional Headquarters and the Northwest River Forecast Center in Portland have reviewed the draft copy of the "Review of Flood Control - Columbia River Basin". We have no problems with the material presented in the report.

I understand that your office has maintained periodic contact with the Northwest River Forecast Center during the development of the report. I encourage this to continue and if there are any changes that may affect river forecast operations, please do not hesitate to inform my office.

Thanks for keeping us informed of changes that may potentially affect our operations.

Sincerely,

Thomas H. Grayson

Thomas H. Grayson
Regional Director

cc: HIC, NWRFC - Charles E. Orwig

NORTHWEST POWER PLANNING COUNCIL

851 S.W. SIXTH AVENUE • SUITE 1100
PORTLAND, OREGON 97204-1337 • (503) 222-5161

Toll free number for Idaho, Montana & Washington: 1-800-222-3355
Toll free number for Oregon: 1-800-452-2324

April 29, 1988

Colonel James R. Fry
Corps of Engineers
P.O. Box 2870
Portland, OR 97208-2870

RE: Review of Flood Control Rule Curves in Columbia River Basin

Dear Colonel Fry:

We have reviewed the Corps of Engineers' draft report Review of Flood Control - Columbia River Basin, and have the following comments.

First, this study was conducted, in part, in response to the Fish and Wildlife Program's measure 703(a)(14)(A) and action item 2.6, which calls on the Corps to study the feasibility of improving flows for fish in the Columbia River Basin. Therefore, it would be helpful if the final report would show the effects in storage for each year of the proposed flood control rule curve changes, i.e., in which years of the 50-year record do the flood control changes result in additional storage available for water budget flows. More importantly, it would help if the report would indicate the extent to which incremental changes in storage would affect water budget flows.

The draft report leads us to believe that there will be some benefit to fish flows as a result of gaining additional storage at Dworshak and Grand Coulee dams, and a minimal benefit to flows of gaining additional storage at Libby, Hungry Horse and Brownlee dams. It would help if the final report could be more specific about the magnitude, the frequency and occurrence of potential benefits to fish flows due to the proposed modifications to the flood control rule curves, particularly when power drawdowns may negate gains in storage due to implementation of the new rule curves.

Second, it is noted in the report that the proposed new rule curves will be used as interim guidance for Columbia Basin flood control operations but that the curves are subject to further study, possible revision and approval before being accepted as official operating criteria. Is there a time frame for official adoption of these rule curves? We would appreciate it if you would notify the Council when new rule curves are adopted and send us revised rule curves as they are developed.

I have attached a list of additional specific comments and questions and hope they will be useful in preparation of the final report

Thank you for the opportunity to comment

Sincerely,

Ed

Edward Sheets
Executive Director

Attachment

Specific comments/concerns

1. The active storage volumes, listed in the "total" and "committed for flood control" columns in Table 2-1 on page 5, appear to contain errors in addition. The columns sum to 40,430,000 acre-feet and 39,874,000 acre-feet, respectively.

2. It is unclear which design flood was selected for each project in the study. How did the Corps make the determination at each project whether to use: a) a probable maximum flood, b) a standard project flood, or c) a frequency-based flood, i.e., 100-year flood? What criteria were used to select one design flood over another in the study?

3. The draft report states that rule curves have been developed incorporating a factor of safety to cover the possibility of adverse forecast error. How much of a factor of safety is built into each of the project's flood control rule curves? Given that an unpredictable extreme rain event occurs infrequently, has consideration been given to the probability of occurrence and risk of exceedance of such an event?

4. How does the Dworshak standard project flood compare to the frequency-based 100-year flood, i.e., what is its exceedance probability?

5. On page 34, it would help to explain further why Upper Snake River projects and major Canadian storage projects were not included in this study.

6. From the discussion on page 34, it is clear that this study represents a refinement of the existing rule curves and that the current flood control capability of the system is not degraded by these changes. Clarification is needed about there being no consideration or review to evaluate the lower Columbia River levee system for improvements to accommodate increased flood stages.

7. On page 49 in the Hungry Horse analysis, it appears that the third paragraph should state that "more storage space...is called for in years that have forecasts of less than <u>2</u> million acre-feet."

8. On page 57, in discussing the many uses of the Grand Coulee project, its value as an important storage project for the mid-Columbia River water budget should be mentioned.

9. In Table 4-1 on page 64, how were the allowable percent chance of exceedance criteria determined?

10. Figure 4-19 on page 63 would benefit from clarification. It is difficult to interpret.

11 How will the tabular-envelope flood control approach proposed for Brownlee Dam be formally adopted? Will this proposed approach require revision of Idaho Power Company's FERC license?

12. Figures 4-28 through 4-31 would benefit from reformatting or the use of color graphics so that they can be more easily read and understood.

13. On page 84, when the upper rule curves are lower than the variable energy content curves, it would help to explain in more detail the "conflict" the current study is attempting to minimize.

14. In Fig. 4-33, are the Dworshak project rule curves labeled correctly? Can this figure be simplified?

COMMENTS ON LETTER FROM NORTHWEST POWER PLANNING COUNCIL, APRIL 29, 1988

Paragraph 1 - Report should show specific effects of the rule curve changes, on a year-by-year basis. Also, the extent to which the incremental changes affect the Water Budget flows should be shown.

The final version of the report has been improved to show specific, year-by-year changes in the storage at the four major reservoirs. Also shown, in association with the Grand Coulee and Dworshak projects, are the resulting changes in flow at Priest Rapids and Lower Granite as simulated by the HYSSR model, using regulation criteria currently in effect.

Paragraph 2 - Report should contain more information on the frequency and occurrence of potential benefits to fish flows.

The improved statistical summaries in the final version will clarify the frequency and occurrence of incremental amounts of increase stored water due to changes in the flood control curves. Refer to Figures 4-29 through 4-31 and discussion beginning on page 81 of the report.

Paragraph 3 - Is there a time frame for official adoption of the proposed new rule curves?

A time frame for future work in finalizing the proposed flood control curves has been added to the final version of the report.

Attachment, "Specific Comments/Concerns".

Responses that follow are by the same paragraph number as in the attachment to the letter.

1. Table 2-1 has been corrected in the final version.

2. Specific criteria exists within the Corps for application of the various design floods referred to. The Probable Maximum Flood is used for design of spillways in large dams, as a standard to insure the safety of the structure even during occurrences of very extreme floods. The Standard Project Flood (SPF) and

frequency-based floods are used in flood protection design; ie, levee capacity or storage quantity allocated to flood control in a reservoir. The frequency-based flood that is selected for project design is generally arrived at through economic analysis. If there is concern for extensive loss of life associated with the exceedance of the design, then a higher flood - the SPF - may be used in lieu of a frequency-based flood. The SPF is generally on the order of a 500 to 1000 year flood.

3. The original curves for most projects reflected a factor of safety that was subjectively arrived at, based upon studies of the 1948 flood. The point of the new study was to quantify this factor more objectively. As discussed in the report a 100-year rainstorm (Standard Project rainstorm for Dworshak) was the basis for the new factor of safety. (See page 34)

4. The Standard Project Flood at Dworshak is greater than a 1000-year flood.

5. The upper Snake and Canadian storage projects were not included in the study because it was clear that with changes in flood control curves very little return - in terms of clear-cut potential increased downstream river flows for the water budget - would be achieved. In the case of the upper Snake projects above Brownlee, irrigation diversions and operational considerations predominate in the basin, such that any relaxation of flood control criteria would have very little probability of leading to a corresponding benefit downstream from Brownlee in low to medium runoff years. Not only are reservoirs operated below flood control in dryer years as in the rest of the system, but withdrawals by irrigators with junior water rights in the upper Snake Basin would cancel out any potential increased flows from the project. It would take a significant political agreement to assure that incremental amounts of storage gained by revision of flood control rule curves would be designated for the lower Snake and Columbia and not for in-state irrigation. Given the difficulty of such an agreement, the infrequency of the occurrence of a benefit, and the small amount of water involved, it was considered appropriate to omit this part of the basin from the study.

There were several reasons not to include the Canadian Treaty projects in the flood control analysis. First, flood control at the Canadian projects is a factor that determines the flood control requirement at Grand Coulee. Thus, any reduction in flood control space in Canada would be offset by an increase at Grand Coulee thereby reducing generating head. The Treaty allows 8.45 million acre-feet (maf) of primary space allocated amongst Canadian Reservoirs in the following manner:

Project	Flood Control Space, maf
Mica	2.08
Arrow	5.10
Duncan	1.27

Historic operation at Mica project suggests there would be no benefit to reducing flood control storage space, because its power operating curves require the draft of storage significantly greater than draft required by the flood control curves. At Duncan and Arrow system studies indicate that current flood control criteria rarely, if ever, control the operations in low to medium runoff years. Finally, the provisions of the Columbia River Treaty and the ownership of projects by the Canadian Entity make it highly conjectural that any increases in storage resulting from changes in flood control rule curves could be assumed transferable downstream for water budget in the United States.

6. The scope of the study did not include an examination of trade-offs between storage and levees. The study scope would have to be greatly expanded if trade-offs were considered (to include economic and environmental analyses, for instance), and our preliminary evaluation had lead to the conclusion that increased levee heights in lieu of reduced flood control storage would not be viable because the costs incurred would exceed the benefits obtained. This does not preclude further examination of this question in the future, and a forthcoming report on the lower Columbia levees will help address the feasibility of such an effort.

Congress, in authorizing the federal projects, allocated specific amounts of storage space to meet flood control objectives at local damage areas and in the lower Columbia. Conceivably, if flood control criteria were changed to the extent that the original flood control benefits were reduced, then a reauthorization process would have to be initiated.

7. The text has been corrected to reflect this comment.

8. The text has been revised to reflect this comment.

9. These criteria were based upon the existing regulated frequency curve at The Dalles, the basic idea being to retain approximately the same degree of control that currently exists in the lower Columbia. Some rounding to a slightly more conservative value was done as shown in the Interim Report.

10. Comment noted. Reliance needs to be placed on the supporting text to interpret this plot.

11. After a period of further testing and interim application, we will consider a request to change the FERC License so that the 1 March drawdown criteria becomes a more flexible requirement as shown on the proposed tables.

12. Comment noted. These plots have been improved in the final version of the report.

13. Comment noted. This section of the text has been removed.

14. Comment noted. Revisions in the plot (now figure 4-32) and text have been made.