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11.0 FLOOD MANAGEMENT

11.1 FLOOD MANAGEMENT STUDY (FLD 1)

11.1.1 Study Objectives

The objective of the study is to document current flood control requirements, analyze flood management under current operations, and identify opportunities for future improvements in flood management.

11.1.2 Study Area

The Flood Management Study covers the Lewis River valley from Merwin Dam to the mouth of the Lewis River, at its confluence with the Columbia River.

11.1.3 Methods

The Flood Management Study will consist of 3 basic tasks:

- Documentation of the basis for the current license requirements with respect to flood management;
- Analysis of flood management under the current license requirements; and
- Identification and analysis of opportunities for future improvements in flood management.

Work for the Flood Management Study will rely to the extent possible on NHC's previous work for PacifiCorp investigating project operations and flooding downstream from Merwin Dam during the major flood of February 1996. Particular products from NHC's previous work which are available for this study include: aerial photographs and topographic mapping of the Lewis River valley from just below Merwin Dam to the mouth (dated October 1996), an unsteady flow hydraulic (UNET) model of the Lewis River from Merwin to the mouth, inundation maps for the February 1996 flood, and a STELLA simulation model of the (lumped) Lewis River Projects suitable for analysis of current and possible future alternative flood control operating policies.

11.1.3.1 Basis for Current License Requirements

Documentation will be assembled describing the current license requirements as they relate to flood management, and the flood management considerations and other factors that were used to determine those requirements. The documentation will include details of the flood hydrographs used to determine flood storage requirements, the flood frequency relationships and water surface profiles that may have been considered in establishing the current operating practices, and the methodologies followed for flood frequency analysis and hydraulic routing. Existing contractual obligations will be summarized as they relate to flood management, including PacifiCorp's agreement with the Federal Emergency Management Agency (FEMA). Current notification practices and procedures to provide warning in the event of a flood will also be documented. NHC is very familiar with current operating practices through its previous work on the February 1996 flood. Much of the information required for this sub-task is available in NHC's archives from this previous work. Much of the information is understood to be also available in the Emergency Action Plans prepared for each project.

11.1.3.2 Flood Management under Current License Requirements

Considerable changes have taken place in both hydrologic and hydraulic data availability and the physical condition of the Lewis River watershed since the project's operating procedures were originally developed. These changes include the eruption of Mount St. Helens, which contributed to sedimentation and loss of storage in the project reservoirs (particularly in Swift), as well as continuing residential development in the Lewis River valley and floodplain below Merwin Dam. Experience during the February 1996 flood also demonstrates that the existing FEMA flood hazard maps for the Lewis River are incorrect in several locations. Accordingly, the analysis of the project's flood management or flood control capabilities will be updated to reflect currently available information assuming operations according to the current license requirements. The following work will be performed:

- Stage-storage relationships for the 3 reservoirs (Merwin, Yale, and Swift) will be reviewed and updated as necessary. PacifiCorp is currently conducting a new bathymetric survey for Swift Reservoir (the reservoir most affected by the eruption of Mount St. Helens). Survey information will be obtained in digital form from PacifiCorp and used to update the existing stage-storage curve. Detailed surveys are not proposed at this time for Yale and Merwin; however, an assessment will be conducted to evaluate the likely degree of sediment accumulation in those reservoirs. The change in storage volume in all 3 reservoirs due to the eruption of Mount St. Helens will be estimated by comparison against pre-eruption stage-storage data.

- The project's flood control operating policies were originally developed to provide for control of a flood similar to that of December 1933. Existing flood frequency curves for the Lewis River (used to create the current flood insurance maps) were based on simulations of project performance for floods through 1978. There are now an additional 20 years of data on the Lewis, including data for the major flood of February 1996. The project's flood control performance will be determined by simulation for major floods through 1996 using updated stage-storage data and current operating practices. Updated flood frequency curves will be developed for both natural (i.e., unregulated) and regulated flows.

- Updated 100-year water surface profiles and floodplain maps will be developed for the Lewis River from Merwin Dam to the mouth. Several different study contractors developed the existing floodplain maps over the course of several years for three different jurisdictions (Cowlitz County, Clark County, and the City of Woodland). In NHC's investigation of the February 1996 flood for PacifiCorp, it was apparent that the existing flood insurance maps, while generally correct in many places, were significantly in error in other locations. For example, FEMA 100-year flood elevations downstream from Woodland are low because the original analyses failed to properly account for backwater from the Columbia River. Floodplain maps will be updated using the unsteady flow (UNET) model developed by NHC in its work on the February 1996 flood. The model will be calibrated to February 1996 high water marks surveyed by NHC. Floodplain maps will be provided in hard copy and digital form at a scale of 1 inch = 400 feet and a 5-foot contour interval using the mapping prepared in October 1996 for NHC's investigation of the February 1996 flood. The result will be a set of maps in digital form, which will give a much more reliable picture of flood hazard than currently available for the Lewis River valley.

- Approximate flow/hazard information will be established for the Lewis River valley below Merwin Dam. Information on water levels at properties affected by the February 1996 flood and more recent floods will be collected by members of the Flood Management Group. Information on the number and location of properties damaged in the February 1996 flood will also be provided by members of the Flood Management Group. Information obtained will be compiled to the extent available to produce threshold data on flows at which key access routes are flooded and to produce approximate relationships between flow and the number of residences damaged.

11.1.3.3 Identification and Analyses of Opportunities for Future Improvements in Flood Management.

Opportunities and constraints for improving flood control and reducing downstream flood hazard will be examined. Particular emphasis will be placed on identifying and evaluating reliable flood hazard reduction strategies that have minimal impact on hydropower production. Consideration should be given to both operational changes at the project and non-structural (and possibly structural) changes within the Lewis River valley. In other words "flood management" should not be focused solely on the Lewis River Projects but should consider regulatory and/or institutional opportunities to reduce flood hazard under the existing flow regime. Approaches to be examined will be developed in consultation with PacifiCorp and Cowlitz PUD but are expected to include the following:

- <u>Modification of current operating rules to improve flood control performance with the current flood control storage amounts in the absence of flow forecasts</u>. There are a large number of alternative ways in which the current flood control storage could be managed. Simulations will be performed to investigate the flood control benefits of increased releases (pre-releases) on the rising limb of flood hydrographs to preserve flood control storage and provide greater control for large flood events. Simulations will also be performed to investigate the merits of alternative management of flood control storage conditioned on both inflow amounts and storage (existing high runoff procedures are conditioned largely on the current storage).

- <u>Modification of current operating rules and flood control storage amounts to improve flood control performance during a recurrence of the February 1996 flood</u>. Simulations will be performed to investigate the effects of varying flood control storage amounts and operating policies on the flood control performance during a recurrence of the February 1996 flood. A ranking of power generation against flow scenario will be determined for all simulations performed.

- Temporary increases or decreases in the amount of flood control storage provided conditioned on the watershed state. Development of low elevation snow pack invariably increases the potential for flooding and could be used to trigger a temporary increase in flood control storage. The potential for using this information will be examined but detailed analyses will not be performed at this time.

- Temporary increases or decreases in the amount of flood control storage provided conditioned on weather forecasts and quantitative precipitation forecasts (QPFs). While this approach is theoretically attractive, the accuracy of QPFs is currently very poor, and operational use of QPFs requires considerable judgment and caution. Nevertheless, hedging policies could, for example, be developed to temporarily increase flood storage when major storms are forecast. Again, the potential for using this information will be examined, but detailed analyses will not be performed at this time.

- Strengthening regulatory control of land use. Continuing development in the Lewis River floodplain is clearly putting more and more people at risk from flooding and will inevitably result in increased pressure to devote more storage to flood control with a possible concomitant loss in hydropower production. Consideration should be given to promoting improved flood hazard reduction regulations, for example by adoption of a zero-rise floodway. Consideration could also be given to promoting a multi-jurisdictional program for buy-out of high hazard properties and possibly flood-proofing of other selected properties.

- Public outreach. Flood hazard in the Lewis River valley is not well understood by many local businesses and residents; consideration should be given to promoting periodic educational outreach.

- Modification of current notification procedures. Opportunities for improving existing communication and warning systems and procedures in the event of a flood will be identified.

11.1.4 Key Questions

Results of the Flood Management Study can be used to address the following “key” watershed questions identified during the Lewis River Cooperative Watershed Studies meetings:

- What are the current flood storage capabilities and requirements of the project reservoirs?

  The flood storage capabilities and requirements are described in Sections 11.1.5.1 and 11.1.5.2.

- What are the current effects of the projects on flood peaks of various recurrence intervals?

The current flood control performance effects of the projects are described in Section 11.1.5.2.

- What assumptions were used to develop current flood storage requirements?

  The basis for current flood storage requirements is described in Section 11.1.5.1.

- What is the present policy with regard to the level of protection afforded floodplain areas downstream of the hydroelectric projects (i.e., what recurrence interval event frequency is accounted for) and what was the basis for formulating this policy?

  This question is interpreted to mean: what is the present level of protection afforded areas downstream of Merwin Dam as indicated by the area inundated during the 100-year flood? The basis for determining the current regulatory floodplain is described in Section 11.1.5.1. Current floodplain regulations are also described in Section 11.1.5.3.

- What are the legal mandates for the projects for flood control?

  Contractual obligations with respect to flood control are summarized in Section 11.1.5.1.

- What communication systems, warning systems, and evacuation requirements are currently in place?

  The communication and warning systems for the Lewis River valley are currently in flux. Communication systems, warning systems, and evacuation procedures currently in place are described in Section 11.1.5.2.

- What opportunities exist for increasing the efficiency of a warning system in order to give residents sufficient notice for evacuating in the case of flood emergencies?

  Improved flood warning systems are discussed in Section 11.1.5.3.

- What are the potential effects of forest management practices in the basin on flooding?

  It is known that timber harvesting can increase both the runoff volume and peak flow during flood events. Detailed assessments of the effects of various forest management practices on flooding on the Lewis River have not been made in this study. However, under current harvesting practices, the USFS (which controls more than 75 percent of the drainage area upstream from Merwin Dam), and PacifiCorp rarely clearcut areas larger than 20 to 30 acres at a time. The large timber companies operating in the watershed (Weyerhaeuser and Pope Resources [formerly Plum Creek]) historically have clear-cut large areas, but such practices have become less common in recent years. The general indication is that current harvesting practices will result in smaller increases in flood peaks and volumes than under past practices, and that overall peak flows and volumes may show some modest reductions as forest lands mature under current harvesting regimes.

- What are the potential effects of landsliding on the sedimentation and flood storage capacities of reservoirs?

  The Reservoir Fluctuation Study (TER 6) will consider the effects of reservoir shoreline erosion on sediment inputs to the reservoir but will not consider landslides elsewhere in the watershed. An analysis of landslide inputs at the watershed scale is not being proposed. An assessment of the impacts of sedimentation from the time of project construction to present is described in Section 11.1.5.2. It was found that sedimentation has had essentially no impact on flood storage capabilities since project construction, even though the assessment period included large sediment loadings from the eruption of Mount St. Helens. Given this information on historic sedimentation, it is unlikely that future landslides within the watershed will have any noticeable impact on flood storage capacities. Additional information on sediment inputs due to reservoir shoreline erosion will be produced by the Reservoir Fluctuation Study (TER 6), currently in progress.

- What are the potential effects of urbanization and suburban development on flooding?

  The effects of urban and suburban development on flooding along the main stem of the Lewis River are expected to be negligible for several reasons. First, the great majority of storm runoff originates in the headwaters of the system upstream from Merwin Dam, in areas that are not expected to be developed. Second, runoff from areas downstream from Merwin Dam which are available for development can be expected to produce their peak discharges before releases from Merwin Dam have peaked. This difference in timing means that runoff from urban and suburban areas should not appreciably increase overall peak flows on the main stem Lewis River. Finally, storm water management regulations for new developments are intended to restrict post-development peak runoff rates to their pre-development amounts.

- What are the potential effects of diking in the Woodland area on downstream reaches during the flood events?

  The Portland District, U.S. Army Corps of Engineers will address this issue in an upcoming Section 205 flood reduction study. The Applicants will provide information to the Corps in support of their flood reduction study.

  In qualitative terms, diking in the Woodland area can be expected to increase peak flows and water levels in downstream reaches during flood events. Detailed quantitative information on the effects of diking had been expected from the proposed Section 205 flood reduction study. However, because of funding problems, that study has not been conducted.

- What is the effect of flood management on stream and floodplain ecosystems?

  The Stream Channel Morphology and Aquatic Habitat Study (WTS 3) will examine the Lewis River from Swift Dam downstream to the downstream end of Eagle Island, and the Riparian Habitat Information Synthesis Study (TER 9) will examine the Lewis River from Merwin Dam downstream to the downstream end of Eagle Island.

The effect of flood management at the Lewis River Projects on stream channel morphology and aquatic habitat from Merwin Dam to Eagle Island is discussed in Section 2.3 (WTS 3). The effect of the projects on riparian habitat from Merwin Dam to Eagle Island is described in Section 5.9 (TER 9).

- What are the effects of flood management and flood storage capacity on recreation and fishing?

  The effects of flood management on access to the reservoirs for recreation and fishing will be addressed by the Recreation Needs Analysis (REC 6) and the Recreation Resource Management Plan (REC 7) with input from the Flood Management Study. The need to extend boat ramps to provide reservoir access under current and future project operations is discussed in Section 7.6 (REC 6). The Recreation Resource Management Plan (REC 7) will respond to the results of Settlement Agreement discussions where decisions on flood management will be made.

- What additional flood protection would potentially be gained by increasing the current flood storage requirements in reservoirs?

  The effects of increased flood control storage are discussed in Section 11.1.5.3.

- What are the potential effects of alternative reservoir management strategies and operating regimes on flood storage capability and management?

  The effects of alternative flood control operating policies are discussed in Section 11.1.5.3.

- What would be the potential benefits and impacts of changes to zoning on floodplains and/or relocating dikes to reduce the risk or incidence of damage during flood events?

  Possible means of reducing flood hazard through changes in floodplain management regulations are discussed in Section 11.1.5.3. Relocation of existing dikes is considered impractical and has not been investigated in this study.

- What opportunities exist for improving communication and warning systems between the utilities, city, county, and state agencies, and communities in the event of a flood?

  Improved flood warning systems are discussed in Section 11.1.5.3.

11.1.5 Results

11.1.5.1 Basis for Current Flood Management License Requirements

Flood Storage and Flood Control Operations[1]

From a flood management perspective, the central feature of the Lewis River Projects is the series of 3 dams and their associated reservoirs. From upstream to downstream these

[1] This section is based in part on the testimony of Stanley A. de Sousa, PacifiCorp, before the Federal Energy Regulatory Commission, April 29, 1982.

are Swift Dam, completed in 1958, Yale, completed in 1953, and Merwin, completed in 1931, with usable capacities of approximately 447,000 acre-feet, 190,000 acre-feet, and 263,700 acre-feet, respectively.

All 3 dams were designed and constructed as hydroelectric projects and do not include low level outlets or other special provisions normally associated with flood control projects. However, optimizing hydropower generation generally implies following operating procedures that seek to reach a balance between minimizing spill and operating with water levels (head) as high as possible. This balance is achieved by operating the reservoirs with some freeboard (i.e., at lower than maximum normal water levels), allowing most flows to be captured and stored for power generation while spilling water only during the larger flood events. Furthermore, meeting power demands of the PacifiCorp generation system as a whole has often meant that reservoir water levels are significantly below maximum normal levels during the winter flood months. For both these reasons, the Lewis River Projects have provided significant incidental[2] flood control since they were completed.

Dependable[3] flood control operations at the Lewis River Projects were initiated after the flood of November 20, 1962. This event resulted in serious flood damage in the Lewis River valley below Merwin Dam. The maximum release from Merwin during the event was about 75,500 cfs. On review of data and project performance from the 1962 flood, PacifiCorp started providing approximately 35,000 acre-feet of dedicated flood storage space during the winter months. This storage was distributed between the 3 reservoirs.

As more experience was gained, operating procedures were modified and improved, and the amount of dependable winter flood storage was increased. During the late 1960s and early 1970s, PacifiCorp was retaining about 50,000 acre-feet of storage for flood control which, at the time, seemed to provide a reasonable level of control. However, as a result of the 5-day 1975 storm (November 30 – December 4, 1975) with 2 major peaks, it was concluded that additional space would be useful. Thus, the dedicated flood control space was increased to 70,000 acre-feet.

PacifiCorp's experience with floods through the mid-1970s indicated that severe damage only started to occur in the Lewis River valley when the Merwin discharge exceeded about 60,000 cfs. Experience indicated that for releases above 60,000 cfs, flooding would start in the more heavily developed parts of the City of Woodland. Standard flood control operating policies developed in the mid-1970s thus dedicated a significant proportion of the dependable flood storage space (46,000 out of 70,000 acre-feet) to controlling releases from Merwin to 60,000 cfs or less. At that time, reservoir routing analyses were conducted on data from the floods of December 1933, December 1975, and December 1977. The analyses concluded that the dependable flood storage of 70,000 acre-feet was sufficient to control all floods on record (except that of 1933) to a release of 60,000 cfs from Merwin. It was also concluded that a recurrence of the 1933 flood could be controlled to a maximum release of 85,000 cfs from Merwin. Note that during major

[2] "Incidental" flood control is defined as flood control which is solely a byproduct or outcome of normal hydroelectric operations.
[3] "Dependable" flood control is that achieved through dedicated flood control storage.

floods, local inflows to the Lewis River between Merwin Dam and the City of Woodland may increase peak flows by between 5,000 and 8,000 cfs. Thus a release of 60,000 cfs from Merwin Dam during a major flood equates to a peak flow at the County Bridge in Woodland in the range of 65,000 to 68,000 cfs. Similarly, a release of 85,000 cfs from Merwin could be expected to result in peak flows at the County Bridge in the range of 90,000 to 93,000 cfs.

Further modifications of the project flood control operating policies were made following the May 1980 eruption of Mount St. Helens to provide for additional mudflow control storage in Swift Reservoir. This requirement was later rescinded by FERC when the mud flow hazard from Mount St. Helens was judged to have dropped to acceptable levels. The current flood control operating procedures for the Lewis River Projects are the same as those developed in the mid-1970s in all essential details, and provide for the following seasonal variation in flood storage amounts (Table 11.1-1).

Table 11.1-1. Current flood storage volume in Lewis River reservoirs.

Date	Minimum Flood Storage Space (acre-feet)
September 20	0
October 10	35,000
November 1 through April 1	70,000
April 15	35,000
April 30	0

The current flood control operating procedures are fully documented in PacifiCorp's Standard Operating Procedure (1994), hereinafter referred to as the "High Runoff Procedures."

Flood control storage available at the Lewis River Projects is commonly described in terms of "hole," this being the available storage in feet of depth between the current reservoir level and normal maximum full pool elevations of 1,000 feet NGVD at Swift, 490 feet NGVD at Yale, and 239.6 feet NGVD at Merwin. Total project hole is the sum of the holes at Swift, Yale, and Merwin. The surface areas at full pool of Swift, Yale and Merwin are 4,540 acres, 3,795 acres, and 4,000 acres, respectively. Thus, an average 1 foot of hole is equivalent to approximately 4,100 acre feet of storage. "Hole" is used as a readily understood measure of available storage; however, throughout this report, computations are based on actual volumetric storage in acre-feet in the 3 reservoirs.

Under the current operating procedures, project releases are made during a flood as a function of both the magnitude of the natural inflow and the amount of remaining flood control storage. The key aspects of flood control storage allocations for rising inflows, as paraphrased from the High Runoff Procedures, are as follows

- *Storage 70,000 acre-feet (17 feet of hole) or greater* – Water in excess of power operation requirements may be stored until the available storage is reduced to

100,000 acre-feet (24 feet of hole). The outflow is then increased so that when the available storage is reduced to 70,000 acre-feet (17 feet of hole) the Merwin outflow equals the smaller of the natural inflow or 40,000 cfs.

- *Storage 70,000 acre-feet (17 feet of hole) or less* – Merwin outflow is regulated to 40,000 cfs until the peak of the runoff has passed or until available storage is reduced to 60,000 acre-feet (14.5 feet of hole).
- *Storage 60,000 acre-feet (14.5 feet of hole) or less* – Merwin outflow is regulated to 50,000 cfs until the peak of the runoff has passed or until available storage is reduced to 50,000 acre-feet (12 feet of hole).
- *Storage 50,000 acre-feet (12 feet of hole) or less* – Merwin outflow is regulated to 60,000 cfs until the peak of the runoff has passed or until available storage is reduced to 24,000 acre-feet (6 feet of hole).
- *Storage 24,000 acre-feet (6 feet of hole) or less* – Merwin outflow is regulated to 75,000 cfs until the peak of the runoff has passed or until available storage is reduced to 20,000 acre-feet (5 feet of hole).
- *Storage 20,000 acre-feet (5 feet of hole) or less* – Merwin outflow is regulated to 85,000 cfs until the peak of the runoff has passed or until available storage is reduced to 8,000 acre-feet (2 feet of hole).
- *Storage 8,000 acre-feet (2 feet of hole) or less* – Merwin outflow is regulated to 90,000 cfs until the peak of the runoff has passed or until 3.5 feet of surcharge (-3.5 feet of hole) is utilized.
- *Storage equivalent to 3.5 feet of surcharge-* Merwin discharge is regulated to equal the natural inflow until the peak runoff has passed.

After the runoff peak has passed, a similar set of requirements applies to operations on the receding or falling limb of the runoff hydrograph with the intent of restoring the mandatory minimum flood control storage as rapidly as is reasonable in anticipation of a following flood. Full details are provided in the High Runoff Procedures.

While flood control operating policies developed by PacifiCorp through the mid-1970s provided significant flood relief to the Lewis River valley, these operating policies were not then a condition of the project licenses, and no formal agreements had been made by PacifiCorp to dedicate storage to flood control.

In 1975, a flood insurance study of the area in and around the City of Woodland was conducted by the Corps for the Department of Housing and Urban Development (HUD). HUD's policy in such studies was to disregard reservoir capacity that was not formally dedicated to flood control. Consequently, that study did not consider the flood reduction benefits of PacifiCorp's operation of the Lewis River Projects. The HUD study identified significant areas in Woodland and its vicinity that would be flooded during the 100-year event considered for flood insurance purposes. Such areas were thus subject to high flood insurance rates and development restrictions. This included areas planned by the City of Woodland to be principal areas of future residential expansion.

Public and local governmental interest in flood management led to continued discussions of flood control operations at the Lewis River Projects among PacifiCorp, the Corps, and the Federal Emergency Management Agency (FEMA), which had taken over responsibility for the national flood insurance program from HUD. These discussions culminated in the formalization of the flood control operating procedures, as described in the High Runoff Procedures, in a contract between PacifiCorp and FEMA dated August 18, 1983. Under this contract, PacifiCorp formally agreed to provide 70,000 acre-feet of dependable flood control storage in the 3-reservoir system and to follow the other procedures and practices described in the High Runoff Procedures manual. The same agreement subsequently became a condition for the 1983 relicensing of the Merwin Project. The relevant condition reads as follows:

> "Article 43. The Licensee shall provide not less than 70,000 acre-feet of storage space in the Merwin, Yale, and Swift hydroelectric developments for flood control on the Lewis River, beginning withdrawal by September 20 and reaching not less than 70,000 acre-feet by November 1 of each year, and retaining such space through April 1 and permitting gradual refilling by April 30 of the following year, according to the following schedule:

Date	Minimum Flood Storage Space (acre-feet)
September 20	0
October 10	35,000
November 1 through April 1	70,000
April 15	35,000
April 30	0

> Periodically, the Licensee shall review the Standard Operating Procedure Manual (Lewis River Projects -- High Runoff Operation) with the Corps of Engineers and shall revise Section 3.3 thereof or the procedure of said section when deemed necessary by the Licensee and the Corps of Engineers, and shall promptly file any such changes with the Commission."

The formalization of flood control procedures allowed FEMA to modify its delineation of the regulatory 100-year floodplain, recognizing the reduction in 100-year discharges resulting from the coordinated flood control operation of the Lewis River Projects. The basis for the current floodplain delineation is discussed in more detail below.

Floodplain Delineation

As noted above, the original 1975 flood insurance studies for the Lewis River did not consider the flood reduction benefits of PacifiCorp's operation of the Lewis River Projects, in effect assuming that floods on the Lewis River were unregulated. The flood insurance studies were revised following the 1983 agreement between PacifiCorp and FEMA to reflect the availability of 70,000 acre-feet of flood control storage.

Hydrologic analyses for the 1975 flood insurance studies and the subsequent revisions were conducted by the Portland District of the Corps. Unfortunately, the work files and basic data from these hydrologic analyses cannot be located and only a brief description of the analysis procedures is available in the flood insurance studies. The most recent revision of the Cowlitz County Flood Insurance Study (FEMA 1995) provides the following descriptions of the hydrologic analysis for the Lewis River:

> "The peak discharges for the 10-, 50-, 100-, and 500-year floods were reduced due to the availability of approximately 70,000 acre-feet of storage for flood control. The Lewis River stream gage records were statistically analyzed using the standard log-Pearson Type III distribution as outlined by the U.S. Water Resources Council (Reference 9). Natural and regulated discharge-frequency curves were developed for the U.S. Geological Survey (USGS) gages at Ariel and Amboy, using data from 1912 to 1978. Peak annual flows used in deriving the natural discharge-frequency curves were calculated by combining observed flows at the gage and by correlating adjacent gaging stations in the Lewis River basin and working downstream to Merwin Dam. The regulated discharge-frequency relationship was developed by comparison of natural versus regulated discharges for six flood events in the basin. The regulated discharges for these floods were based on the Pacific Power & Light plan of flood-control operation, considering the 70,000 acre-feet of flood control storage at Merwin Dam."

The effect of the flood control storage was to reduce flood discharges and hence reduce base flood elevations (i.e., regulatory 100-year flood elevations) throughout the lower Lewis River valley. The 100-year peak discharge in Woodland, for example, was reduced from 128,000 cfs to 102,000 cfs. The peak discharges used in the current flood insurance studies are summarized in Table 11.1-2.

Table 11.1-2. Summary of discharges for current flood insurance studies.

Location	Drainage Area (square miles)	Peak Discharges (cfs)			
		10-year	50-year	100-year	500-year
Lewis River[1]					
Near Ariel	731	49,000	79,000	94,000	132,000
At Woodland	820	54,400	86,300	102,000	142,000
At mouth	1,046	75,000	114,100	132,700	181,000

Note: [1] Peak discharges based on data from 1912 through 1978 with 70,000 acre-feet of storage in the Lewis River Projects.

Floodplain boundaries in the current flood insurance studies were determined with the Corps' HEC-2 computer program. Channel cross-section data for the hydraulic routing analyses date primarily from 1973. Selective updates to this information may have been made in the course of minor map revisions, but this cannot be confirmed. Overbank topography for current mapping is based on aerial photogrammetric maps from 1973 at a scale of 1:4,800 with a 5-foot (1.5 m) contour interval. Downstream boundary conditions for the hydraulic routing (i.e., water levels at the mouth of the Columbia River) were "selected to correspond with estimated Columbia River elevations at the time the Lewis

River peaks" (FEMA 1991). The actual basis for the selected Columbia River elevation (17.1 feet National Geodetic Vertical Datum [NGVD]) is unclear; however, it appears to correspond to a Columbia River water level with an approximate recurrence interval of once every 5 years. The underlying assumption was that major floods on the Lewis River are not coincident with major floods on the Columbia. Large floods on the Columbia River, however, result in backwater flooding in the lower reaches of the Lewis. The 100-year water level on the Columbia was assumed to result from a large spring or early summer snowmelt flood when Lewis River flows are low, with a 100-year Columbia River water level at the mouth of the Lewis of 23.0 feet NGVD. The current flood insurance studies thus show that 100-year water levels on the lowest 3 miles (4.8 km) of the Lewis River are controlled solely by backwater from the 100-year flood on the Columbia. The 100-year water surface profiles for the Lewis River from Merwin Dam to the mouth are shown in Figure 11.1-1, along with the water surface profile from the February 1996 flood. Note that during the February 1996 flood, the water level on the Columbia River at the mouth of the Lewis River was greater than the predicted 100-year water level. Backwater from the Columbia thus had a significant effect on water levels in the lower reaches of Lewis during that event, as discussed in more detail in Section 11.1.5.2.

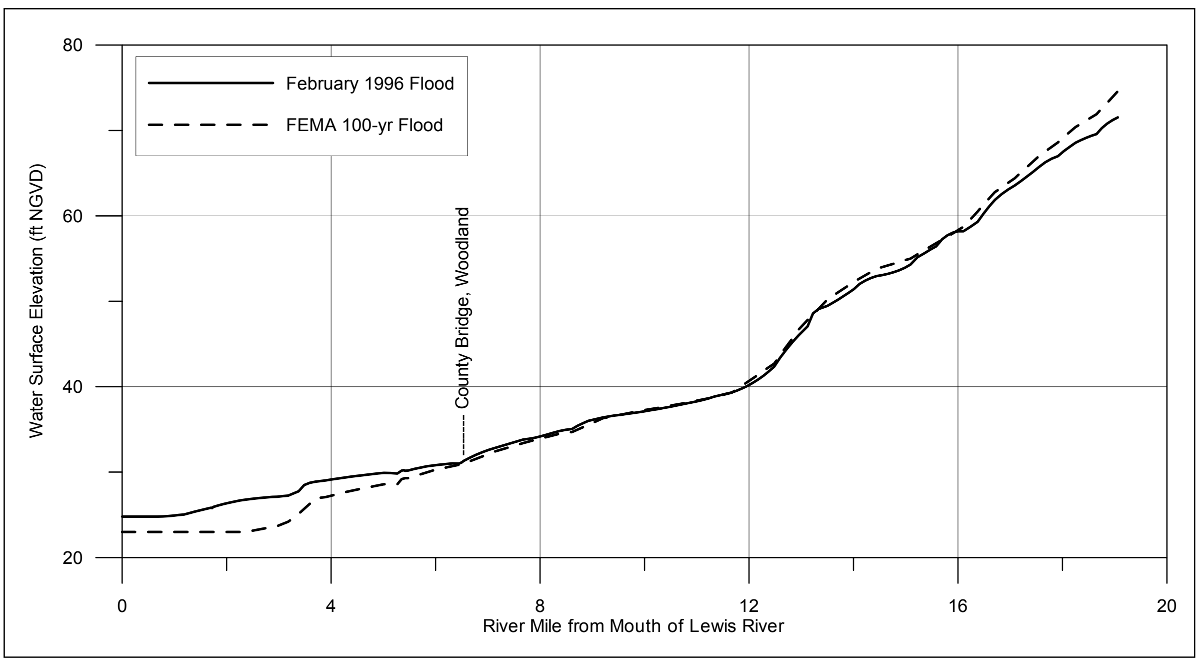


Figure 11.1-1. Water surface profile comparison.

11.1.5.2 Flood Management Under Current License Requirements

Considerable changes have taken place in data availability and the physical condition of the Lewis River watershed since the projects' operating procedures were originally developed in the mid-1970s. These changes include the eruption of Mount St. Helens, which is believed to have contributed to sedimentation and loss of storage in the project reservoirs (particularly in Swift), as well as continuing residential development in the Lewis River valley and floodplain below Merwin Dam. Experience during the February

1996 flood also indicates that the existing FEMA floodplain maps for the Lewis River understate flood risk, particularly below Woodland. Accordingly, this section updates the analysis of the projects' flood management capabilities to reflect currently available information. It is based on the assumption that the projects operate in accordance with the current FERC license requirements.

Reservoir Stage-Storage Data

Concern has been expressed about the possible effects of reduced reservoir storage due to sediment accumulation on flood control capabilities. Reservoir drawdown to meet flood control obligations is currently based on reservoir stage-storage tables developed at the time of project construction. These tables have not been updated since that time. During and following the 1980 eruption of Mount St. Helens, several large mud flows entered Swift Reservoir. The reservoir was substantially drawn down at the time in anticipation of such events; hence, it is unlikely that sediment accumulation from the eruption significantly encroached into flood control space, which currently accounts for a total of about 17 feet (5 m) of drawdown at Swift, Yale, and Merwin combined.

To evaluate the potential loss of flood control storage since project construction, and particularly since the eruption of Mount St. Helens, the existing reservoir storage tables were compared with recent bathymetric data. These data, in the form of topographic maps with a 2-foot (0.6 m) contour interval, were reviewed for both Swift and Yale reservoirs (pers. comm., J. Hirsch, PacifiCorp, 2000). Data for Swift were based on aerial photographs taken on October 28, 1998, when Swift Reservoir was partially drawn down. Data for Yale were based on aerial photographs taken on March 25, 1997. No recent data are available from Merwin.

The bathymetric data for Swift Reservoir were analyzed to determine storage available in 2-foot (0.6 m) increments between elevation 972.6 feet NGVD and the top of the flood control pool at elevation 1,000.0 feet NGVD. Over this range, estimates of storage from the new bathymetric data are consistently larger than estimates provided in the original reservoir storage tables, by between 1.5 and 3.5 percent, depending on the actual elevations considered. These discrepancies probably arise from differences in survey techniques and survey accuracy and are not significant from a flood control perspective. The trend of the data does, however, indicate a potential loss of storage to sedimentation at lower elevations, below about 980 feet NGVD.

The bathymetric data for Yale Lake were similarly analyzed between elevation 472.6 feet NGVD and the top of its flood control pool at elevation 490 feet NGVD. The new bathymetric data show slightly greater storage than the existing tables, with new storage estimates between 1.3 and 2.0 percent greater, depending on the range of elevations considered. As noted at Swift Reservoir, these differences probably can be attributed to differences in survey accuracy and are not significant from a flood control perspective.

The available bathymetric data for Swift and Yale reservoirs show no loss in reservoir storage due to sediment accumulation over the range of elevations likely to be of importance for flood control. Given this finding, it is reasonable to conclude that there has been no loss of potential flood control storage at Merwin due to sediment accumulation. Merwin is the farthest downstream of the 3 reservoirs and is the least likely to have been affected by mud flows from Mount St. Helens. For the purposes of flood control, it is appropriate to continue use of the existing reservoir storage tables. It should be noted that the present bathymetric analysis at Swift only extends down to elevation 972.6 feet NGVD; it is likely that sediment accumulation has affected storage in Swift at lower elevations.

Flood Control Performance and Floodplain Delineation

Flood magnitude and frequency estimates for the current generation of flood insurance studies on the Lewis River were based on analyses of flow records from 1912 through 1978, as discussed previously. In this section of the report, flood frequency estimates are updated to account for more recent information, utilizing flow records from 1912 through 2000 (an additional 20 years of data). Flood frequency analyses were conducted for both unregulated (natural) and regulated flows on the Lewis River at Ariel and for local inflows between Ariel and the mouth of the Lewis River.

Unregulated (Natural) Flow Frequency - Annual maximum daily unregulated flows at Ariel were obtained from PacifiCorp for water years 1929-2000. Additional daily average discharge data were obtained from the USGS gage Lewis River near Amboy (USGS gage 14219500) from 1912-1923, and from the USGS gage Lewis River at Ariel (USGS gage 14220500) from 1924-1928. Merwin Dam was completed in 1931, thus the USGS records prior to 1931 represent the natural unregulated condition. Flows from the Amboy record were increased by 16 percent to represent flows at Ariel based on a regression of daily flows at Amboy against those at Ariel for the period 1924 through 1930. The available USGS and PacifiCorp records were then concatenated to produce a record of annual maximum daily unregulated flows at Ariel from 1912 through 2000. The data and a fitted log-Pearson Type III probability distribution are shown in Figure 11.1-2.

Instantaneous unregulated annual peak flows were obtained from USGS gage records at Ariel and Amboy (adjusted to Ariel) for the period prior to closure of Merwin Dam in 1931. For the 8 largest floods since 1931, hourly reservoir storage and release data obtained from PacifiCorp were used to reconstruct unregulated (natural) flood hydrographs at Ariel by the standard process of inverse routing of flows through the upstream reservoirs. The resultant unregulated annual peak flows for those 8 largest events plus the flood of December 1917 are summarized in Table 11.1-3 and are plotted on probability paper in Figure 11.1-2. A probability distribution for the instantaneous unregulated peak flows was estimated by increasing flood quantiles from the analysis of the unregulated daily record by a uniform 25 percent, based on the average ratio of instantaneous peak to maximum daily flows for all available unregulated events in the Ariel and Amboy records. The estimated probability distribution is shown in Figure 11.1-2, and the resultant flood quantiles (i.e. flood magnitudes for selected recurrence intervals or return periods) are shown in Table 11.1-4.

Table 11.1-3. Historical and simulated peak flows for Lewis River at Ariel.

Date of Peak	Unregulated Peak (cfs)	Regulated Peak (cfs)
18 December 1917	92,000	85,000
22 December 1933	116,000	90,000
13 December 1946	67,300	n/a
20 November 1962	79,200	60,000
20 January 1972	76,600	60,000
15 January 1974	76,200	60,000
4 December 1975	80,700	60,000
2 December 1977	82,900	60,000
8 February 1996	111,400	85,000

Note: Regulated flows based on simulation assuming flood control operations to the current High Runoff Procedures with 70,000 acre-feet of dependable flood control storage

Table 11.1-4. Lewis River flood magnitude and frequency.

Location	Drainage Area (sq mi)	Flow Quantile (cfs) by Return Period (yrs)				
		2	10	50	100	500
Unregulated flows						
Near Ariel	731	42,000	71,900	99,100	111,000	140,000
Regulated flows with 70,000 acre-feet dependable flood control storage						
At Ariel	731	n/a	60,000	85,000	90,000	140,000
At Woodland	820	n/a	65,600	92,600	98,400	150,500
At mouth	1,046	n/a	85,400	119,400	128,200	187,600
Regulated flows with actual historic flood control storage						
At Ariel	731	22,000	60,000	n/a	n/a	n/a

Note: Analyses based on the period of record 1912-2000.

Regulated Flow Frequency Under Current Operations - The full record of flows on the Lewis River cannot be analyzed directly to provide information on the magnitude and frequency of floods under current regulated conditions since the record is not homogeneous. The number of projects in operation, the amount of dedicated flood storage space, and the way in which the projects are operated for flood control and power generation have all changed over time. Furthermore, analysis of regulated flows for the purposes of floodplain delineation or flood hazard assessment typically requires the assumption that only the dependable flood control storage space is available. Analysis of regulated flows for other purposes, such as various environmental assessments, is, however, more meaningful when based on actual flood control storage.

Regulated Flow Frequency under Current Operations with Dependable Flood Control Storage - Under this scenario, regulation of flood flows was assumed to follow the current High Runoff Procedures with 70,000 acre-feet of flood storage space available at the start of flood events. Hourly natural hydrographs for the floods containing the top 8 unregulated flow peaks were routed through the Swift-Yale-Merwin reservoir system according to the current published High Runoff Procedures using a STELLA computer simulation model. Each simulation assumed that 70,000 acre-feet of flood storage was available at the start of the event per the current High Runoff Procedures. The simulations reported here thus reflect the effects of dependable flood control storage only – additional incidental flood control storage may be available during actual operations. Instantaneous regulated peak flows from these simulations are summarized, along with the unregulated peaks, in Table 11.1-3 and are plotted on probability paper in Figure 11.1-2. A frequency curve was fitted by hand to the regulated data points, with the fit reflecting the stepped nature of the reservoir operations. The top 8 events were not quite sufficient to extend the frequency curve back to the 10-year return period event, so the magnitude of the 10-year flood was estimated from a frequency analysis of instantaneous regulated peak flows at Ariel from 1978 to 1998, when current High Runoff Procedures were in effect. Instantaneous regulated peak flow quantiles are shown in Table 11.1-4. Note that the 2-year flow for regulated conditions with dependable flood control storage is of little interest from the point of view of regulatory floodplain delineation and has not been determined for this scenario in the current studies. The 2-year flow for regulated conditions with actual historic flood control storage is discussed in the following section.

Note from the table of unregulated (natural) and regulated peak flows (Table 11.1-3) that the updated analysis presented here largely confirms previous analyses conducted by PacifiCorp as referenced above. Under the current High Runoff Procedures, all floods on record except 1917, 1933 and 1996 are controlled to a release of 60,000 cfs from Merwin Dam. The 1917 and 1996 floods are controlled to 85,000 cfs, and the 1933 flood is controlled to 90,000 cfs. As far as can be determined, the 1917 flood has not previously been used by PacifiCorp in evaluating project flood control performance and no comparable data from earlier analyses is available. The simulations conducted for this work show a slightly higher release during the 1933 flood than in previous analyses (90,000 cfs as opposed to 85,0000 cfs). This is due to an upward adjustment in the current work of the unregulated (natural) flows for the 1933 flood.

<u>Regulated Flow Frequency Under Current Operations with Actual Historic Flood Control Storage</u> - As noted previously, actual storage space available during the flood control season is frequently much greater than the minimum required under the current High Runoff Procedure. Estimation of flood magnitude and frequency for current operations analysis of instantaneous annual peak flows recorded at Ariel from 1978 through 1998. The current High Runoff Procedures were in effect during this period and operations for power generation are considered to be similar to current operations. In other words, the record of flows over the period 1978 – 1998 is believed to be relatively homogeneous and reasonably representative of current operations and historic flood control storage amounts. The data and a graphically fit probability distribution are shown in Figure 11.1-2, and the resultant flood quantiles are provided in Table 11.1-4. Note that in many years, the peak annual flow was a little under 12,000 cfs, indicating that flows in those years were controlled to the turbine capacity at Merwin Dam. Note also that flood quantiles are only provided for flows up to a 10-year return period; the 20-year record of characterization of more extreme events.

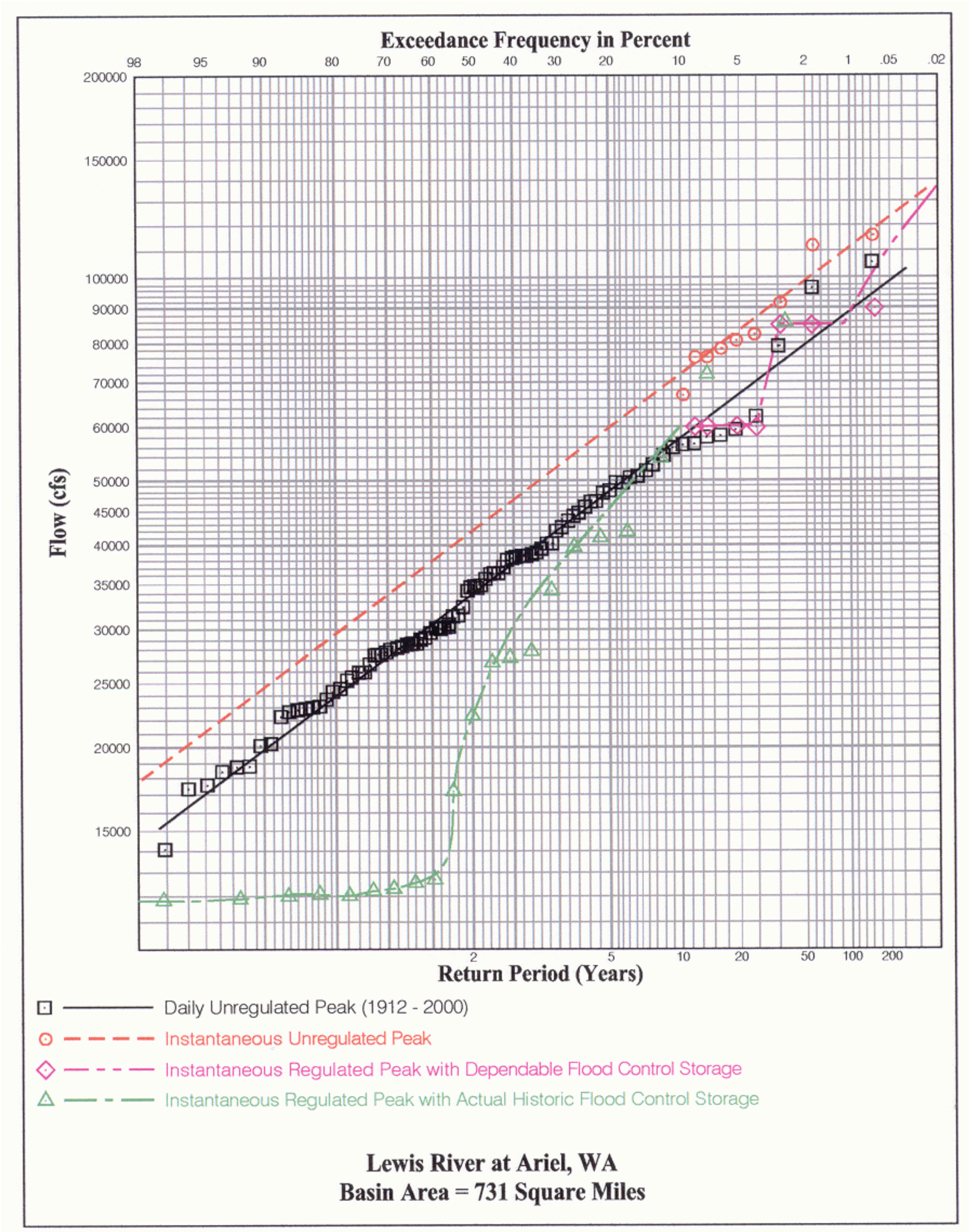


Figure 11.1-2. Flood Frequency Curves, Lewis River at Ariel.

Local Inflows - The Lewis River at Ariel has a tributary area of about 731 square miles. An additional 90 square miles is tributary to the river between Ariel and the County Bridge in Woodland, and a further 225 square miles is tributary to the river between Woodland and the mouth. The total drainage area of the Lewis River at its mouth is about 1,046 square miles. The principal tributaries to the Lewis River below Ariel are Cedar Creek (total tributary area approximately 58 square miles) and the East Fork Lewis River (total tributary area approximately 208 square miles).

USGS gage records were available for Cedar Creek near Ariel (USGS gage 14221500, drainage area 40.8 square miles) for a total of 14 years between 1952 and 1989 and for the East Fork Lewis River near Heisson (USGS gage 14222500, drainage area 125 square miles) from 1930-1996 and 1998. Flow frequency quantiles for the East Fork Lewis River watershed above the Heisson gage were determined by fitting a log-Pearson Type III distribution to the Heisson record. The Cedar Creek record was deemed too short for flood frequency analysis, but comparison of concurrent peaks flows on Cedar Creek against those on the East Fork near Heisson showed peak flows on Cedar Creek consistently about 17 percent of East Fork flows. Flow quantiles for the Cedar Creek basin at the gage were thus generated by applying this factor to the quantiles estimated for the East Fork near Heisson.

Flow quantiles for the remaining local tributary areas to the Lewis River below Ariel (including lower Cedar Creek, and the lower East Fork Lewis River below the Heisson gage) were scaled from the Cedar Creek gage quantiles on the basis of drainage area ratios, using relationships developed by the USGS (Sumioka et al. 1998). Flows were not scaled directly from records from the East Fork Lewis River near Heisson due to significant differences in basin elevation and precipitation. The estimated flow quantiles for local inflows to the Lewis River between Ariel and Woodland and between Woodland and the mouth were added to estimates of instantaneous regulated peak flows at Ariel (assuming 70,000 acre-feet of dependable flood control storage) to produce estimates of total discharges in the Lewis River at Woodland and at the mouth. The resultant flow quantiles are summarized in Table 11.1-4.

The updated flood magnitudes and frequencies for the Lewis River shown in Table 11.1-4 can be compared with flows used in the current Flood Insurance Studies which were shown in Table 11.1-2. Updated estimates show a significant increase in 10-year discharges, 50-year discharges are slightly higher, and 100-year discharges are slightly lower than previous estimates.

Floodplain Delineation – Revised 100-year floodplain inundation maps for the Lewis River from Merwin Dam to the mouth were prepared using the updated 100-year regulated flows from Table 11.1-4. These 100-year flow estimates were used as input to a UNET unsteady flow hydraulic model of the Lewis River. The UNET model used channel cross-section data taken from previous HEC-2 hydraulic models of the Lewis River and was calibrated to high water mark data and estimates of flows from the flood of February 1996. Observed water levels in 1996 were significantly higher than the regulatory 100-year water levels downstream of Woodland (see Figure 11.1-1) because the high flows in the Lewis were coincident with extreme high water levels in the Columbia River. As discussed earlier, previous analyses had assumed that extreme floods in the Lewis River would not occur at the same time as major floods in the Columbia (extreme floods in the Lewis occur in the winter months while the highest flows in the Columbia were expected to occur from spring and early summer snowmelt events). However, the historic record of major floods in rivers in southwest Washington and Oregon now includes at least 3 events where such floods have occurred in conjunction with high flows in the Columbia; December 1933, December 1964, and February 1996. These are all regional floods affecting large portions of Oregon and Washington, with large flows in the Willamette River contributing to high water in the Columbia. In short, the historic experience suggests that extreme floods in the Lewis can be expected to occur in conjunction with high water levels in the Columbia. For this analysis we therefore assumed that the 100-year flows in the Lewis River would occur in conjunction with 100-year water levels in the Columbia River at the mouth of the Lewis. The regulatory 100-year water level for the Columbia at the mouth of the Lewis River is currently 23 ft NGVD compared with an observed maximum water surface elevation of about 24.5 ft NGVD during the February 1996 flood.

The UNET model was used to determine 100-year water surface elevations at key locations along the Lewis. This information was then transferred to topographic maps of the Lewis River valley to produce updated maps of the 100-year inundated area. Topographic mapping used for this purpose was at a scale of 1:4,800 with a 5-foot (1.5 m) contour interval and was prepared from aerial photographs flown on 10 July 1996. The revised 100-year floodplain maps prepared for this study are provided in Figure 11.1-3. A revised 100-year water surface profile for the Lewis River from Merwin Dam to the mouth is provided in Figure 11.1-4 along with the observed water surface profile from the February 1996 flood. The revised 100-year water levels are up to 3 feet (0.9 m) higher than the current regulatory 100-year water level downstream from the confluence with the East Fork Lewis River; and up to 1 foot (0.3 m) higher in parts of East Woodland. Elsewhere, differences are minimal.

Seasonal Distribution of Floods

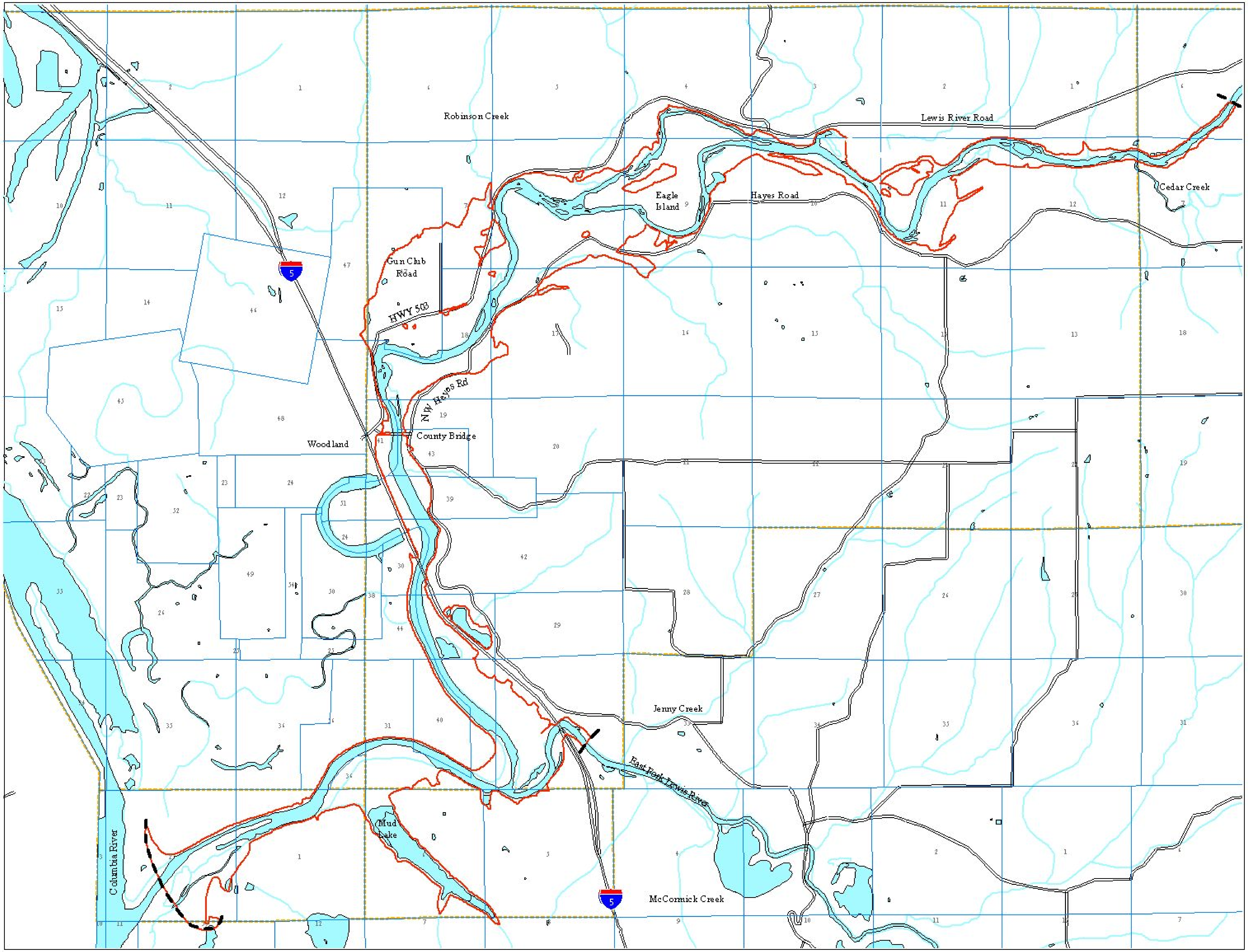
The seasonal variation of flood risk was examined by analyzing the reconstructed daily record of natural flows for water years 1911 through 2000. The number of independent flood events with daily peak flows in excess of 40,000, 50,000, 60,000, and 75,000 cfs were counted in each month of record and are plotted in Figure 11.1-5. The figure shows, for example, that December is the month with the largest number of historic floods, with 16 events having a daily peak flow of 40,000 cfs or greater. There have been no events in the months March through October in which the daily natural inflow exceeded 40,000 cfs.

Under the existing High Runoff Procedures, evacuation of flood storage space starts on September 20th and is required to reach the mandatory minimum 70,000 acre-feet by November 1st. This appears to be entirely appropriate given the risk of large floods in November. The 70,000 acre-feet of flood storage is currently maintained through April 1st, and the projects are then allowed to refill by April 30th. The analysis illustrated in Figure 11.1-5 shows that flood risk in March has historically been lower than in the period November through February. This is consistent with detailed analysis by the U.S. Department of Commerce (Hansen et al. 1994) in probable maximum precipitation (PMP) studies for the Pacific Northwest which show reductions in PMP amounts after the

Lewis River
Hydroelectric Projects

Figure 11.1-3
Sheet 1

Lewis River 100 - Year Floodplain (as defined during Lewis River Relicensing Studies)



100 - Year Base Flood Elevations
Limit of Study
100 - Year Floodplain
Lake
Section
Township

* All 100 - Year base flood elevations to NGVD (1929)

0.5 0 0.5 1 Miles

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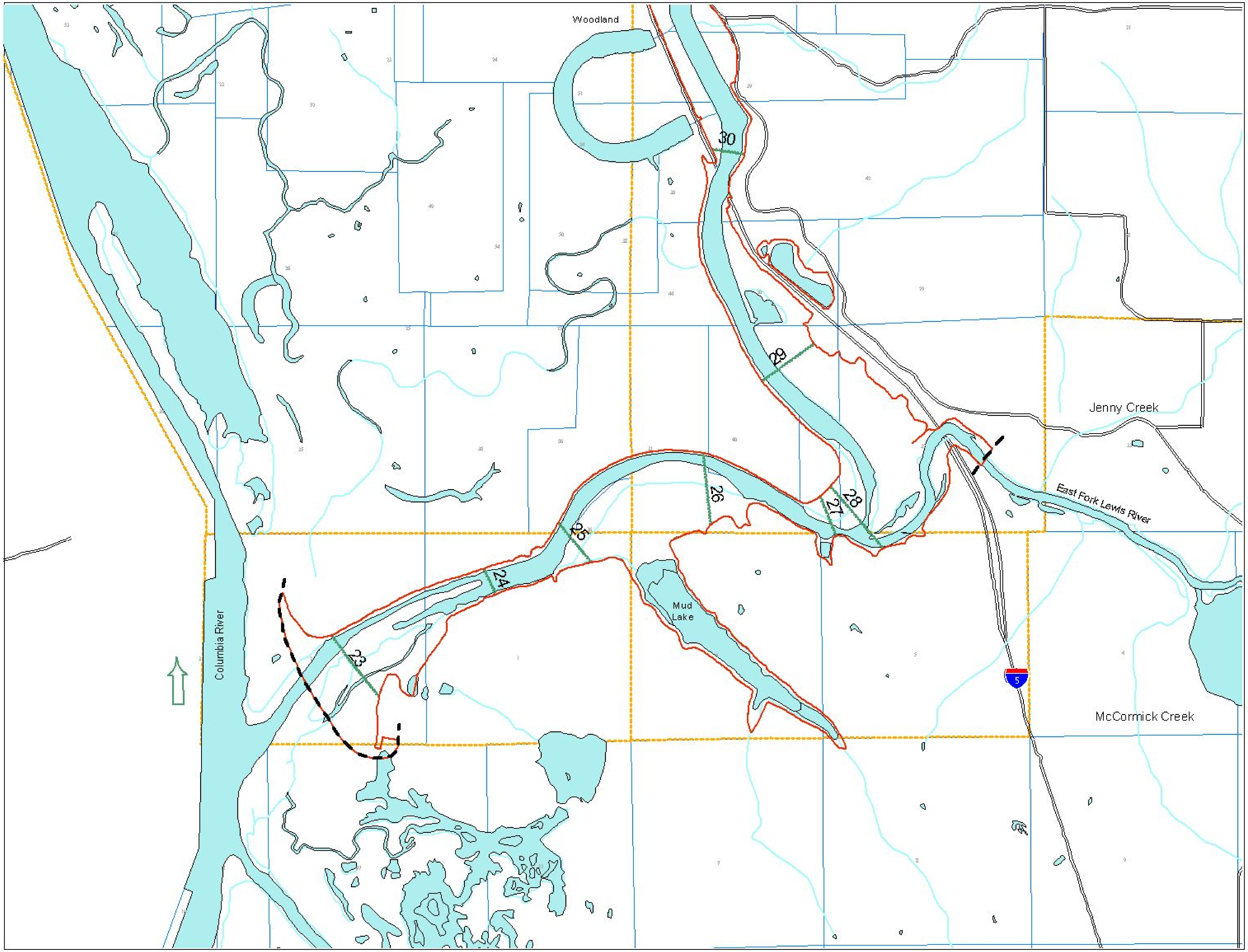
Lewis River
Hydroelectric Projects

Figure 11.1-3
Sheet 2

Lewis River 100 - Year Floodplain (as defined during Lewis River Relicensing Studies)



100 - Year Base Flood Elevations
Limit of Study
100 - Year Floodplain
Lake
Section
Township

* All 100 - Year base flood elevations to NGVD (1929)

0.3 0 0.3 0.6 Miles

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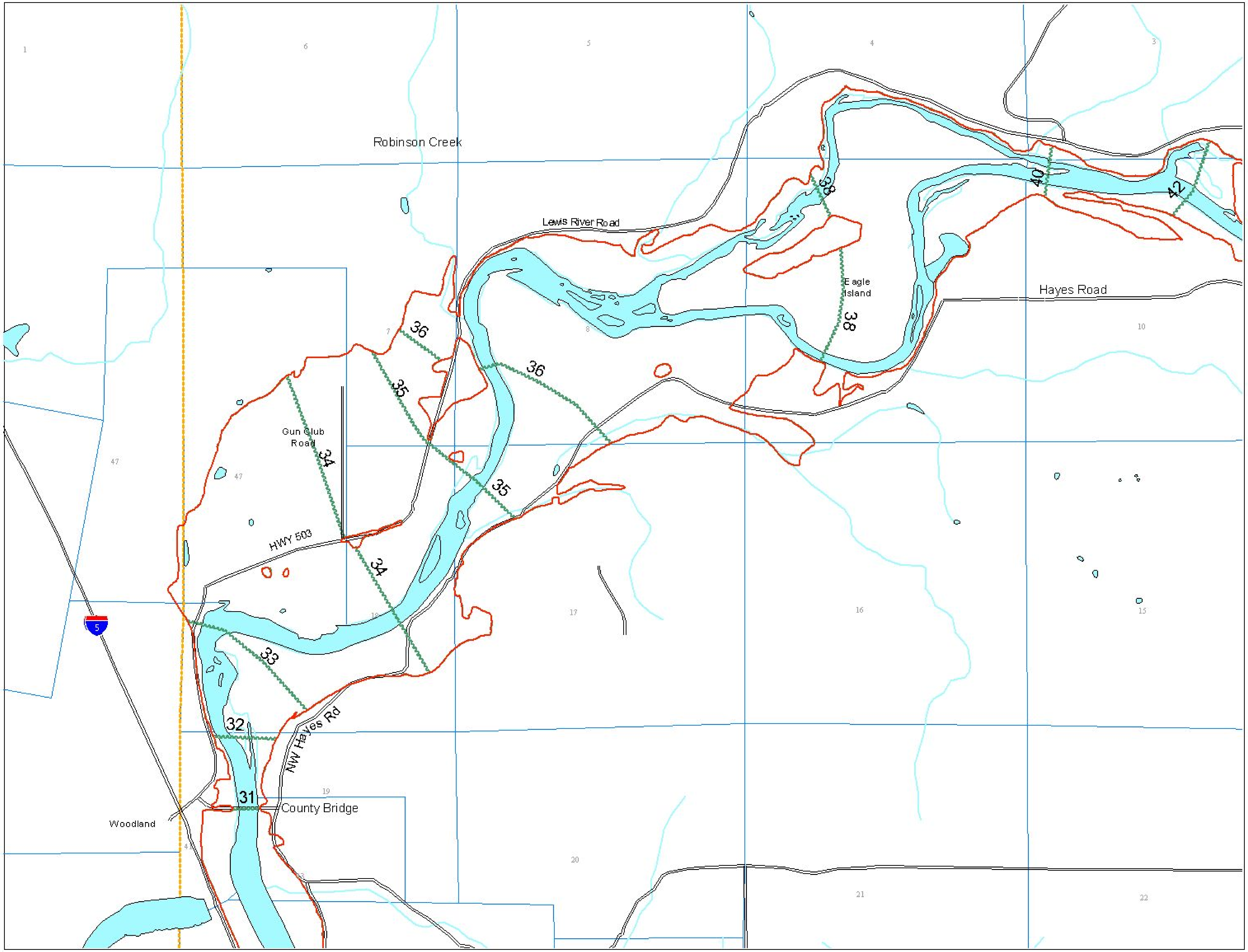

Lewis River
Hydroelectric Projects

Figure 11.1-3
Sheet 3

Lewis River 100 - Year Floodplain (as defined during Lewis River Relicensing Studies)

100 - Year Base Flood Elevations
Limit of Study
100 - Year Floodplain
Lake
Section
Township

* All 100 - Year base flood elevations to NGVD (1929)

0.2 0 0.2 0.4 Miles

GIS PACIFICORP
Property Mgt. Geographic Information System

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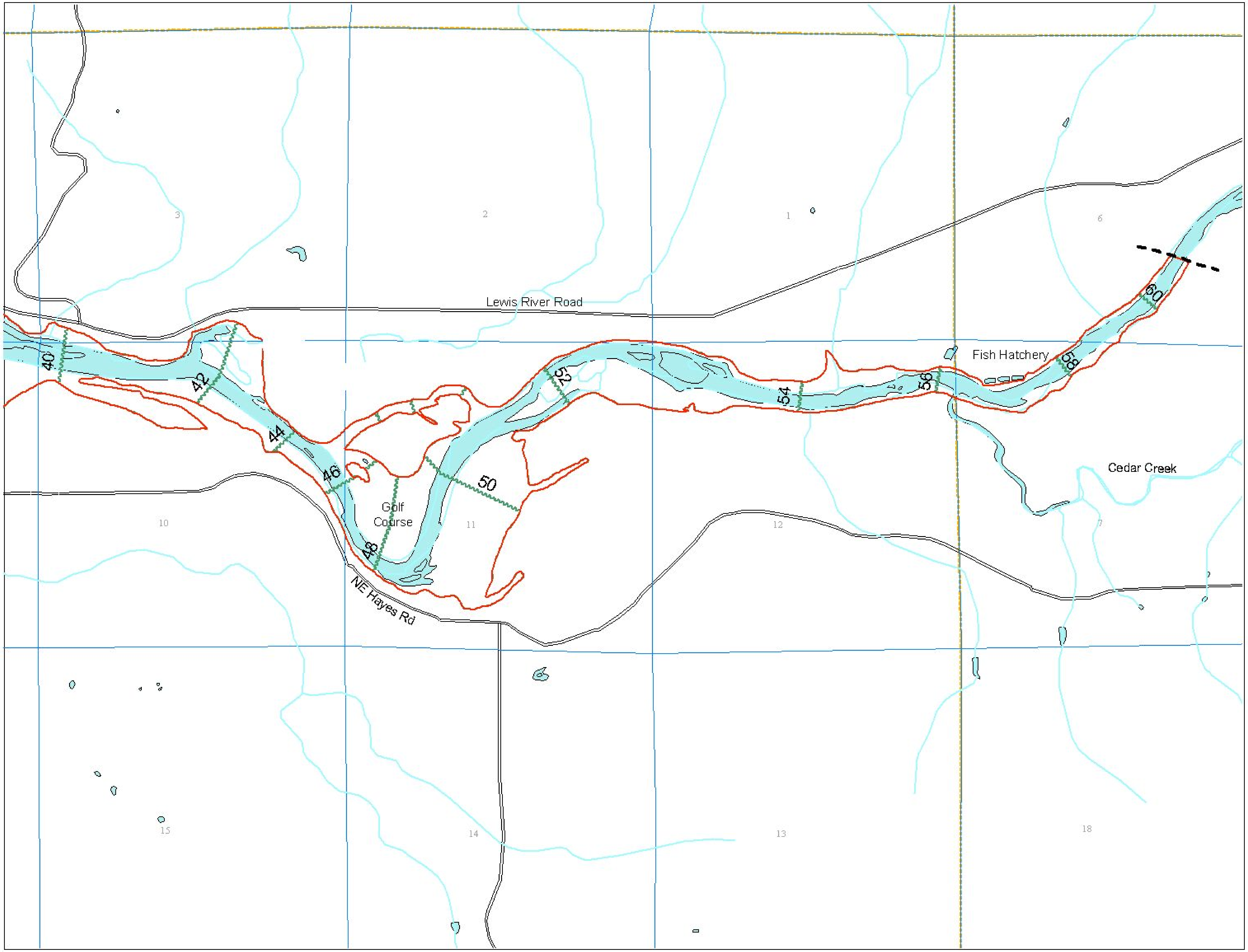
Lewis River
Hydroelectric Projects

Figure 11.1-3
Sheet 4

Lewis River 100 - Year Floodplain (as defined during Lewis River Relicensing Studies)



100 - Year Base Flood Elevations
Limit of Study
100 - Year Floodplain
Lake
Section
Township

* All 100 - Year base flood elevations to NGVD (1929)

0.2 0 0.2 0.4 Miles

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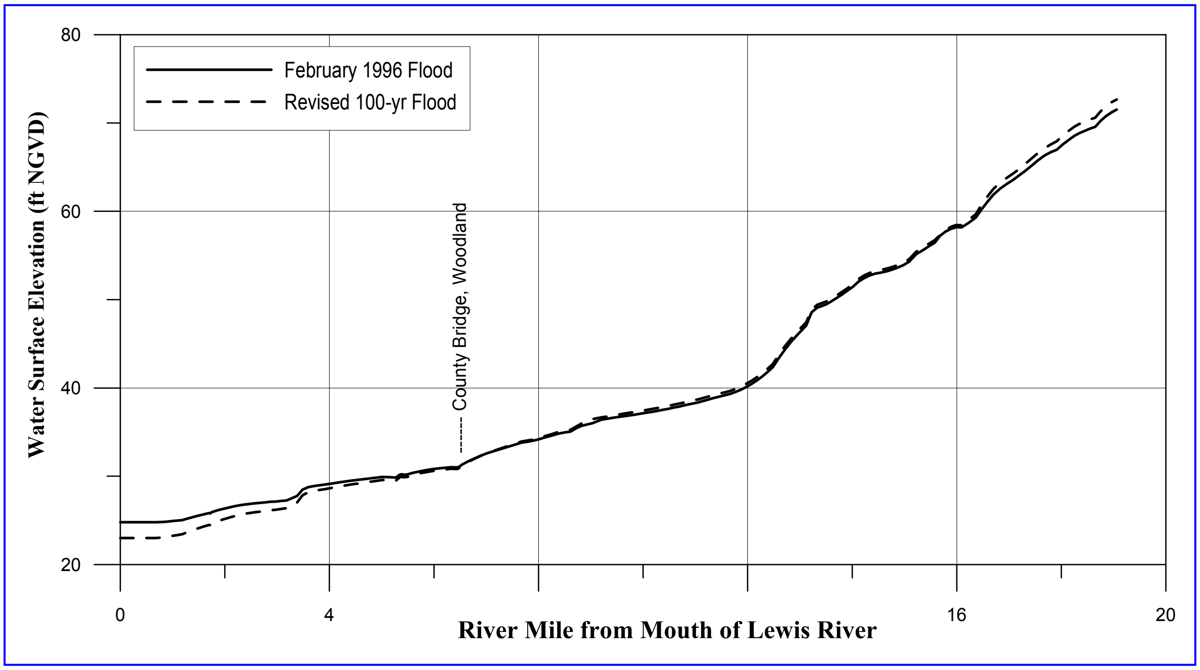


Figure 11.1-4. Revised 100-year water surface profile.

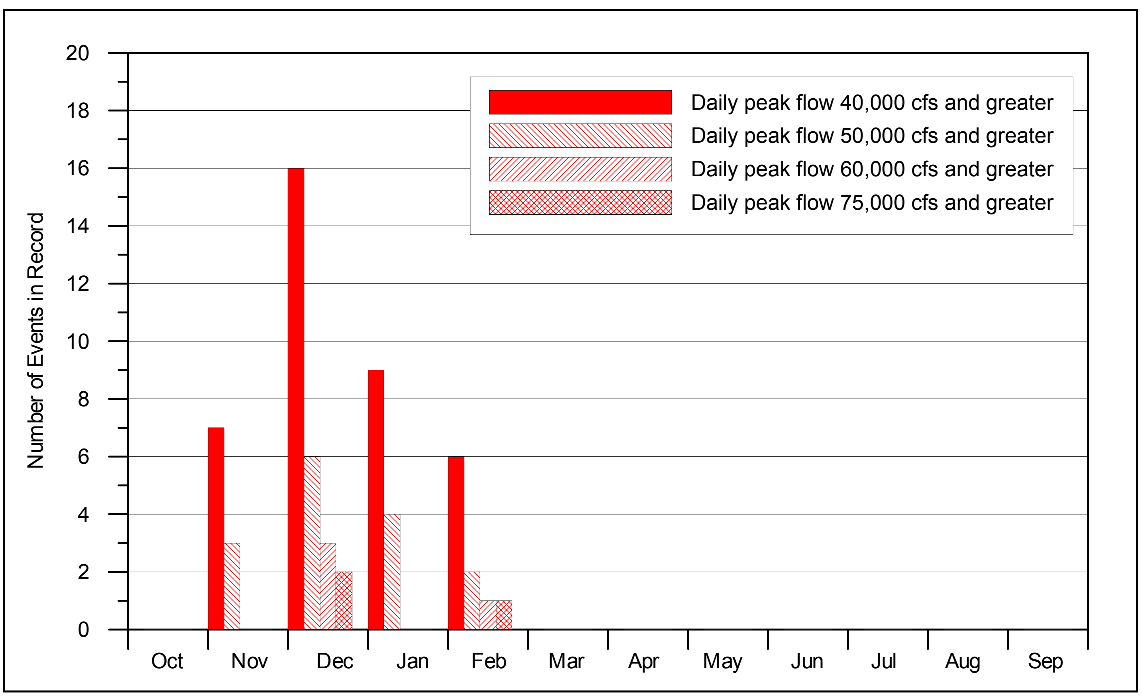


Figure 11.1-5. Seasonal distribution of floods based on daily flow record, water years 1911 through 2000.

end of February. The analysis conducted here indicates that the flood control season could be shortened by 2 weeks, with project refill commencing on March 15th and reaching pool by April 15th. The refill start date (either March 15th or April 1st) could be conditioned on the snow pack conditions in the watershed, with the earlier refill being permitted in dry years when spring snow pack may be too low to guarantee project refill. Analysis of spring runoff volumes, however, has not been conducted for this study.

Flow/Hazard Relationships

There is currently no detailed information on the relationship between flow in the Lewis River and flood hazard. Existing Flood Insurance Rate Maps (FIRM) show areas that would be inundated during the 100-year and 500-year floods, but there is no information on the number of properties that are prone to flooding, the amount of flood damage that would result at different flow rates, or the flow rates at which principal egress routes for homes or businesses are flooded. Development of such information would involve significant effort beyond the scope of the current study, including detailed surveys of the elevations of home and businesses in flood-prone areas, valuation of flood-prone property, and surveys of egress routes. Approximate flood hazard relationships for the present study have been developed on the basis of topographic surveys and limited damage assessment from the flood of February 1996, augmented by additional topographic surveys of selected egress routes, as described below.

Basis for Flood Damage Assessments – Topographic survey data were taken from Northwest Hydraulic Consultants' records on finished floor levels and depth of flooding in the February 1996 flood. Relevant survey data were available from 5 flood-damaged residences at various locations along the Lewis River, from about River Mile 6.4 (just below the County Bridge in Woodland) to about River Mile 12.7. Estimates of depth of flooding above finished floor levels for 19 residences were also extracted from an American Red Cross flood damage assessment incorporated into a Clark County report on the February 1996 flood (Clark County Water Division 1996). The Red Cross assessment included information on flooded residences in both Clark and Cowlitz counties. In addition, a questionnaire was distributed in the course of this study by the Flood Management Resource Group. It solicited information on flooding in 1996 and resulted in estimates of depths of flooding above finished floor level for a further 14 residences. Compilation of data from the above 3 sources produced estimates of flooding depth above finished floor level for a total of 38 residences. These data are summarized in Figure 11.1-6. This figure indicates, for example, that approximately 40 percent of the flooded homes had water depths above finished floor level of less than 1 foot (0.3 m).

The approximate flood hazard assessment reported here was originally intended to provide information on damage to residences which had been built to the regulatory standards in force at the time of their construction, as indicated by water depths exceeding authorized finished floor levels. The assessment was not intended to include damage to outbuildings, foundations, or basements. In reality the amount of work required to determine compliance with regulatory standards was found to be excessive and so all relevant data on flooding above finished floor levels were included in the analysis.

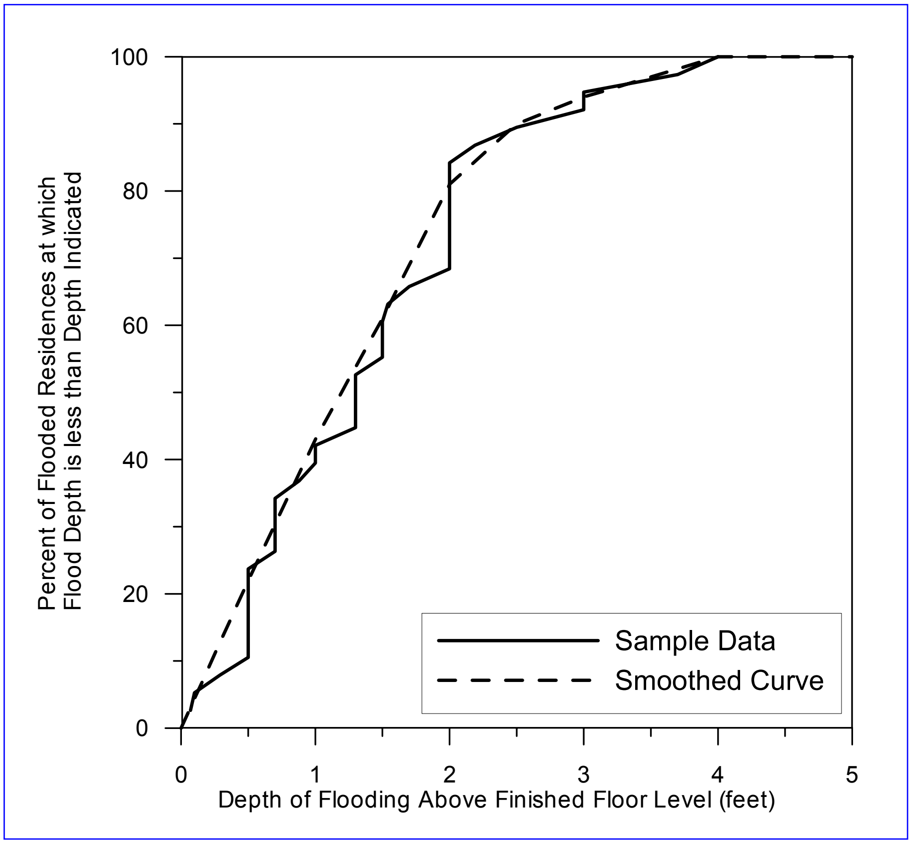


Figure 11.1-6. Distribution of February 1996 residential flooding depths.

For this study, the 38 residences with flood depth data from February 1996 were assumed to provide a representative sample of flood depths for all residences flooded in that event. The total number of properties flooded in February 1996 is not known. However, the City of Woodland reported issuing 56 building permits to repair flood damage, 65 mobile homes in the mobile home park at 6307 NW Pacific Highway (immediately below the County Bridge in Woodland) were reported to have suffered interior flood damage, and Clark County reported issuing 111 permits paid for by FEMA following the 1996 flood. Not all of these 111 permits were for flood repairs to damaged residences or businesses; some were for grading and some for repair to or replacement of outbuildings (barns and sheds). In addition, there were many instances in which multiple permits were found to have been issued for a single property. No equivalent permit information was available from unincorporated Cowlitz County outside the City of Woodland. Based on the permit data and a count of the number of buildings within the estimated inundation area, it is likely that around 250 residences or businesses were flooded above finished floor levels in February 1996. Thus, this sample of 38 represents about 15 percent of the total.

The data in Figure 11.1-6 are from the best available information; however, it may not be fully representative of flood damage from the February 1996 event. First, a large number of homes in East Woodland suffered relatively shallow flooding (less than 0.5 feet [0.15 m]) which may be understated in the available information. Second, the Red Cross report generally provided only depth of flooding above ground level. Only a few report entries included depth of flooding inside a residence above finished floor level. It appears that the sample of quantitative data extracted from the Red Cross report may understate the percentage of residences with flooding depths greater than 3 feet (0.9 m). Despite these qualifiers, it is felt that the information in Figure 11.1-6 provides a reasonable indication of the distribution of flooding depths in the February 1996 flood.

Having established an approximate distribution of flooding depths for the February 1996 event, the next step was to convert this information into a relationship between flow at some index point and the number of residences flooded above their finished floor levels. The index point used for this study was the Lewis River at the County Bridge (River Mile 6.5). An approximate rating curve (discharge vs. depth relationship) for the Lewis River at this point, developed from the UNET hydraulic model of the river, is provided in Figure 11.1-7. The Lewis River at the County Bridge is affected by backwater and tidal effects from the Columbia River, particularly at low flows. The rating in Figure 11.1-7 was based on UNET model simulation results for the period leading up to and including the February 1996 flood. Both the Columbia River water levels and flows in the Lewis were rising throughout the period of time used to establish the rating. While the rating is believed to reflect conditions during the February 1996 flood reasonably well, because of high water levels in the Columbia, the rating may understate the discharge at the County Bridge for stages less than about 26 feet for normal water conditions in the Columbia. The rating curve in Figure 11.1-7 should thus be used with caution.

It was assumed that the estimated peak flow of 93,800 cfs at the County Bridge in February 1996 resulted in flooding of some 250 residences. It was further assumed that a 1-foot (0.3 m) drop in water levels at the index point would produce an average 1-foot (0.3 m) drop in water levels at all flood-prone properties. Thus, using the discharge rating in Figure 11.1-7 to relate change in discharge to change in water level together with the flood depth distribution data in Figure 11.1-6, and assuming 250 residences flooded at the peak of the February 1996 event, allows one to estimate an approximate relationship between discharge and number of flooded residences. The relationship developed in this manner is shown in Figure 11.1-8.

Note that the residences damaged in the 1996 flood are very heavily concentrated between River Miles 6.2 (approximately 0.3 miles (0.5 km) below the County Bridge) and 9.0 (upstream from East Woodland). About 200 of the estimated 250 residences with water levels above finished floor level in February 1996 were located along that 3.8 mile (6.1 km) reach of the river. Comparison of the observed water surface profile from the February 1996 flood against FEMA's current 100-year profile (see Figure 11.1-1) shows that no homes upstream from River Mile 6.0 built to the current regulatory standard (finished floor 1.0 ft (0.3m) above the FEMA 100-year water level) would have been flooded above the finished floor level in February 1996. Below River Mile 6.0, high Columbia River water levels caused water levels in February 1996 to significantly exceed the FEMA 100-year water level.

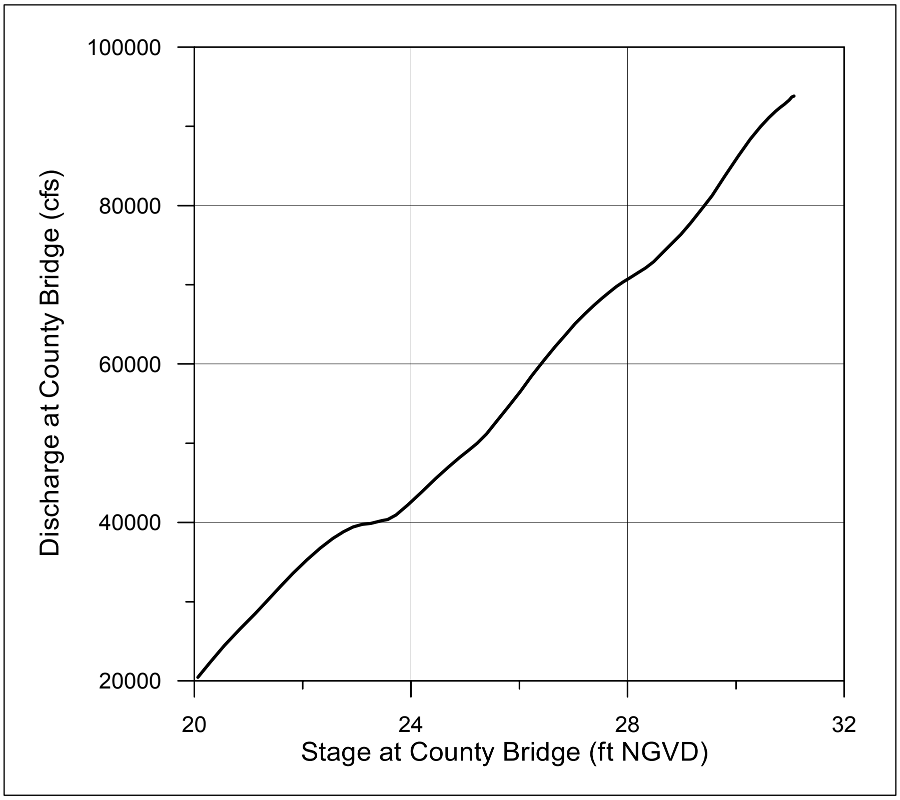


Figure 11.1-7. Rating curve for Lewis River at County Bridge (River Mile 6.5) from the February 1996 flood.

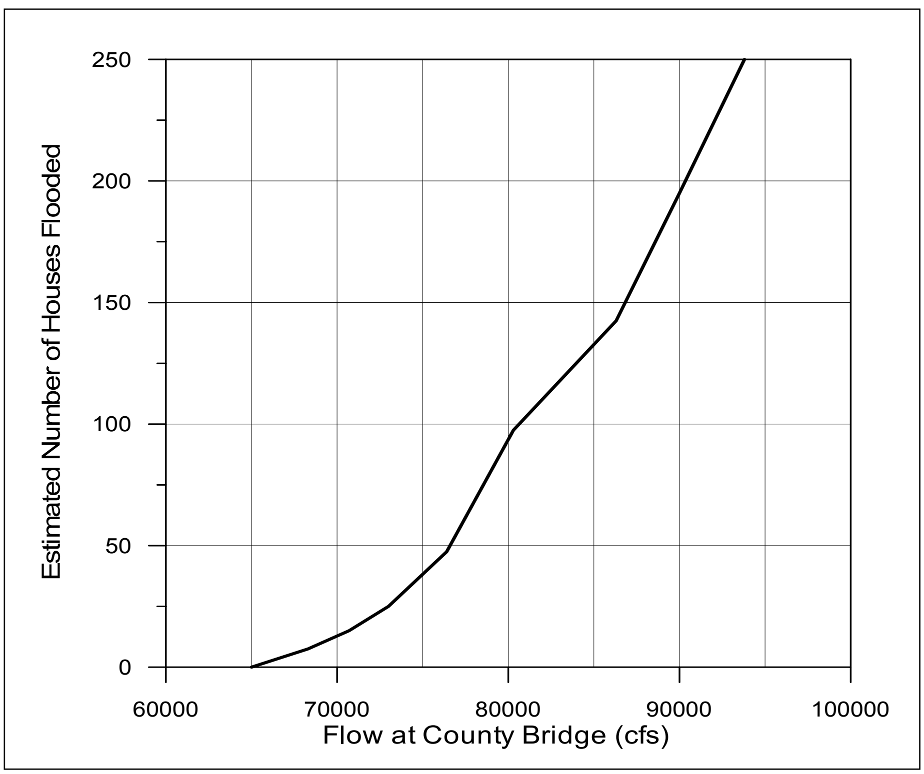


Figure 11.1-8. Flow-hazard curve for February 1996 flooding.

Threshold Data for Flooding of Egress Routes **-** A potentially serious hazard in the Lewis River valley below Merwin Dam is flooding of egress routes. Flooding of minor roads and private driveways is reported to begin at about 25,000 cfs, however reliable quantitative information on discharges at which inundation occurs at any particular location is currently lacking. During severe floods, such as occurred in February 1996, the principal roads on both the north and south banks of the Lewis River (Lewis River Road and Hayes Road, respectively) are inundated, cutting the principal access routes for a large number of valley residents. Egress in some locations, such as the Sandpiper Drive area in Clark County, becomes especially hazardous during large floods, as access is cut by deep, fast-flowing water.

Surveys and analyses were conducted to estimate threshold flows at which the principal egress routes and a representative sample of minor egress routes are flooded. Low points in the selected roads and driveways were determined by topographic survey. The UNET hydraulic model of the Lewis River, described above, was then used to determine the discharge rates at which these roads and driveways would first become flooded. This information is summarized in Table 11.1-5.

Note that the discharges in Table 11.1-5 are at the locations specified. For discharges of the magnitude of interest here, local inflows between Merwin Dam and Woodland are expected to be in the range of 3,000 to 6,000 cfs. Thus, the threshold flow of 70,000 cfs at which Hayes Road is flooded east of Amidon Road may be associated with releases from Merwin Dam in the range of 64,000 to 67,000 cfs. Similarly flooding of Blue Heron Drive, which occurs during significantly smaller events (threshold discharge of about 36,000 cfs), may be associated with releases from Merwin Dam in the range of 30,000 to 33,000 cfs. Because of the variability in local inflows between Merwin Dam and Woodland, more precise estimates cannot be given of the release rates from Merwin which would result in flooding of specific egress routes.

Table 11.1-5. Threshold flows for flooding of egress routes.

Location	River Mile	Elevation at which flooding first occurs (ft NGVD)	Flow at which flooding first occurs (cfs)
Lewis River Rd. east of Scott Avenue	7.7	30.0	70,000
Amidon Rd. nr NW Hayes Rd.	6.7	25.5	47,000
Brown Dr. nr NW Hayes Rd.	6.7	26.4	52,000
NW Hayes Rd. about 1000 ft northeast of Amidon Rd.	7.6	30.0	70,000
Sandpiper Dr. about 2200 ft northwest of NW Hayes Rd	8.7	23.3	29,000
Gilliam Residence Driveway (3306 NW Hayes Rd)	9.8	24.5	28,000
Blue Heron Dr. about 1200 ft north of Hayes Rd.	9.8	26.6	36,000
NW Hayes Rd. nr Sandpiper Dr.	9.8	33.0	68,000

Notifications and Warnings

During flood events, considerable coordination takes place between PacifiCorp, the National Weather Service, Clark County and Cowlitz County emergency services agencies, the City of Woodland, and, in very severe events, the U.S. Army Corps of Engineers. In general terms, PacifiCorp notifies the National Weather Service and county and local government of actual or expected large releases from Merwin Dam. The National Weather Service and the relevant county and local government agencies issue notifications and warnings to the public and, if the situation warrants, may initiate evacuations.

PacifiCorp Notifications – PacifiCorp's procedures and protocols for providing notification of large releases from Merwin Dam were incorporated into the original High Runoff Procedures for the project. Some changes in procedures have been made as technology has improved and with experience of large floods. The basic procedures, as paraphrased from the most recent version of the High Runoff Procedures, are as follows:

- **Any spill at Merwin** – Whenever any water is to be passed, of any magnitude, by the spillway at Merwin, or if there is any change in spill, PacifiCorp's Hydro Control Center (HCC) provides official notice in advance to each of the following:

  – Lewis River Hatchery Complex Manager (WDFW)
  – Lewis River Hatchery
  – PacifiCorp Hydro Licensing

  These notifications are repeated each time a significant increase in the amount of water spilled is expected.

- **Merwin total outflow 15,000 cfs or more –** Whenever the combined outflow of power plant and spillway at Merwin meets or exceeds, or is expected to meet or exceed 15,000 cfs, the HCC provides notice as follows:

  – All notifications listed above.

  – Cowlitz County Department of Emergency Management. For combined flows at and above 35,000 cfs, PacifiCorp requests that information be provided to the City of Woodland and appropriate water, dike and road commissioners.

  – Clark Regional Communications Agency. For combined flows at and above 35,000 cfs, PacifiCorp requests that information be provided to Clark County Roads Maintenance.

  – City of Woodland Fire Chief. PacifiCorp requests that information be forwarded to City of Woodland Police.

  – The National Weather Service Forecast Office, Portland. This notification is actually provided by PacifiCorp Operations Planning, as discussed below under "Coordination with the National Weather Service."

These notifications are repeated for every cumulative 5,000 cfs increase, or decrease, in total outflow from Merwin while total outflow (including turbine discharge) meets or exceeds 15,000 cfs.

Notifications made to the emergency management service agencies listed above are made by telephone and followed up with a faxed copy. Information provided in each notification includes the following:

- Total Merwin outflow (including turbine discharge) prior to spill change,
- Total Merwin outflow (including turbine discharge) after spill change,
- Expected, or actual, time of spill change,
- If requested, reservoir status, and,
- If known, information is provided on expected future operations.

All notifications are entered into the HCC log and a copy of faxed notifications are kept on file.

In addition to the above notifications, information on the total release from Merwin Dam is updated on the Merwin flow information recording which is available to the public via telephone dial-in to Merwin Headquarters.

- **Merwin total outflow 60,000 cfs or more** – When Merwin outflow is expected to reach or exceed 60,000 cfs, the HCC provides notice as follows:

  - All notifications listed above.
  - U.S. Army Corps of Engineers, Northwestern Division, Reservoir Control Center, Portland.
  - U.S. Army Corps of Engineers, Portland District, Reservoir Regulation and Water Quality Section, Portland.

  These notifications are repeated each time a significant increase in the amount of water spilled is expected.

Redundancy is provided in the notification system by having PacifiCorp's System Dispatch act as a backup and provide notification if HCC is unable to do so.

<u>Coordination with the National Weather Service</u> – PacifiCorp coordinates its operations closely with the National Weather Service during flood conditions. The National Weather Service provides PacifiCorp with forecasts of project inflows on a regular basis and uses information on project releases, provided by PacifiCorp, to forecast river stage on the Lewis River at Woodland. These forecasts provide the basis for various National Weather Service flood notifications and warnings. Flow forecasts issued by the National Weather Service are currently produced using the following general procedures:

1. Quantitative precipitation, temperature, and freezing level forecasts are produced by the National Weather Service Hydrometeorological Prediction Center in Washington, DC, for a 72-hour forecast horizon.

2. These meteorological forecasts are reviewed by the National Weather Service Portland Weather Forecast Office and revised as necessary based on knowledge of local conditions.

3. The revised forecasts are issued to the National Weather Service Northwest River Forecast Center (RFC) whose meteorologists may make further adjustments based on local conditions including observed real-time meteorological conditions.

4. Observed and forecast meteorological data are used by the RFC as input to a hydrological model of the Lewis River basin above Merwin Dam to produce forecasts of project inflows at a one hour time step over a 6-day forecast horizon. Observed stream flow data (for example, from a telemetered gage on Muddy River) are used to the extent possible to validate flow forecasts.

5. The project inflow forecasts are provided by the RFC to PacifiCorp, where the information is used for guidance in determining project operations. During normal flow conditions, the flow forecasts are updated daily, and during flood conditions, twice a day. The potential exists to provide updates 4 times a day but because of the large workload during floods, this is not usually done.

6. The timing and amount of current and expected releases from Merwin Dam are provided by PacifiCorp to the RFC via the Weather Forecast Office whenever Merwin outflow meets or exceeds, or is expected to meet or exceed, 15,000 cfs. PacifiCorp also provides information on the status of Swift, Yale and Merwin reservoirs.

7. The flow release data provided by PacifiCorp are routed by the RFC to Woodland by means of a hydraulic model, with flows being adjusted as necessary to reflect local inflows below the projects. The hydraulic model currently in use is an unsteady flow model which accounts for tidal and backwater effects from the Columbia River. The result of the routing is a forecast of hourly stage for the Lewis River at the County Bridge in Woodland.

8. The RFC provides the stage forecast for the Lewis River at the County Bridge to the Portland Weather Forecast Office. When the forecast or actual stage exceeds or is expected to exceed the designated flood stage at Woodland (24.00 ft NAVD or 20.46 ft NGVD), notification procedures are triggered. Real time data in support of forecast operations are available via telemetry from gages at Ariel (flow and stage) and the County Bridge in Woodland (stage). The dissemination of forecast information is discussed below.

<u>Dissemination of Flood Notifications and Warnings:</u> Flood notifications and warnings specific to the Lewis River are issued or disseminated by the Portland Weather Forecast Office, Clark Emergency Services Agency and Cowlitz County Department of

Emergency Management. The Portland Weather Forecast Office issues flood notifications at 3 levels, as follows:

1. Flood Potential Outlook: A flood potential outlook is issued if flow or stage forecasts and hydrologic and atmospheric conditions indicate a potential for flooding 36 to 72 hours from the present time.

2. Flood Watch: A flood watch is issued if flow or stage forecasts and hydrologic and atmospheric conditions indicate probable flooding 12 to 36 hours from the present time.

3. Flood Warning: A flood warning is issued if flooding is imminent or is actually in progress. Flood warnings provide up to 12 hours advance notice of floods.

The 3 notification levels provide for increasing levels of confidence in the flow forecasts as the forecast horizon is narrowed. Notifications are disseminated by the Weather Forecast Office by a number of methods including via National Oceanographic and Atmospheric Administration (NOAA) Weather Wire Service to the media, via the Internet, and via NOAA Weather Radio. Clark County and Cowlitz County emergency management services are notified by telephone of flood watches and flood warnings. The County emergency management services in turn issue warnings via radio and broadcast media.

As discussed further in Section 11.1.5.3, a significant portion of the Lewis River valley lies in a reception shadow and many people cannot receive warnings broadcast via radio and television, including NOAA weather radio. Public access to streamflow conditions has, however, improved since the February 1996 flood. Real-time or near real-time data on stream flows and/or stages are now available for the Lewis River at Ariel and the Lewis River at the County Bridge in Woodland via the Portland Weather Forecast Office web site at www.wrh.noaa.gov/portland/public_hydro. Real-time or near real-time reservoir pool elevation and storage data are also available at the same web site.

In the event that evacuations are necessary, these are coordinated by the County emergency service agencies with the County Sheriff's Department and the City of Woodland Police and Fire departments. Evacuations are implemented through door-to-door notification.

Both the County and State emergency service agencies can issue warnings via the Emergency Alert System (EAS). However, the EAS is reserved for catastrophic situations and would likely not be used to warn of flooding along the Lewis River. (Note that the EAS was not activated in the February 1996 flood.)

11.1.5.3 Identification and Analyses of Opportunities for Future Improvements in Flood Management

The February 1996 flood resulted in significant damage along the Lewis River and throughout large areas of southwestern Washington and western Oregon. The event prompted local interest in improvements in flood management on the Lewis River, with attention being focused in particular on flood notification and flood control operations at the Lewis River projects. While modifications to project operations could improve flood control, flood hazard could also be reduced through other means such as through land use controls and improved public awareness of flood hazard. Accordingly, this report section explores a variety of topics that could lead to improvements in flood management in the Lewis River Valley, as follows:

- Use of low elevation snow pack data to guide flood control operations
- Use of flow forecasts in flood control operations
- Development of alternative flood control operating policies
- Improved flood notification and warning procedures
- Strengthened land-use regulations and public outreach

<u>Operations Conditioned on Low Elevation Snow Pack</u>

Large floods on the major rivers of the western Washington are invariably caused by heavy rain falling over several days in the late fall or winter months. Temperatures during such flood events are usually mild, with precipitation falling as rain at relatively high elevations. Runoff during several of the largest floods in the region over the past 40 years has been augmented by melt of low elevation snow pack. A typical chronology for such a rain-on-snow event would be as follows:

- Colder-than-normal conditions result in accumulation of moderate amounts of snow at low elevations (below about 2,000 feet [609 m]).
- A transition from cold to milder wet conditions occurs with the arrival of a subtropical jet stream and a westerly or southwesterly upper-level air flow.
- Temperatures rise rapidly and the moist air mass associated with the jet stream brings prolonged heavy rainfall. Heavy rain falls at the highest elevations in the Cascade Range, with runoff augmented by rapid melt of the ephemeral low elevation snow pack.

It is generally recognized that an accumulation of low elevation snow pack increases flood risk on the major rivers of Western Washington. Accordingly, this section examines the potential for conditioning flood control operations on the presence of low elevation snow pack in the Lewis River watershed.

Data on low elevation snow are generally available at NOAA cooperative weather stations as depth of snow on the ground. Snow on the ground data for this study were obtained from NOAA station Cougar 6E (Station 451760 – elevation 659 feet). The data obtained comprise daily observations of snow depth in inches, recorded daily at 09:00 a.m. from 1954 through 1998. (Note that these data only show snow depth – they do not show the water content or snow water equivalent of low elevation snow pack.) These data were augmented by snow depth data from NOAA station Merwin Dam (Stations 0242 and 5305 – elevation 224 feet) for the period of record 1964 through 1998. Exploratory analysis of these data was conducted to compare flood occurrence and magnitude on the Lewis River at Ariel against snow depth at Cougar. Table 11.1-6 shows the estimated maximum annual daily natural flows and observed maximum annual regulated flows (instantaneous peaks) at Ariel, compared with maximum observed snow depths at Cougar and/or Merwin Dam in the period up to about one week prior to each maximum flow. Also shown on Table 11.1-6 are rainfall totals recorded at Cougar 6E for the 3-day period up to and including the date of the maximum daily natural flow.

Table 11.1-6. Comparison of snow depth and flood data in the Lewis River basin.

	Annual Maximum Flow at Ariel (cfs)				Snow Depth (inches)			3-Day Precip. at Cougar (inches)	Did Melt Directly Contribute to Peak?
Water Year	Daily Natural Flow	Date	Inst. Regulated Flow	Date	Cougar	Merwin	Date		
1996	96468	2/8/96	86400	2/8/96	9	0	2/1/96	14.22	No
1978	62095	12/2/77	71900	12/2/77	M	0		8.23	
1974	59396	1/15/74	59600	1/15/74	M	M		9.3	
1972	58000	1/20/72			M	M		10.81	
			36400	3/13/72	M	M		5.56	
1963	56560	11/20/62	75500	11/20/62	0			7.06	
1990	56400	1/9/90	42000	1/10/90	0			9.46	
1976	55829	12/4/75	64500	12/4/75	9	0	11/30/75	10.91	No
1981	50673	12/26/80	53700	12/26/80	M	0		8.39	
1982	50318	2/20/82	40700	2/20/82	0			6.81	
1967	49706	12/13/66	50500	12/13/66	1	M	12/7/66	8.09	No
1973	47896	12/21/72	18000	12/24/72	M	M		8.32	
1965	45715	12/23/64	44000	12/22/64	14	M	12/21/64	9.47	Yes
1961	44241	11/24/60	48200	11/24/60	0			8.13	
1995	43496	2/19/95	26600	2/20/95	M*	2	2/15/95	M	No
1968	42511	2/19/68	31100	2/23/68	0			8.39	
1997	42017	1/1/97	34100	1/1/97	0			7.67	
1983	40065	1/7/83	27000	1/7/83	0			9.72	
1970	39045	1/23/70	41800	1/23/70	2	M	1/17/70	5.88	No
1956	38873	11/27/55			M	n/a		M	
			49100	12/12/55	M	n/a		M	
1987	38075	2/1/87			0			7.4	
			12100	11/24/86	0			7.89	
1986	36215	2/23/86	27700	2/24/86	0			7.47	
1991	36213	11/25/90	39600	11/25/90	0			6.75	
1964	36063	1/25/64	17700	1/25/64	12	0	1/20/64	7.31	Yes
1975	34608	1/14/75	22400	1/14/75	10	5	1/10/75	8.35	Yes
1971	34594	1/19/71	23300	1/25/71	0			2.17	
1954	34211	12/9/53	41700	12/9/53	0			5.32	
1958	30449	4/20/58			M	n/a		M	
			18300	2/12/58	M	n/a		M	
1993	30077	3/23/93			0			4.61	
			12000	4/3/93	0			3.19	
1988	29224	12/10/87	12300	12/10/87	0			5.21	
1959	29006	1/24/59	32800	1/24/59	M	n/a		6.79	
1960	28626	11/23/59			0			6.8	
			21400	10/12/59	0			4	
1957	28491	2/26/57			M	n/a		M	
			27100	3/9/57	M	n/a		M	
1979	28344	3/5/79			2	0	3/1/79	6.73	No
			11800	11/15/78	0			0.01	
1998	28193	10/30/97			0			6.07	
			12200	11/21/97	0			6.15	
1969	26644	1/5/69			14	M	1/1/69	3.87	Yes
			21000	11/11/68	0			5.14	
1962	25864	12/24/61	11900	12/20/61	M	n/a		3.7	
1984	25156	11/17/83	17100	11/17/83	0			6.45	

Table 11.1-6. Comparison of snow depth and flood data in the Lewis River basin (cont.)

Water Year	Annual Maximum Flow at Ariel (cfs)				Snow Depth (inches)			3-Day Precip. at Cougar (inches)	Did Melt Directly Contribute to Peak?
	Daily Natural Flow	Date	Inst. Regulated Flow	Date	Cougar	Merwin	Date		
1955	23624	2/8/55			M	n/a		M	
			20200	6/11/55	M	n/a		M	
⊘ 1966	22908	3/9/66			3	M	3/3/66	7.53	No
			11900	8/1/66	0			0	
1985	22791	6/7/85	22100	6/7/85	0			5.3	
1992	22677	1/28/92	12600	1/30/92	0			6.39	
1980	20116	12/18/79			0			4.4	
⊘			12000	1/12/80	45	M	1/11/80	4.45	Yes
1989	18739	11/22/88			0			5.37	
⊘			11700	2/6/89	M*	1	2/4/89	0	Yes
1994	17313	1/5/94	11800	1/8/94	0			5.36	
1977	9874	3/9/77			M	0		4.7	
			11800	12/2/76	0			0	

Key: M = Missing M* = Missing; snow likely
⊘ = Snow at Cougar 6E

After accounting for missing data, there are a total of 32 years with maximum annual natural flows at Ariel and concurrent low elevation snow depth data at Cougar. In addition, there is one year where snow depth data are missing at Cougar but in which the natural daily flow peak coincides with recorded snow on the ground at Merwin, presumably indicating that the higher elevation Cougar station would also have had snow. This 33-year record contains 18 flood events with daily natural flows at Ariel greater than 35,000 cfs. Of these, low elevation snow was present within a week prior to the peak in 7 (about 40 percent) of the events, with melt of low elevation snow pack judged to have directly augmented runoff amounts to a significant degree in 2 (about 11 percent) of the events: January 1964 and December 1964. In other words, melt of low elevation snow pack contributed directly to peak flows in about 11 percent of the potentially damaging floods (daily natural flows greater than about 35,000 cfs) for which we have low elevation snow depth data. Low elevation snow and/or frozen ground augmented flood peaks indirectly in several other events, either through melt in the days prior to the flood contributing to saturation of the watershed (e.g., December 1975) or through frozen ground reducing soil infiltration rates.

Low elevation snow appears to have directly or indirectly augmented flood peaks or flood runoff volumes in about 40 percent of the potentially damaging floods in the Lewis River watershed. The actual contribution of snowmelt to flood flows cannot be quantified without additional analysis beyond the scope of this study. However, it should be noted that the direct contribution of snow to most of these floods is quite modest. For example, prior to the February 1996 flood, the maximum water content of the snow pack at Cougar was probably less than about 1.8 inches (4.6 cm) (assuming a snow density of 20 percent), which represents only about 12 percent of the 3-day rainfall at Cougar during that event. There have been years with substantial accumulations of low elevation snow (e.g., 45 inches [114 cm] of snow at Cougar in 1980), but these have not resulted in or been associated with significant floods.

The snow depth data available for the above analysis is less than ideal. The station at Cougar is at elevation 659 feet, while less than 5 percent of the Lewis River watershed above Merwin Dam is below that elevation. The Cougar station is too low to provide a completely reliable assessment of the contribution of low elevation snow pack to flood flows on the Lewis River. One or more snow stations at higher elevations should be installed to provide more representative data coverage.

It appears that the relationship between low elevation snow pack and the occurrence of large floods is rather weak. Nevertheless, melt of low elevation snow pack may augment flood peaks and volumes during potentially damaging events. Project operating policies which hedge against floods during periods with low elevation snow pack may be of some benefit. A policy in which minimum project releases are maintained when snow depth at Cougar exceeds 6 inches (15 cm) is investigated later in this report under "Alternative Flood Control Operating Policies."

Flow and Precipitation Forecasts

Project inflow forecasts and Quantitative Precipitation Forecasts (QPFs), issued by the National Weather Service (NWS), are currently used by PacifiCorp for general guidance in determining project operations during floods. The flow forecasts are made by taking QPFs over a 3-day forecast horizon and transforming these into flows by means of a hydrologic simulation model. Procedures for developing these flow forecasts were described in more detail under "Notification and Warning Procedures" in Section 11.1.5.2. Given the fast response time of the upper Lewis River basin to rainfall, reliance on QPFs is the only feasible approach for producing flow forecasts with sufficient lead time to be useful in project operations. The potential to improve flood management through greater reliance on flow forecasts in flood control operations is clearly dependent on forecast accuracy. Unfortunately, there is currently no archive of historic flow forecast information for the Lewis River. Thus, for the purposes of this study, assessment of forecast accuracy is based on limited information regarding the accuracy of QPFs.

The NWS Hydrometeorological Prediction Center (HPC) currently provides QPFs for the contiguous United States for a 3-day forecast horizon at a 6-hour time step. Provided they are reasonably accurate, QPFs can be valuable tools for providing guidance for reservoir flood control operations. Unfortunately, there is no comprehensive archive of historic QPFs and no basis for evaluating QPF accuracy specific to the Lewis River watershed. The National Weather Service has, however, recently completed an assessment of QPFs issued for the Pacific Northwest region as a whole[4]. This assessment compared QPFs issued by the HPC against observed precipitation based on data from the Pacific Northwest region from November 1999 through March 2000.

The ability to forecast large storms is most critical for reservoir flood control operations. The Applicants reviewed the HPC QPF assessment results for forecast and observed rainfall amounts in excess of 1 inch (2.5 cm) in a 6-hour period. The data extracted from the HPC assessment are provided in Table 11.1-7. The HPC assessment statistics for the first day of the 3-day forecast (Forecast Day 1) shows that the QPFs under-predicted the

[4] Assessment results are available at http://www.hpc.ncep.noaa.gov/npvu/

number of times rainfall depths exceeded 1 inch (2.5 cm) in 6 hours by about 60 percent (92 observed occurrences versus 30 forecast). The assessment results also show a significant bias. For observed amounts greater than 1 inch (2.5 cm), the mean forecast amount was on average 0.73 inch (1.8 cm) less than the mean observed amount (an average under-prediction of about 56 percent). For forecast amounts greater than 1 inch (2.5 cm), the mean forecast amount was on average 0.21 inch (0.5 cm) greater than the mean observed amount (an average over-prediction of about 22 percent). As seen in Table 11.1-7, data for the second and third days of the 3-day forecast (Forecast Days 2 and 3) show a further degradation in accuracy.

Table 11.1-7. Pacific Northwest QPF assessment results (November 1999 - March 2000).

Category	No. of Cases	Mean of Observed Values (inches)	Mean of Forecast Values (inches)	Mean Error (inches)	Mean Absolute Error (inches)
Forecast Day 1					
Forecast amount > 1 inch in 6 hours	30	0.951	1.164	0.213	0.523
Observed amount > 1 inch in 6 hours	92	1.300	0.569	-0.732	0.753
Forecast Day 2					
Forecast amount > 1 inch in 6 hours	16	0.799	1.256	0.457	0.553
Observed amount > 1 inch in 6 hours	47	1.318	0.461	-0.857	0.881
Forecast Day 3					
Forecast amount > 1 inch in 6 hours	17	0.711	1.443	0.732	0.763
Observed amount > 1 inch in 6 hours	46	1.282	0.416	-0.867	0.909

Source: http://www.hpc.ncep.noaa.gov/npvu/

It is clear from Table 11.1-7 that current QPFs are of limited accuracy. The 6-hour Day 1 forecast amounts greater than 1 inch (2.5 cm) have a relatively small mean error, indicating in qualitative terms that large forecast precipitation amounts generally result in large observed amounts. The converse, however, is not true in that large observed amounts frequently occur in the absence of a large forecast amount. This suggests that QPFs could be a useful tool in operating the Lewis River reservoirs to hedge against the risk of a large flood given a large QPF. Beyond that, given their current accuracy, QPFs and any resultant flow forecasts should only be used for general guidance in project flood control operations.

Although there is no archive of QPF data specific to the Lewis River watershed, QPF data from the major storm of February 1996 are available from the project records. At that time, QPFs used as input to a SSARR streamflow simulation model for forecasting flows on the Lewis River were taken as the weighted average of QPFs for 3 nearby weather stations: Portland Airport, Cinebar, and Bonneville Dam. The weighted QPFs for the Lewis River watershed for the February 1996 event were calculated and compared with precipitation at Cougar to provide a general indication of watershed QPF accuracy during that event. The results, summarized in Table 11.1-8, show that the weighted QPFs greatly under-predicted actual rainfall amounts at Cougar, again illustrating the danger of relying on QPFs for other than general guidance in flood control operations.

Table 11.1-8. Lewis River watershed QPF accuracy (February 5-8, 1996).

Forecast Time	Quantitative Precipitation Forecast (inches)		
	Day 1	Day 2	Day 3
Forecast Time 12Z[1] 05 Feb 96			
Portland A forecast	1.04	1.1	0.8
Cinebar forecast	0.5	1.0	1.8
Bonneville forecast	1.25	1.7	1.1
Lewis R. watershed QPF	0.96	1.31	1.22
Cougar observed	2.9	5.0	4.6
Forecast Time 12Z 06 Feb 96			
Portland A forecast	1.75	1.1	0.2
Cinebar forecast	1.3	1.3	0.8
Bonneville forecast	2.6	1.85	0.4
Lewis R. watershed QPF	1.96	1.46	0.46
Cougar observed	5	4.6	3.3
Forecast Time 12Z 07 Feb 96			
Portland A forecast	1.9	1.5	0.2
Cinebar forecast	1.3	0.6	0.2
Bonneville forecast	3.8	3.0	0.2
Lewis R. watershed QPF	2.48	1.83	0.20
Cougar observed	4.6	3.3	0
Forecast Time 12Z 08 Feb 96			
Portland A forecast	1.9	0.05	0
Cinebar forecast	2.1	0	0
Bonneville forecast	3	0.1	0
Lewis R. watershed QPF	2.40	0.06	0.00
Cougar observed	3.3	0	0

[1]12Z is 12 Zulu or 1200 Greenwich Mean Time

Alternative Flood Control Operating Policies

Alternative flood control operating policies, consisting of a pre-release rule, modifications to turbine operations, and modifications to the High Runoff Procedures (HRP), were simulated using a STELLA computer model of the lumped reservoirs to determine how the projects could be operated to control releases during a repeat of the February 1996 flood to non-damaging rates. The alternative policies were then compared with the existing operating policy for the 1996 flood and for other historical floods.

Definition of Non-Damaging Project Releases – For purposes of this analysis, non-damaging flows were defined as those which would maintain water levels below the finished floor levels of residences between Merwin Dam and River Mile 6.2 (about 0.3 miles [0.5 km] below the County Bridge in Woodland). This definition excludes flooding of basements and outbuildings such as sheds and barns. The small number of residences between River Mile 6.2 and the mouth of the Lewis were also excluded from this analysis because backwater effects from the Columbia River were a dominant factor in determining water levels in this reach during the February 1996 flood. At least one residence in this reach has finished floor levels below the February 1996 peak water level on the Columbia River and would have been flooded irrespective of the flow rate on the Lewis River.

The flow/hazard relationships described earlier in Section 11.1.5.2 estimated a non-damaging flow at the County Bridge in Woodland of about 65,000 cfs (see Figure 11.1-8). Local inflows to the Lewis River between Merwin Dam and Woodland during major floods (up to the 100-year event) are expected to be in the range of 5,000 cfs to 8,000 cfs, equivalent to a non-damaging release from Merwin Dam in the range of 57,000 cfs to 60,000 cfs. Actual conditions during the February 1996 flood resulted in a maximum release from Merwin Dam of about 83,500 cfs and a peak flow in the Lewis River at the County Bridge in Woodland estimated at 93,500 cfs (i.e., a 10,000 cfs increase in peak flows between Merwin and Woodland). Local inflows to the Lewis River downstream from Merwin Dam during the February 1996 flood are known to have been exceptionally large (the peak flow on the East Fork Lewis River for example had an estimated return period in excess of 200 years). A 10,000 cfs local inflow is at the top end of the reasonable range of estimates for investigation of flood control operations. For the most part, the analyses presented below target control of the February 1996 flood to a 60,000 cfs release from Merwin. However, the implication on flood control storage of controlling releases to 55,000 cfs was also examined.

Pre-Release Rules – Three alternative pre-release rules were devised to create additional flood storage space in the reservoirs early in high flow events, as follows:

- *Normal Pre-Release*. A 25,000 cfs release would be initiated when rising project inflows exceed 40,000 cfs and project hole is less than 63 feet (less than 260,000 acre-feet of available storage). The pre-release would be continued until higher releases are invoked by the High Runoff Procedures or until project inflows drop below the 40,000 cfs threshold level.

- *Aggressive Pre-Release 1*. In alternatives with Aggressive Pre-Release 1, the Normal Pre-Release policy would be followed but the pre-release would be increased to 40,000 cfs when rising project inflows exceed 60,000 cfs and project hole is less than 40 feet (less than 164,000 acre-feet of available storage). The pre-release would be continued until higher releases are invoked by the High Runoff Procedures or until project inflows drop below the threshold level.

- *Aggressive Pre-Release 2*. In alternatives with Aggressive Pre-Release 2, the Normal Pre-Release policy would be followed but the pre-release would be increased to 40,000 cfs when rising project inflows exceed 50,000 cfs and project hole is less than 40 feet (less than 164,000 acre-feet of available storage). The pre-release would again be continued until higher releases are invoked by the High Runoff Procedures or until project inflows drop below the threshold level.

Based on the reconstructed record of daily natural flows at Ariel, it is estimated that Normal Pre-Releases would have been made in a maximum of 78 events over the period of record (water years 1924 through 2000). Aggressive Pre-Release 1 would have been implemented in about 19 events and Aggressive Pre-Release 2 in about 38 events over the same period of time.

Turbine Operations – Based on an examination of low elevation snow pack data, it is envisaged that a hedging policy could be instituted that would dictate maintenance of minimum project releases when there is low elevation snow pack in the watershed and project storage amounts are less than some minimum level. This would ensure maintenance of (or possibly increase in) project hole when there is low elevation snow pack; a condition which increases flood risk as discussed earlier in this report. The specific policy examined for simulation of a repeat of the 1996 flood would require minimum releases of 11,500 cfs (the nominal maximum turbine capacity) when there is more than 6 inches (15 cm) of snow on the ground at Cougar, and less than 63 feet of hole (260,000 acre-feet of available project storage). In the simulation of the 1996 flood, alternatives were thus run with actual turbine releases as reported by PacifiCorp and with the maximum turbine release of 11,500 cfs throughout the event. Simulations for all other high flow events, in which the start of the flood event was defined by inflows exceeding 10,000 to 15,000 cfs, were run assuming maximum turbine releases throughout the event.

Modified High Runoff Procedures with Existing Dependable Flood Control Storage (Modified HRP1) – The existing High Runoff Procedure for Merwin Dam with existing dependable flood control storage (17 feet of hole or 70,000 acre-feet of storage) was modified to provide earlier release of flows at non-damaging levels. Initial releases were increased to 25,000 cfs at 24 feet of hole, ramping up to the existing 40,000 cfs release at 17 feet of hole. The 50,000 cfs release level was dropped. Storage allocated to the 60,000 cfs release rate was increased with the 60,000 cfs release triggered at lower project storage levels. The amount of storage allocated to the 75,000 cfs release was also increased. Storage allocations for the existing and modified policies are compared below in Table 11.1-9.

Modified High Runoff Procedures with Increased Dependable Flood Control Storage (Modified HRP2a and 2b) – The Modified HRP1 with existing dependable storage (described above) was further modified to investigate the benefits of increases in dependable flood control storage. The amount of flood control storage was increased to allow releases from Merwin Dam to be controlled to either 60,000 cfs (Modified HRP2a) or 55,000 cfs (Modified HRP2b) in a repeat of the February 1996 flood.

In the first alternative (Modified HRP2a), dependable flood storage was increased from 17 feet of hole (70,000 acre-feet) to 21 feet of hole (86,500 acre-feet). All additional storage was allocated to the assumed non-damaging 60,000 cfs release rate. In the second alternative (Modified HRP2b), the existing 60,000 cfs release level was reduced to 55,000 cfs and the dependable flood storage was increased from 17 feet of hole (70,000 acre-feet) to 23.5 feet of hole (96,800 acre-feet). In this case all additional storage was allocated to the 55,000 cfs release rate. As noted earlier, this policy was included to examine the effects on required flood control storage of uncertainty in the non-damaging release from Merwin Dam. Storage allocations for the existing policy and modified policies are again shown in Table 11.1-9.

Table 11.1-9. Comparison of storage allocations for existing and modified high runoff procedures.

Existing HRP		Modified HRP1		Modified HRP2a		Modified HRP2b	
Project Hole (ft)	Release (cfs)	Project Hole (ft)	Release (cfs)	Project Hole (ft)	Release (cfs)	Project Hole (ft)	Release (cfs)
24		24		28		30.5	
	11,500 - 40,000 (linear)		25,000 - 40,000 (linear)		25,000 - 40,000 (linear)		25,000 - 40,000 (linear)
17		17		21		23.5	
	40,000		40,000		40,000		40,000
14.5		15		19		21.5	
	50,000		60,000		60,000		55,000
12		6		6		6	
	60,000		75,000		75,000		75,000
6		4		4		4	
	75,000		85,000		85,000		85,000
5		1		1		1	
	85,000		90,000		90,000		90,000
1		-3.5		-3.5		-3.5	
	90,000						
-3.5							
< -3.5	Greater of 90,000 or inflow	< -3.5	Greater of 90,000 or inflow	< -3.5	Greater of 90,000 or inflow	< -3.5	Greater of 90,000 or inflow

Note: One foot of project hole is equivalent to about 4,000 acre-feet of storage below the normal maximum full-pool reservoir level. A negative project hole indicates reservoir surcharge, i.e., operations with water levels greater than the normal maximum.

<u>1996 Flood Simulation</u> – STELLA model simulations of the February 1996 flood were run for the period February 1-15, 1996 for a total of 12 scenarios:

- Existing HRP with actual and maximum turbine flows, with and without Normal Pre-Release (4 scenarios).
- Modified HRP1 with existing dependable storage, with actual and maximum turbine flows, with and without Normal Pre-Release (4 scenarios).
- Modified HRP1 with existing dependable storage, with actual turbine flows, with Aggressive Pre-Release 1 and Aggressive Pre-Release 2 (2 scenarios).
- Modified HRP2a with increased dependable storage, with actual turbine flows, with Normal Pre-Release (1 scenario).
- Modified HRP2b with increased dependable storage, with actual turbine flows, with Normal Pre-Release (1 scenario).

For Existing HRP and Modified HRP1 with existing dependable storage, the starting hole for the event (February 1, 1996) was the actual 43.6 feet. For the Modified HRP2a and 2b with increased dependable storage, it was assumed that operating the projects at lower levels (with either 4 feet or 6.5 feet of additional flood control storage) would have resulted in a corresponding increase in starting hole to either 47.6 feet or 50.1 feet.

Results of the STELLA model simulations are summarized in Table 11.1-10 and are plotted for selected scenarios in Figure 11.1-9. With existing operations (Existing HRP/actual turbine flows/no pre-release), the theoretical peak release was 85,000 cfs (Figure 11.1-9a). Actual operations resulted in an estimated maximum release of 83,500 cfs. The peak release was reduced to 60,000 cfs for both Existing HRP and Modified HRP1 with existing dependable storage assuming Normal Pre-Release and maximum turbine flow throughout the event (e.g. Figure 11.1-9c). The additional storage allocated to the Modified HRP2a and 2b with increased dependable storage allowed control of releases to 60,000 cfs or 55,000 cfs depending on alternative (e.g. Figure 11.1-9f). Peak releases under Modified HRP1 with actual turbine operations were held to 75,000 cfs with adoption of Aggressive Pre-Release 1 and to 60,000 cfs with adoption of Aggressive Pre-Release 2. Modified HRP1 with actual turbine flows and Aggressive Pre-Release 1 just fails to control releases to 60,000 cfs. Because of a rising reservoir pool on the falling limb of the flood hydrograph[5], the existing falling limb policy would, in theory, increase project releases to 75,000 cfs. Additional simulations with a modified falling limb policy held the maximum project release to 60,000 cfs (Figure 11.1-9e). Under the modified falling limb policy, the project would be operated at slightly higher levels (2 feet less hole) on the falling limb than on the rising limb of inflow hydrographs for project releases between 60,000 cfs and 85,000 cfs.

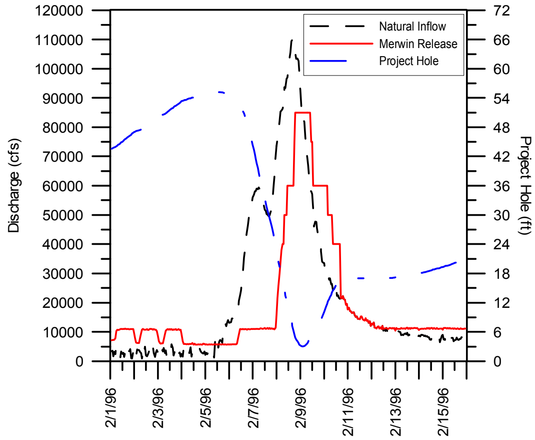
Table 11.1-10. Peak release (cfs) during February 1996 flood under alternative operating policies.

	Turbine Operations/Pre-Release Combination					
High Runoff Procedure	**Actual/ None**	**Max/ None**	**Actual/ Normal**	**Max/ Normal**	**Actual/ Aggressive 1**	**Actual/ Aggressive 2**
Existing HRP	85,000	85,000	85,000	60,000	n/a	n/a
Modified HRP1	85,000	75,000	75,000	60,000	75,000*	60,000
Modified HRP2a	n/a	n/a	60,000	n/a	n/a	n/a
Modified HRP2b	n/a	n/a	55,000	n/a	n/a	n/a

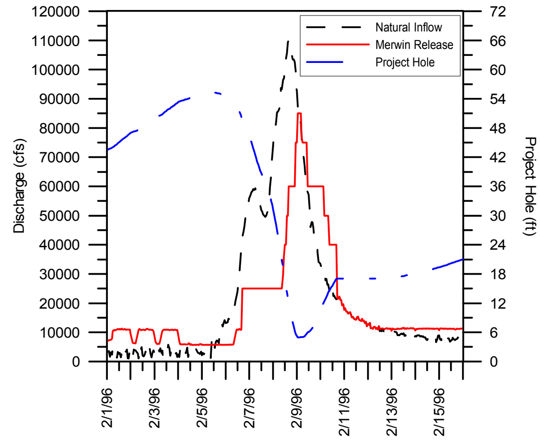
Note: *Control to 60,000 cfs for this scenario was achieved with a modified falling limb operation.

Simulations for Large Historical Floods - Simulations of the 8 largest historical floods were run using the STELLA model to compare existing and modified HRPs with and without pre-releases at 3 starting hole levels – 30, 45, and 60 feet of hole. Simulations for all events were started at the first significant increase in project inflows. Turbines were assumed to operate at maximum nominal capacity (11,500 cfs) through all of these simulations. Results of the historical flood simulations are summarized in Table 11.1-11.

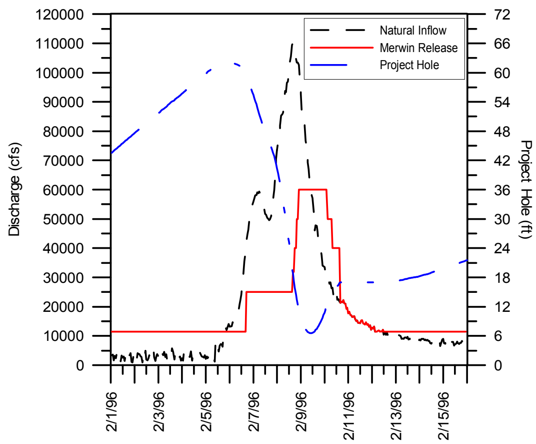
[5] The "falling limb" refers to the receding portion of the flood hydrograph after project inflows have peaked.



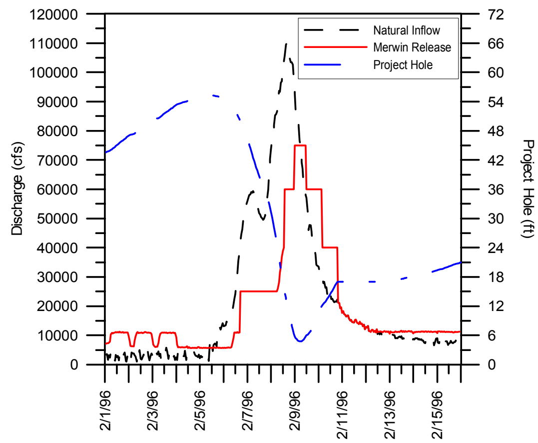
a) 1996 Flood with Existing HRP, Actual Turbine Flow, No Pre-Release



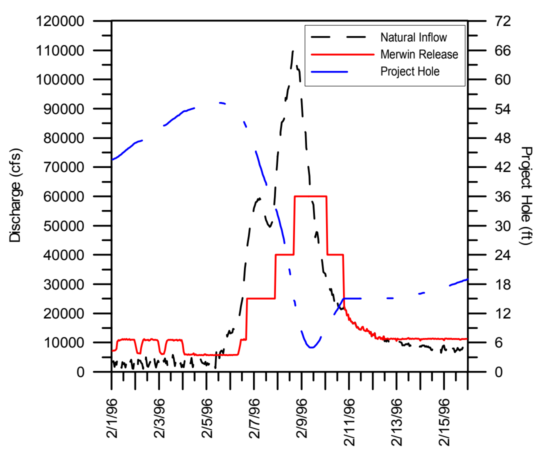
b) 1996 Flood with Existing HRP, Actual Turbine Flow, Normal Pre-Release



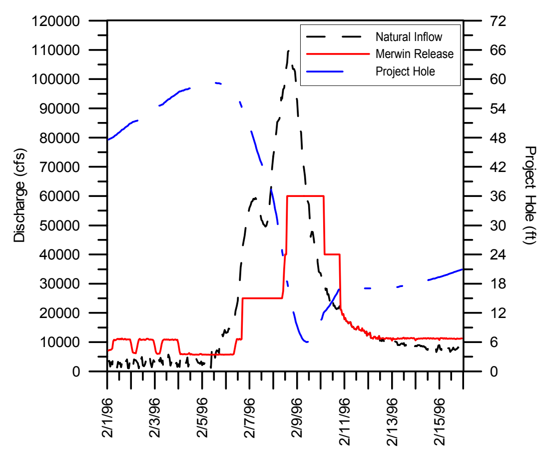
c) 1996 Flood with Existing HRP, Maximum Turbine Flow, Normal Pre-Release



d) 1996 Flood with Modified HRP1, Actual Turbine Flow, Normal Pre-Release



e) 1996 Flood with Modified HRP1, Actual Turbine Flow, Aggressive Pre-Release 1, Modified Falling Limb Rule



f) 1996 Flood with Modified HRP2a, Actual Turbine Flow, Normal Pre-Release

Figure 11.1-9. Simulation results for February 1996 flood under alternative operating policies.

Table 11.1-11. Peak release (cfs) during large historical floods for alternative operating policies and varying starting hole.

Event (Duration)	High Runoff Procedure	Pre-Release Policy	Peak Inflow (cfs)	Starting Hole (feet) 17	21	23.5	30	45	60
December 1917 (288 hr)	Existing HRP	None	91,988	85,000			85,000	85,000	85,000
		Normal					85,000	85,000	75,000
	Modified HRP1	None		75,000			75,000	75,000	75,000
		Normal					75,000	75,000	75,000
	Modified HRP2a	None			60,000				
		Normal					60,000	60,000	60,000
	Modified HRP2b	None				73,602			
		Normal					73,600	73,600	64,400
December 1933 (240 hr)	Existing HRP	None	116,000	90,000			90,000	90,000	90,000
		Normal					90,000	90,000	90,000
	Modified HRP1	None		90,000			90,000	90,000	90,000
		Normal					90,000	90,000	90,000
	Modified HRP2a	None			90,000				
		Normal					90,000	90,000	90,000
	Modified HRP2b	None				90,000			
		Normal					90,000	90,000	90,000
November 1962 (72 hr)	Existing HRP	None	79,227	60,000			50,000	24,450	11,500
		Normal					40,000	25,000	25,000
	Modified HRP1	None		60,000			51,655	27,140	11,500
		Normal					40,000	25,000	25,000
	Modified HRP2a	None			60,000				
		Normal					57,100	25,000	25,000
	Modified HRP2b	None				55,000			
		Normal					55,000	25,000	25,000
January 1972 (120 hr)	Existing HRP	None	76,551	60,000			60,000	50,000	40,000
		Normal					60,000	40,000	25,000
	Modified HRP1	None		60,000			60,000	40,000	40,000
		Normal					60,000	40,000	25,000

Table 11.1-11. Peak release (cfs) during large historical floods for alternative operating policies and varying starting hole (cont.).

Event (Duration)	High Runoff Procedure	Pre-Release Policy	Peak Inflow (cfs)	Starting Hole (feet) 17	21	23.5	30	45	60
	Modified HRP2a	None			60,000				
		Normal					60,000	58,200	25,000
	Modified HRP2b	None				55,000			
		Normal					55,000	55,000	25,000
January 1974 (103 hr)	Existing HRP	None	76,038	60,000			60,000	50,000	47,400
		Normal					60,000	50,000	34,000
	Modified HRP1	None		60,000			60,000	60,000	40,000
		Normal					60,000	42,400	34,000
	Modified HRP2a	None			60,000				
		Normal					60,000	60,000	34,000
	Modified HRP2b	None				55,000			
		Normal					55,000	55,000	34,000
December 1975 (134 hr)	Existing HRP	None	80,262	60,000			60,000	60,000	60,000
		Normal					60,000	60,000	50,000
	Modified HRP1	None		60,000			60,000	60,000	60,000
		Normal					60,000	60,000	59,400
	Modified HRP2a	None			60,000				
		Normal					60,000	60,000	60,000
	Modified HRP2b	None				55,000			
		Normal					55,000	55,000	55,000
December 1977 (144 hr)	Existing HRP	None	82,865	60,000			54,800	40,000	19,500
		Normal					50,000	25,000	25,000
	Modified HRP1	None		60,000			60,000	34,630	19,500
		Normal					60,000	28,200	25,000
	Modified HRP2a	None			60,000				
		Normal					60,000	32,500	25,000
	Modified HRP2b	None				55,000			
		Normal					55,000	40,000	25,000

Table 11.1-11. Peak release (cfs) during large historical floods for alternative operating policies and varying starting hole (cont.).

Event (Duration)	High Runoff Procedure	Pre-Release Policy	Peak Inflow (cfs)	Starting Hole (feet) 17	21	23.5	30	45	60
February 1996 (144 hr)	Existing HRP	None	110,035	85,000			85,000	85,000	85,000
		Normal					85,000	85,000	75,000
	Modified HRP1	None		85,000			85,000	85,000	81,800
		Normal					85,000	85,000	75,000
	Modified HRP2a	None			85,000				
		Normal					85,000	85,000	60,000
	Modified HRP2b	None				85,000			
		Normal					85,000	85,000	55,000

Notes: Normal Pre-Release is 25,000 cfs for inflows greater than 40,000 cfs
Turbine flow of 11,500 cfs was assumed for each scenario

With the exception of the 3 largest events (December 1933, February 1996, and December 1917) all project releases were controlled at or below 60,000 cfs (or 55,000 cfs for Modified HRP2b) in all scenarios. The December 1917 event was controlled at best to 75,000 cfs except under Modified HRP2a where control to 60,000 cfs was achieved. The February 1996 event was controlled at best to 75,000 cfs except under Modified HRP2a (60,000 cfs) and Modified HRP2b (55,000 cfs) with 60 feet of starting hole. (Note that the "historical simulations" for the February 1996 flood were started at the first significant increase in project inflows, early on February 6, 1996. The simulations specific to the 1996 flood described earlier assumed a start date for simulation of February 1, 1996 with actual observed or estimated hole as of that date). The peak release for the December 1933 event (90,000 cfs) was not reduced in any scenario.

Simulations of the alternative operating policies considered here show that pre-releases and modification of operating policies with existing dependable storage results in reductions in damaging flow rates under certain scenarios. The Modified HRP1 by itself (i.e. with no pre-release) reduces peak flows in the December 1917 event by 10,000 cfs (from 85,000 to 75,000 cfs), irrespective of starting hole. The Modified HRP1 with Normal Pre-Release also reduces peak flows in the February 1996 event by up to 10,000 cfs (from 85,000 to 75,000 cfs) for the scenario with starting storage of 60 feet of hole. Further reductions in peak flows in the historic events are achieved by increases in dependable flood control storage under Modified HRP2a and HRP2b.

While mandatory flood control storage currently amounts to 17 feet of hole (70,000 acre-feet of storage), considerable additional incidental flood control storage is generally available in the winter months as a result of power generation operations. This is demonstrated in Figure 11.1-10, which shows duration exceedence data for total project hole for the months November through February (the months with greatest flood risk) based on data from water years 1991 through 2001. Figure 11.1-10 shows, for example, that, over the past decade, the project hole exceeded 50 feet about 50 percent of the time in the period November through February. The hole actually available for flood control operations is thus commonly in the range of, or greater than, the hypothetical starting holes assumed for simulation of these large historical events.

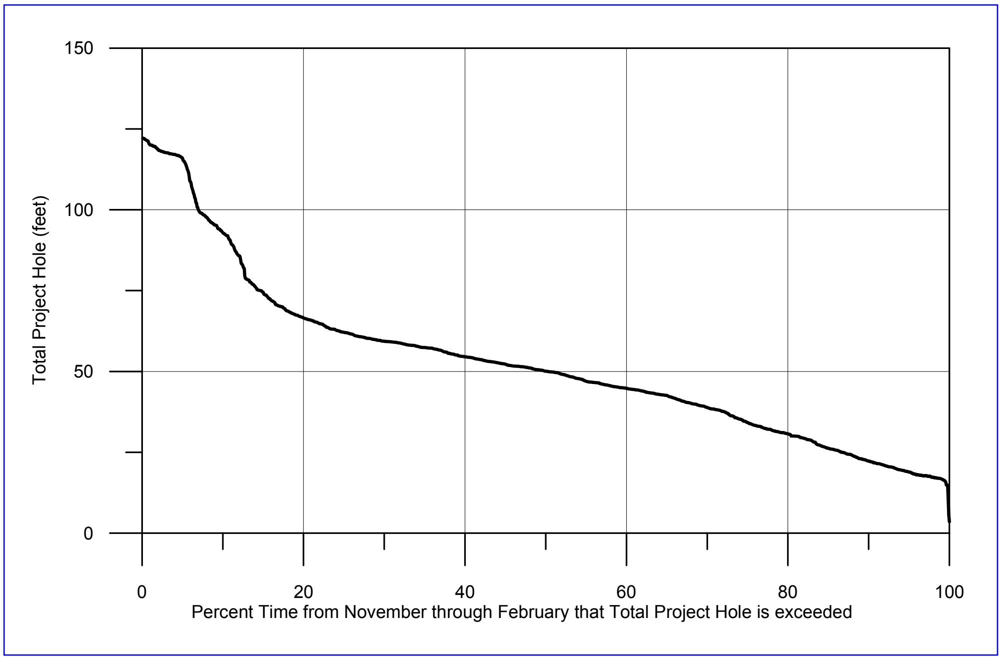


Figure 11.1-10. Duration exceedance curve of total project hole from November through February, water years 1991-2001.

Simulations for Moderate Historical Floods – While the emphasis in this study is on control of large damaging floods, the effects of alternative flood control operations on flow regimes and project water levels during more frequent moderate flood events is also of interest. Additional STELLA simulations were therefore performed to investigate the effects of alternate project operations for 6 recent moderate floods (November 1990, November/December 1995, December 1996/January 1997, November 1998, December 1998/January 1999, and November 1999). Simulations were performed for each event assuming actual turbine flows and actual starting hole for a total of 6 scenarios:

- Existing HRP with and without Normal Pre-Release (2 scenarios).
- Existing HRP with Aggressive Pre-Release 1.
- Modified HRP1 with and without Normal Pre-Release (2 scenarios).
- Modified HRP1 with Aggressive Pre-Release 1.

Results of the STELLA model simulations are summarized in Table 11.1-12 and are plotted for selected scenarios in Figure 11.1-11.

The simulations for moderate events show that modification of flood control policies by adoption of pre-releases could result in an increase in peak flows. For the November 1998 event, the actual starting hole was such that the entire flood could be absorbed by the available storage under the existing operating policies without discharges exceeding the maximum turbine capacity (Figure 11.1-11a). Adoption of a Normal Pre-Release policy not only would have resulted in an increase in peak flows (to 25,000 cfs), but also would have resulted in a larger ending hole (Figure 11.1-11b). In this particular case, water was spilled which in retrospect need not have been spilled. Impacts on power generation are two-fold – spill of water which could have been used for generation, and a modest reduction in available head. The increased ending hole also indicates a slight increase in risk of being unable to re-fill the reservoirs in dry years.

A somewhat similar situation arises in November 1999. This event had a relatively high peak inflow (over 64,000 cfs) but a relatively small volume. The existing operating policy resulted in a peak release of about 27,300 cfs and an ending hole at the minimum mandatory flood control storage of 17 feet (Figure 11.1-11c). Adoption of Aggressive Pre-Release 1 (Figure 11.1-11d) increased the peak release to 40,000 cfs and again resulted in an increased ending hole.

The reallocation of flood control storage to dedicate more storage to control of flows to 60,000 cfs under Modified HRP1 was also found to result in increased peak outflows. In November 1995, the peak outflow under the Existing HRP was 50,000 cfs. Adoption of Modified HRP1 in which the 50,000 cfs release level is dropped, resulted in an increase in peak outflow to 58,200 cfs (Table 11.1-12). The apparently odd release amount (58,200 cfs instead of 60,000 cfs), reflects a requirement that releases on the rising limb of the release hydrograph be no more than the natural inflow.

Notification and Warnings

Significant improvements in warning and notification procedures have been made since the February 1996 flood. These include improved real-time instrumentation (e.g., installation of the telemetered stage gage at the County Bridge in Woodland), improved dissemination of information via the internet, and improved flow forecast procedures implemented by the National Weather Service. Significant further improvement in flow forecasting is largely dependent on improvements in quantitative precipitation forecasts. Such improvements are the subject of basic and applied scientific research which may take years or decades to come to fruition and which is considerably beyond the scope of this study.

As noted earlier in Section 11.1.5.2, the National Weather Service, Clark County and Cowlitz County issue flood notifications and warnings via cable and broadcast television and radio stations. The greatest single deficiency in the current notification system is that parts of the Lewis River valley lie in a reception shadow and cannot receive radio and television broadcasts.

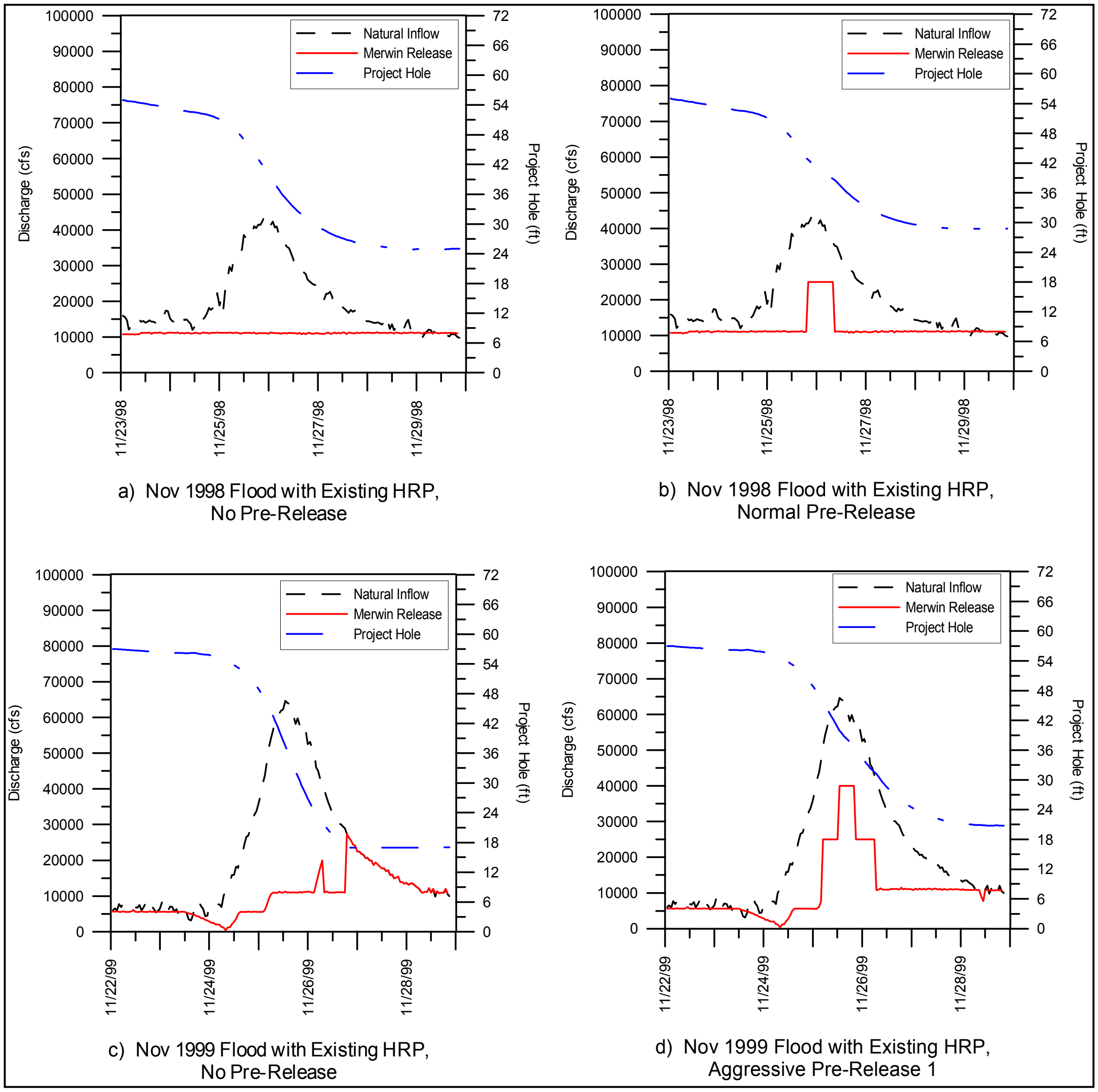


Figure 11.1-11. Simulation results for moderate floods with and without pre-release policies.

Table 11.1-12. Peak release (cfs) and ending project hole (feet) during moderate floods for alternative operating policies.

Event (Duration)	High Runoff Procedure	Pre-Release Policy	Peak Inflow (cfs)	Starting Hole (feet)	Peak Release (cfs)	Ending Hole (feet)
November 1990 (168 hr)	Existing HRP	None	57,427	37	37,600	17.0
		Normal			37,600	17.0
		Aggressive			37,600	17.0
	Modified HRP1	None			34,800	17.0
		Normal			34,800	17.0
		Aggressive			34,800	17.0
November/ December 1995 (213 hr)	Existing HRP	None	58,331	25	50,000	17.0
		Normal			50,000	17.0
		Aggressive			50,000	17.0
	Modified HRP1	None			58,200	17.00
		Normal			58,200	17.00
		Aggressive			58,200	17.00
December/ January 1996/1997 (261 hr)	Existing HRP	None	49,121	56	37,100	17.0
		Normal			34,600	17.0
		Aggressive			34,600	17.0
	Modified HRP1	None			37,100	17.0
		Normal			34,600	17.0
		Aggressive			34,600	17.0
November 1998 (165 hr)	Existing HRP	None	43,828	55	11,300	25.0
		Normal			25,000	28.8
		Aggressive			25,000	28.8
	Modified HRP1	None			11,300	25.0
		Normal			25,000	28.8
		Aggressive			25,000	28.8
December/ January 1998/1999 (213 hr)	Existing HRP	None	43,167	35	38,600	17.0
		Normal			38,300	17.0
		Aggressive			38,300	17.0
	Modified HRP1	None			36,800	17.0
		Normal			35,700	17.0
		Aggressive			35,700	17.0
November 1999 (165 hr)	Existing HRP	None	64,631	57	27,300	17.0
		Normal			25,000	18.8
		Aggressive			40,000	21.0
	Modified HRP1	None			27,100	17.0
		Normal			25,000	18.8
		Aggressive			40,000	21.0

Notes: Starting hole was actual starting hole.
Simulations based on actual turbine flows.

Several approaches to improving receipt of warnings have been investigated by PacifiCorp, Clark County, Cowlitz County, and the National Weather Service. The following possible solutions have been identified:

- Construction of additional transmitter or repeater stations to serve areas now in the reception shadow.
- Implementation of a reverse 911 system.
- Construction of a system of sirens.

To be fully effective, construction of additional transmitter or repeater stations would need to cater to both NOAA Weather Radio and local radio and television stations. At present, many local radio and television stations are not staffed at night and have no capability for automatic transmission of notifications or warnings. If additional transmitter or repeater stations are provided, then information would also need to be provided to the public regarding what frequencies to monitor during potential flooding conditions. The primary disadvantage of relying on broadcast media for notification or warnings is that conventional radios or televisions have to be on and the appropriate channel or frequency has to be monitored for the warning to be received. This problem is avoided with NOAA Weather Radio receivers, which can be turned on automatically by means of the broadcast signal.

In a reverse 911 system, recorded warnings would be transmitted via an automatic telephone system to those within an identified hazard area. In concept, the scheme would work as follows: emergency managers would map the geographic area to receive warnings, GIS techniques would be used to identify all telephones within the warning area, the reverse 911 system would then place a call to all numbers within the hazard area. The system can place large numbers of calls (of the order of hundreds per minute) in a short period of time. This geographic based system does not handle cell phones, which in any event are also affected by the reception shadow in the Lewis River valley. The reverse 911 system is of considerable interest to the county emergency service agencies in that it provides the potential for issuing warnings on a county-wide basis for all hazards– it would not be restricted to weather-related problems along the Lewis River.

In the past, consideration has been given to the use of sirens to provide warning. However, sirens suffer from a number of drawbacks, including high initial and ongoing maintenance cost, and the significant effort required in public education. The public would need to be educated as to both the meaning of a siren and the appropriate response. Local experience with sirens (which are used for warnings of chemical spills in the industrial areas of Cowlitz County and which were part of the warning system for the Trojan Nuclear Plant before it was decommissioned) has been problematic. Sirens provide no explicit information on the meaning of the warning, and have been found to prompt numbers of 911 calls which are so great as to potentially jeopardize the integrity of the 911 system. While it is technically feasible to provide a siren system specifically to provide flood warnings on the Lewis River, such a system is not favored by the responsible emergency management services.

Further improvements in project operations would be possible through improved monitoring of stream flow and meteorological conditions. Of particular interest would be improvements in monitoring or estimating natural inflows on a real-time or near real-time basis. Specific gage sites or techniques for improving estimates have, however, not been identified.

There has been demand in the recent past for greater public access to information on stream flow and reservoir conditions. Near real-time streamflow data are available from several gage sites, including the Lewis River at Ariel, via the Portland Weather Forecast Office web site at www.wrh.noaa.gov/portland./public_hydro. Real-time or near real-time reservoir pool elevation and storage data are available on the same web site. Information on the total release from Merwin Dam is also available via telephone dial-in to the flow information recording at the Merwin Hydro Control Center. Consideration should be given to providing additional information on this recording as follows: the time at which the recording was last updated; the time at which the last change in Merwin release was made; and the release rate prior to the last change.

Land Use Regulations and Public Outreach

The above sections focused on alternative flood control operating policies as a means of reducing peak flows and hence flood hazard in the Lewis River valley. Flood hazard below Merwin Dam could also be reduced through a variety of regulatory and institutional actions which reduce the exposure of people and property to floods through controls on development in the floodplain and through improved public awareness of flood risk.

Development within the Lewis River valley is regulated by Clark County, Cowlitz County and the City of Woodland to meet the minimum requirements established under the National Flood Insurance Program. These requirements essentially prohibit development within the regulatory floodway and require that new structures built within the 100-year floodplain outside the floodway have finished floor elevations one foot above the 100-year water surface elevation.

Encroachment on floodplains, such as by structures and fill, reduces flood-carrying capacity, increases water surface elevations and flow velocities, and increases flood hazards in areas beyond the encroachment itself. One aspect of floodplain management involves balancing the economic gain from floodplain development against the resulting increase in flood hazard. For the purposes of the National Flood Insurance Program, a floodway is used as a tool to assist local communities in floodplain management. Under this concept, the area of the 100-year floodplain is divided into a floodway and a floodway fringe, the floodway fringe being the area between the floodway and the 100-year floodplain boundary. The floodway is defined as the channel of the river plus any adjacent floodplain areas that must be kept free of encroachment such that the 100-year flood can be carried without increasing the water surface elevation at any point by more than a designated amount in the event that the floodway fringe is completely obstructed[6]. The minimum Federal standards limit such water surface elevation increases to 1.0 foot. The "one-foot rise floodway" (the minimum regulatory standard) has been adopted by

[6] Floodway definitions in this section are based on discussions contained in FEMA's guidelines for flood insurance studies (FEMA 1991), and the flood insurance study for Cowlitz County (FEMA 1995).

Clark County, Cowlitz County and the City of Woodland. The current 100-year regulatory floodplain and associated floodway for the Lewis River is described in the most recent flood insurance studies for the 2 counties and the City of Woodland.

While the current standards provide a significant measure of protection from flood damage and flood hazard, several regulatory and non-regulatory actions could be taken to reduce current hazards and to further limit new development in potentially hazardous locations:

- *Update 100-year regulatory floodplain maps:* Analyses conducted for this study indicate that current floodplain maps significantly understate flood hazard in the lower part of the Lewis River from the County Bridge in Woodland to the confluence with the Columbia River. The maps currently used for regulatory purposes should be updated.

- *Adopt a more stringent floodway definition:* The local communities have adopted a one-foot rise floodway which is the minimum standard acceptable under the National Flood Insurance Program. A more stringent definition could be adopted, for example a 0.5-foot rise or a zero rise floodway. More stringent floodway definitions have been adopted in several jurisdictions in the Pacific Northwest (e.g., King County, Washington has adopted a zero-rise floodway). Adoption of a more stringent floodway standard would widen the current floodway and reduce the area of floodway fringe available for new development. Development might still be allowed within the zero-rise floodway, provided it could be demonstrated that there would be no impact on flood levels. Note that floodway definitions are somewhat generalized in nature and do not directly address the problem of development in hazardous locations.

- *Adopt regulations to prohibit development in hazardous locations:* Further control of development in hazardous locations could be achieved through adoption of regulations which prohibit development in areas where flood flows are deep and/or fast. Such a regulation may, for example, prohibit development where the sum of the flow depth (in feet) and the velocity (in ft/sec) is greater than 6. A regulation of this general type has been adopted in Pierce County, Washington.

- *Clarify development standards regarding building elevations in areas adjoining but outside the 100-year floodplain:* Development standards should require that buildings in areas adjoining but outside the 100-year floodplain have finished floor elevations at least 1.0 foot above the 100-year water surface elevation. This would result in a consistent level of flood protection throughout the Lewis River valley.

- *Revise building standards as necessary to reduce flood damage:* Building standards should be reviewed and revised where appropriate to limit flood related damage to both residential buildings and critical infrastructure. Consideration should be given to a requirement that the lowest floors of critical buildings be 2 feet above the 100-year water surface elevation.

- *Egress requirements:* Consideration should be given to a requirement that all roads accessing new development be elevated to within 0.5 feet of the 100-year water surface elevation, or similar depth which would allow safe egress.

- *Flood proofing and buy-out of high-hazard property:* A buy-out program should be investigated for properties in high-hazard locations and for properties suffering frequent flood damage. A program to assist in flood proofing of other properties should be considered. A buy-out program could be funded in part through the Hazard Mitigation Grant Program administered by the Washington State Department of Emergency Management.

- *Public outreach:* Public understanding and appreciation of flood risk within the Lewis River valley could be improved through an on-going program of public outreach. Flood damage in future events could be reduced if the public were kept aware of flood risk and measures that individuals can take to reduce flood damage. In particular, the public should be informed of ways in which flood warnings can be accessed or received.

These and other actions to reduce flood risk should be investigated in more detail in a comprehensive floodplain management plan for the Lewis River valley. Funding for plan development may be available through the Flood Control Assistance Program (FCAP) administered by the Washington State Department of Ecology.

11.1.6 Discussion

The analyses conducted for the Flood Management Study provide an update to both the projects' current flood control capabilities and a reassessment of the level of protection provided by the projects in light of the additional 20 years of hydrologic data collected since the last comprehensive analysis. Analyses of available bathymetric data demonstrate that sedimentation (particularly associated with the eruption of Mount St. Helens) has not affected the projects' flood storage capabilities. However, analysis presented here, based on data from the 1996 flood, indicate that the existing flood insurance maps for the lower Lewis River understate flood risk. Updated 100-year inundation maps, which could form the basis for revised flood insurance maps, are included in this report (Figures 11.1-3).

Analyses presented in the study also provide approximate data on flow/hazard relationships and threshold levels at which flooding of egress routes occur. The analyses generally confirm that flood damage to residential structures does not occur until project releases reach or exceed 60,000 cfs. Analyses and surveys of egress routes indicates that flood control pre-releases of 25,000 cfs could be made from Merwin Dam without damage or significant inconvenience to valley residents. More detailed surveys during actual high water conditions should be made to confirm this finding.

Considerable effort was expended in the work described here in investigating alternative flood control operating policies. One of the principal goals of this study was to investigate operating policies which could control a repeat of the flood of February 1996 to non-damaging levels. Several alternative operating policies have been identified which meet this goal, as follows:

- Existing High Runoff Procedures (HRP) with maximum turbine flows (minimum releases conditioned on snow pack) with Normal Pre-Release (release 25,000 cfs for inflows in excess of 40,000 cfs).

- Modified HRP1 with existing dependable flood control storage and maximum turbine flows (minimum releases conditioned on snow pack) with Normal Pre-Release (release 25,000 cfs for inflows in excess of 40,000 cfs).

- Modified HRP1 with existing dependable flood control storage and actual turbine flows with Aggressive Pre-Release 1 (release 25,000 cfs for inflows in excess of 40,000 cfs, and release 40,000 cfs for inflows in excess of 60,000 cfs) with modified falling limb operating policy (operate project at higher levels on the recession limb of flood hydrographs).

- Modified HRP1 with existing dependable flood control storage and actual turbine flows with Aggressive Pre-Release 2 (release 25,000 cfs for inflows in excess of 40,000 cfs, and release 40,000 cfs for inflows in excess of 50,000 cfs).

- Modified HRP2a with dependable flood control storage increased from 70,000 acre-feet to 86,500 acre-feet and actual turbine flows with Normal Pre-Release (release 25,000 cfs for inflows in excess of 40,000 cfs).

- Modified HRP2b (provides control to 55,000 cfs) with dependable flood control storage increased from 70,000 acre-feet to 96,800 acre-feet and actual turbine flows with Normal Pre-Release (release 25,000 cfs for inflows in excess of 40,000 cfs).

The following points should be noted:

- While conditioning a flood control operating policy on the presence of low elevation snow pack is beneficial in a repeat of the February 1996 flood, the relationship between low elevation snow pack and large floods is relatively weak and this policy may not produce significant benefit in other large floods.

- None of the policies examined reduced peak flows in a repeat of the December 1933 flood below those achieved by the Existing HRP. Control of this event to non-damaging levels would require a starting hole of about 80 feet (over 320,0000 acre-feet of storage).

- From simulations of moderate floods, it is apparent that adoption of a pre-release policy could result in a situation where the pre-release is greater than the maximum project release which would have otherwise been made. In the case of a Normal Pre-Release at 25,000 cfs, this would cause minimal damage and inconvenience. However, an Aggressive Pre-Release at 40,000 cfs would result in flooding of egress routes and potential flood damage to low lying land and out-buildings. No residential flooding would occur at this release rate.

Procedures in place for flood forecasting and coordination of operations between PacifiCorp, the National Weather Service and the County emergency management services are to a relatively high standard and are comparable to procedures in place for other areas at flood-risk in the Pacific Northwest. Dissemination of notification and warnings to Lewis River valley residents is, however, severely hampered by the lack of adequate transmitter or repeater stations for broadcasts via radio and television, including NOAA weather radio. The availability of information to the public has improved since the February 1996 flood with installation of additional telemetered gauges on the river and reporting of that data in real-time or near real-time on the internet.

11.1.7 Schedule

The Flood Management Study is complete.

11.1.8 References

Clark County Water Quality Division. 1996. Clark County Flood Report: Flooding of February 8, 1996. Technical Appendix Section 3: American Red Cross Association; List of Flooded Residences, Vancouver, Washington.

FEMA (Federal Emergency Management Agency). 1991. Flood Insurance Study Guidelines and Specifications for Study Contractors. March 1991.

FEMA. 1995. Flood Insurance Study, Cowlitz County, Washington, revised June 2, 1995, p. 57.

Hansen, E.M., D.D. Fenn, P. Corrigan, J.L. Vogel, L.C. Schreiner, and R.W. Stodt. 1994. Probable maximum precipitation – Pacific Northwest states, *Hydrometeorological Report Number 57*, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Silver Spring, MD.

PacifiCorp. 1994. Standard Operating Procedures: Lewis River Hydroelectric Projects High Runoff Operation. Portland, OR. November 1994.

Sumioka, S.S., D.L. Kresch, and K.D. Kasnick. 1998. Magnitude and frequency of floods in Washington, U.S. Geological Survey Water-Resources Investigations Report 97-4277, Tacoma, Washington.

11.1.9 Comments and Responses on Draft Report

This section presents stakeholder comments provided on the draft report, followed by the Licensees' responses. The final column presents any follow-up comment offered by the stakeholder and in some cases, in italics, a response from the Licensees.

Commenter	Volume	Page/ Paragraph	Statement	Comment	Response	Response to Responses
J. Sampson, Technical Advisor to the Conservation Groups	3	FLD 01-57, 58 para 2 and bullets	"Several alternative operating policies have been identified which meet this goal…"	Changes in the flow regime downstream of Merwin dam, including pre-releases of 25,000 cfs for flood control and maintenance of greater storage capacities, have a high potential for changing ecological attributes of the lower river, including: ▪ Processes of habitat development in the channel, and in the riparian zone. ▪ Water temperatures in the reservoirs, and in the river downstream of the projects. ▪ Availability of nutrients to support primary and secondary production in the reach downstream of the Merwin project. ▪ The frequency and temporal distribution of high, mid-level, and low floods in the channel downstream of Merwin dam. ▪ Timing of in-migrations and out-migrations of anadromous species, and the timing of other life history attributes such as egg	*Impacts on Flow Regime* A number of possible modifications to flood management operations are discussed in the Technical Report. Potential changes in the flow regime below Merwin Dam due to modified flood management operations include pre-release policies and either reallocation of existing or increased mandatory flood control storage. Analyses conducted to date and reported in the Flood Management Study have focused mostly on the effects of alternate flood management operations on large and potentially damaging floods having historic releases from Merwin Dam of 60,000 cfs and larger. The effects of alternate operating policies on large infrequent events (recurrence interval of 10 years or greater) are summarized in Tables 11.1-10 and 11.1-11. The impact of	

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				development and fry emergence. The likelihood and degree of specific changes in these attributes must be described, quantitatively where possible, before these flood control measures can be effectively negotiated by the settlement team. Moreover, the effects of changes to these attributes on Analysis Species (Table 4.1-1, p. AQU1-1) must also be described in detail. Graphics that have been provided which illustrate flood hydrographs below the Merwin Project (Figures 11.1-9 and 11.1-11) should be used in this discussion. The following scientific literature should be employed in this analysis (as cited by Richter et al. 1997. How much water does a river need? *Freshwater Biology* 37:231-249): Arthington et al. 1991; Bruwer and Ashton 1989; Calow and Petts 1992; Castleberry et al. 1996; Cushman 1985; Hill et al. 1991; Moog 1993; Morgan et al. 1994; Nilsson et al. 1991; Poff and Ward 1989; Resh et al 1988; Sparks 1995; Stanford and Ward 1992; Stanford et al. 1996; Ward and Stanford 1995. This analysis should include consultations with academic experts	alternate operating policies on large floods is relatively modest. Several operating scenarios are presented which result in control of a repeat of the February 1996 flood to 60,000 cfs. However, no scenarios showed improvement in control of the December 1932 flood over the level achievable with the current high runoff procedures. Under all scenarios examined to date (including the current operations), the 10-year peak discharge would remain in the range of 55,000 to 60,000 cfs, while the 100-year peak discharge would remain unchanged at about 90,000 cfs. Peak flows with a return period between about 20 and 50 years would be reduced in magnitude to about 60,000 cfs, the estimated non-damaging release from Merwin Dam. It is our opinion that changes in the magnitude and frequency of large floods (those with project releases of 55,000 cfs or greater) would have no impact on ecosystem functions downstream from Merwin Dam. Limited analyses of the effects of alternate flood management	

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				such as Dr. Jack Stanford of the University of Montana, and government experts, such as Dr. Tim Beechie, Dr. Michael Pollock, and George Pess of the Northwest Fisheries Science Center of the National Marine Fisheries Service. Alterations to the structure and function of the lower river ecosystem which result from each of the flood management alternatives must be described <u>in the Technical Report</u>. Please see the letter from the Conservation Groups to the Licensees dated March 6, 2002.	operations on smaller events are described in the Flood Management Study (Table 11.1-12 and Figure 11.1-11). Detailed analyses to determine the effects of alternate operations on the frequency and duration of these smaller, less damaging flows have, however, not yet been conducted. Such analyses will be done in the coming months, making use of the recently developed operations model. Additional discussion of pre-release policies is provided below. *Impacts on Water Quality* Potential modifications to flood management procedures are limited to the winter flood management season, November through March. During this period, project reservoirs are isothermal and well mixed. Furthermore, reservoir water level regimes during the flood management season are determined more by operations for power generation than by flood management operations (see for example Figure 11.1-10 of the Flood Management Study). Hence no impacts to either water temperature or	

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					nutrient availability are expected either in the reservoirs or downstream from Merwin Dam due to modified flood management procedures. Potential increases in TDG as a result of pre-release spill will be addressed in the Water Quality Management Plan to be developed by the Licensees in cooperation with WDOE. *Effects on Gravel Transport and Stream Morphology* Analyses presented in the Flood Management Study have examined pre-releases of 25,000 cfs and 40,000 cfs. The available hydrologic record indicates that under the assumptions of the Flood Management Study, pre-releases at 25,000 cfs would occur about once a year on average with an average duration of between 12 and 24 hours. Under the current operating procedures, the regulated peak flow below Merwin Dam is about 12,000 cfs (the nominal turbine capacity) for return intervals of 1.5 years and less, increasing to about 20,000 cfs at a return interval of 2 years. By way of contrast, the	

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					unregulated peak flow (i.e. under natural conditions) was about 35,000 cfs at a 1.5-year return interval, increasing to about 42,000 cfs at a 2-year return interval. Assuming that channel-forming discharges fall in the range of the natural 1.5- to 2-year peak flows, adoption of the pre-release policy would result in a somewhat more natural flow regime with more frequent redistribution of sediments. Note also that the pre-releases would be triggered by high project inflows and would thus mimic the timing of natural flood flows. The 25,000 cfs pre-release is close to the flow predicted and observed to transport spawning-sized gravel below Merwin Dam (30,000 cfs, page WTS 3-112). A pre-release policy that results in flows of 25,000 cfs on an average annual basis may result in transport of gravel through the reach downstream of Merwin Dam at an accelerated rate compared to the existing flood management procedures. Further monitoring to identify	

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					whether or not spawning gravel is being transported at proposed pre-release rates may be required in order to determine whether those release rates are acceptable. *Effects on Riparian Habitat* A 25,000 cfs pre-release for flood management has the potential for changing the processes of habitat development in the riparian zone below Merwin Dam. Creation of new bars or exposed substrates may favor the development of cottonwood stands. In addition, flows at this rate could introduce more LWD and sediment into this reach and may result in the formation of log jams which contribute to floodplain development if left undisturbed for a long enough period of time. However, it is likely that any large accumulations of wood would be removed from the river by boaters to provide for continued boating use. Any changes in ecological processes must be viewed in terms of existing and continued land management practices along the lower river.	

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					Effects on Anadromous Fish Species As noted above, the adoption of a pre-release policy during the flood management season would result in a somewhat more natural flow regime. Pre-releases would be triggered by high project inflows and would thus tend to mimic the timing of natural flood flows. Anadromous salmonid life histories have adapted over thousands of years to take advantage of these relatively frequent high flow events. Juvenile salmon and steelhead outmigration generally peaks during periods of high flow. Upstream migration of adult salmon and steelhead is also triggered by high flow events. These high flow events allow adult salmon and steelhead to reach spawning habitat that may not be accessible at lower flows. Flows up to 25,000 cfs (roughly a 2-year flow under regulated conditions) are not expected to cause substantial scour of gravel substrates below Merwin Dam, nor are they expected to substantially alter water temperatures. Because of this, little impact is expected to occur	

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					to either egg development or fry emergence. As noted, above, however, the pre-release rate of 25,000 cfs is close to the flow predicted to transport spawning-sized gravel below Merwin Dam and further monitoring of gravel transport may be required.	