FLOOD HAZARD ASSESSMENT OF THE HOH RIVER AT OLYMPIC NATIONAL PARK RANGER STATION, WASHINGTON

By David L. Kresch

With a section on Debris Flow and Landslide
Hazard Assessment, by Thomas C. Pierson

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[Plate in back cover pocket]

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CONVERSION FACTORS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter
	2.540	centimeter (cm)
	0.0254	meter (m)
foot (ft)	0.3048	meter (m)
yard (yd)	0.9144	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	28.32	liter per second (L/s)
cubic yard (yd^3)	0.7646	cubic meter (m^3)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada formerly called mean sea level.

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ABSTRACT

Federal regulations require buildings and public facilities on Federal land to be located beyond or protected from inundation by a 100-year flood. Flood elevations, velocities and boundaries were determined for the occurrence of a 100-year flood through a reach, approximately 1 mile long, of the Hoh River at the ranger station complex in Olympic National Park. Water-surface elevations and flow velocities were also determined for 10- and 50-year floods. Peak 10-, 50-, and 100-year flood discharges of 24,000, 31,000, and 35,000 cubic feet per second, respectively, were estimated from regional regression equations using drainage area and mean annual precipitation as independent parameters.

Flood elevations, estimated by step-backwater analysis of the 100-year flood discharge through 14 channel and flood-plain cross sections of the Hoh River, indicate that the extent of flooding in the vicinity of buildings or public facilities at the ranger station complex is likely to be limited mostly to two historic meander channels that lie partly within loop A of the public campground and that average flood depths of about 2 feet or less would be anticipated in these channels. Mean flow velocities at the cross sections, corresponding to the passage of a 100-year flood, ranged from about 5 to over 11 feet per second. Flooding in the vicinity of either the visitors center or the residential and maintenance areas is unlikely unless the small earthen dam at the upstream end of Taft Creek were to fail.

Debris flows with volumes on the order of 100 to 1,000 cubic yards could be expected to occur in the small creeks that drain the steep valley wall north of the ranger station complex. Historic debris flows in these creeks have generally traveled no more than about 100 yards out onto the valley floor. The potential risk that future debris flows in these creeks might reach developed areas within the ranger station complex is considered to be small because most of the developed areas within the complex are situated more than 100 yards from the base of the valley wall.

Landslides or rock avalanches originating from the north valley wall with volumes potentially much larger than those for debris flows could have a significant impact on the ranger station complex. The probability that such landslides or avalanches may occur is unknown. Inspection of aerial photographs of the Hoh River valley revealed the apparent presence, along the ridge crest of the north valley wall, of ridge-top depressions--geologic features that are sometimes associated with the onset of deep-seated slope failures. However, evaluation of the potential landslide hazard associated with these depressions would require an onsite examination of the area by trained personnel. Such an effort was outside the scope of this study.

INTRODUCTION

Buildings and public facilities either constructed on Federal lands or financed with Federal funds are required by Federal regulation to be located beyond or protected from damage by a 100-year flood. The Hoh River ranger station complex, located in Olympic National Park in northwestern Washington, has many buildings and public facilities that are subject to this Federal regulation. Located within the ranger station complex are a visitors center, a residential area that contains several housing units, a maintenance area with workshop and utility buildings, and a public campground that contains nearly 100 campsites. The U.S. Geological Survey, in cooperation with the National Park Service, began a study to determine flood elevations, extent of inundation, and mean flow velocities that may result at the ranger station complex from a 100-year flood on the Hoh River. In addition to the study of a 100-year flood, water-surface elevations and flow velocities were also determined for 10- and 50-year floods on the Hoh River for use by the National Park Service in planning for potential mitigation measures and maintenance needs that might arise from the occurrence of these intermediate-sized floods.

This report presents the results of this study and the results of a separate reconnaissance made to assess the potential hazards at the ranger station complex from debris flows and landslides originating from the north wall and ridge of the Hoh River valley.

DESCRIPTION OF STUDY AREA

The Hoh River flows in a generally westwardly direction from its headwaters at Mount Olympus in the Olympic Mountains to its mouth at the Pacific Ocean. The study area, located about 6 miles inside the western boundary of Olympic National Park (fig. 1), consists of a reach of the Hoh River channel and flood plains about 1 mile long, that extends both upstream and downstream from the ranger station (pl. 1). The north bank flood plain, which is where the ranger station is located, has been developed within the study area; however, the south bank flood plain is undeveloped and uninhabited, and there is no road or bridge access to it.

The Hoh River channel in the vicinity of the ranger station complex has an average width of 700 feet and an average depth of 5 feet. During low-flow periods the channel is braided and the average total width of all flowing channels averages about 150 feet. The bed material consists mostly of gravel, cobbles and small boulders. The major topographic feature on the north bank flood plain throughout the upstream two-thirds of the study area is a steep-faced terrace with heights ranging from about 4 feet to over 10 feet. The downstream portion of the north bank flood plain appears to contain a series of small, old meander channels.

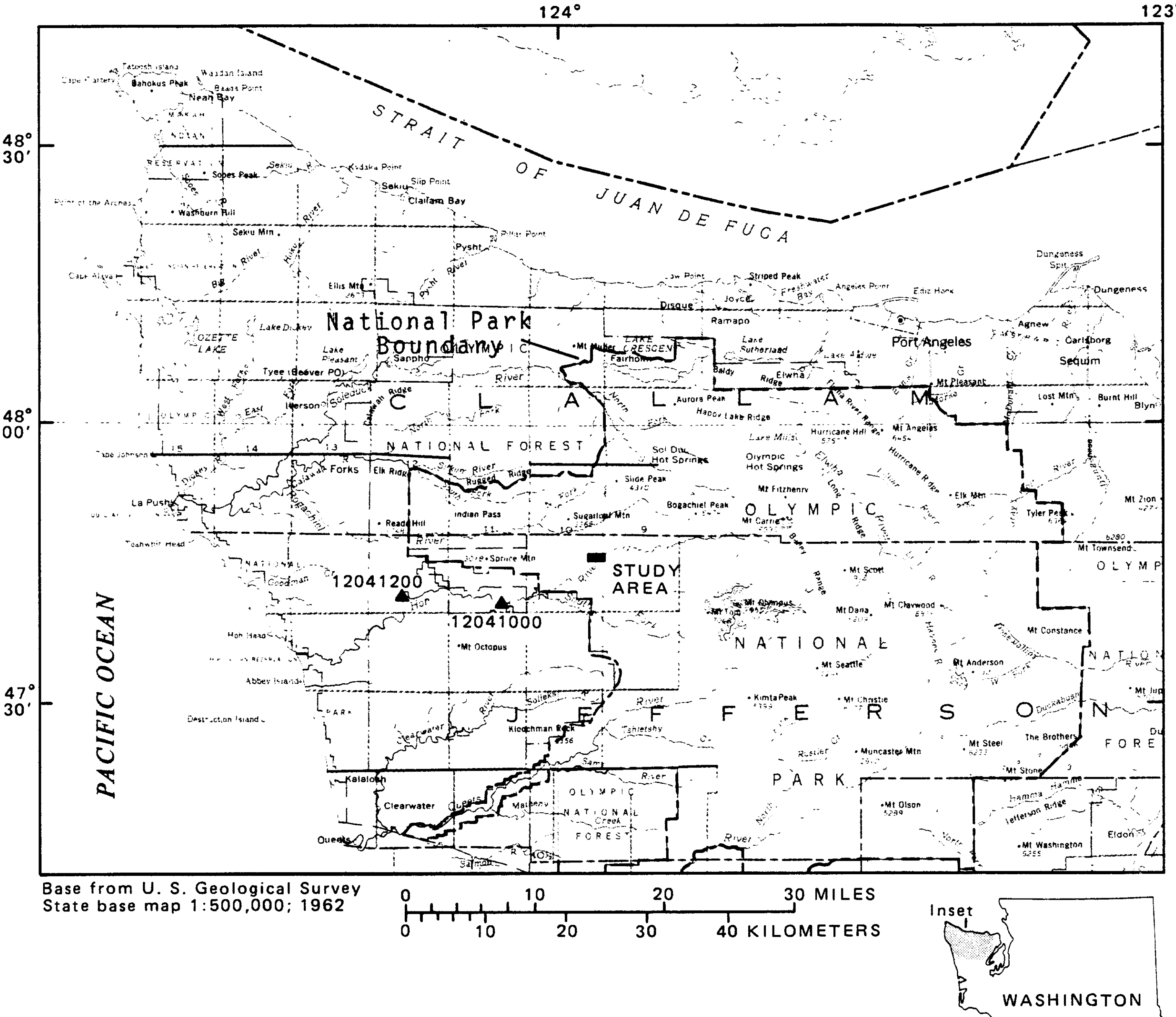

FIGURE 1.--Location of Hoh River stream gaging stations and study area.

Flood plains on each side of the river, except within some of the developed areas along the north bank, are covered with dense forests consisting primarily of Sitka spruce and western hemlock. Large numbers of deciduous trees, including vine maple, bigleaf maple, red alder, black cottonwood and Scouler willow, are found in parts of the study area where the density of spruce and hemlock is somewhat less. Red alder and Scouler willow are especially plentiful along the rocky gravel bars at the river's edge. The flood plains are mantled with large amounts of moss-covered forest debris. This debris, in conjunction with the dense forests, severely retards the passage of floodwaters across the flood plains.

An old meander or flood-bypass channel of the Hoh River lies to the north of the ranger station complex throughout most of the study reach. The upstream portion of this channel contains a small spring-fed branch of Taft Creek, and the downstream portion is inundated by a shallow swamp fed in part by small side-hill Taft Creek tributaries (pl. 1). The swamp is bounded on the north by steep valley walls and on the south by an elevated portion of Upper Hoh Road that is built on fill material. An outlet culvert under the highway at the west end of the swamp allows excess inflow to the swamp to flow down a narrow channel across the Hoh River flood plain and empty into the river.

Some floodwater entered the flood-bypass channel at its upstream end during a Hoh River flood in December 1980. The peak flow of the Hoh River in the vicinity of the ranger station complex during that flood is unknown; however, the peak flow of the river at gaging station 12041200 (fig. 1) was 51,100 ft^3/s, with a recurrence interval of approximately 14 years. Flow entering the channel during the December 1980 flood reportedly did not cause any flood damage (H. Yanish, National Park Service, oral commun., 1985); however, the possibility that larger flows in the channel could result in extensive flood damage to the ranger station complex prompted the National Park Service to dam the upstream end of the channel soon after that flood. This small dam (pl. 1), is about 35 feet long and has a triangular cross-sectional shape that is 15 feet wide at its base and 3 1/2 feet high, is composed of river sediments that were bulldozed across the upstream end of the channel.

There is a small tributary channel to Taft Creek, the upstream end of which is located approximately 500 feet north of the small dam on Taft Creek (pl. 1). It is unknown whether or not there has been flow in this tributary channel in the recent past.

A separate branch of Taft Creek drains an area northwest of the ranger station complex (pl. 1). Outflow from this drainage passes under Upper Hoh Road through a culvert located approximately 400 feet west of Taft Creek swamp, flows down a steep channel along the toe of a hillside and empties into the Hoh River near the downstream end of the study reach. This branch of Taft Creek was not included in the flood hazard assessment because it is located so far downstream from the ranger station complex.

METHODS OF STUDY

The magnitudes of 10-, 50-, and 100-year frequency flood discharges were estimated from regional flood-frequency equations. Peak water-surface elevations corresponding to those discharges were determined by using step-backwater analysis of channel and flood-plain cross sections in the study area. Flood-inundation boundaries were delineated on an aerial photo base map using computed water-surface elevations for a 100-year flood and ground elevations from cross-section surveys.

Flood-Frequency Analysis

Flood-frequency discharges for the Hoh River at the ranger station complex were determined from regional equations for estimating peak discharges at ungaged sites. Two sets of equations, one developed by Moss and Haushild (1978) and the other by Cummans and others (1975), were evaluated for use in this study. Both sets of equations were developed by regional regression analysis that relate peak discharge to drainage area and mean annual precipitation. Peak discharges used in the regression analyses were obtained from probability analysis of records from stream-gaging stations. The selection of which set of regional equations to use was made by comparing flood-frequency discharge values estimated from the equations with values estimated by log-Pearson type III analysis for two stream-gaging stations on the Hoh River (identified as 12041000 and 12041200 in figure 1). Gaging station 12041000 (Hoh River near Forks), located 10.2 miles downstream from the ranger station, was operated for 38 years from 1927 until discontinuance in 1964, and has a drainage area of 208 square miles. Station 12041200 (Hoh River at U.S. Highway 101 near Forks), located 10.4 miles downstream from station 12041000, has been operated since 1961 (25 years to 1985) and has a 253-square mile drainage area. The mean annual precipitation over the drainage area for station 12041000 is 167 inches and for station 12041200 is 160 inches.

Moss and Haushild (1978) did not include data for either one of the two Hoh River gaging stations in their regional regression analysis, which consisted of the development of a separate set of flood-frequency equations for each of six designated runoff regimes for streams in the State of Washington. The regimes were distinguished on the basis of the seasonal distribution of mean monthly streamflow observed at the gaging stations used in their analysis. Two of these runoff regimes, (1) winter peak, and (2) winter and spring peaks: winter peak dominant, were found by Moss and Haushild to represent the occurrence of peaks on streams that drain the western slopes of the Olympic Mountains. The runoff regime used for the Hoh River in this study--winter and spring peaks: winter peak dominant--was selected because, although over 80 percent of the annual peak discharges at gaging stations 12041000 and 12041200 were during the months of November through February, 3 percent of the peaks at station 12041000 and 14 percent at station 12041200 were spring peaks that occurred during the months of March and April. Furthermore, it was the regime determined by Moss and

Haushild for gages on the Soleduck, Queets, and Quinault Rivers, all of which drain the western slopes of the Olympic Mountains and have mean annual snowfalls and average elevations similar to those for the Hoh River drainage basin. Moss and Haushild used annual peak discharges for 30 western Washington gaging stations to generate the flood-frequency equations for this runoff regime. The equations developed by Moss and Haushild to estimate flood-frequency discharges for this runoff regime are as follows:

Recurrence interval (years)	Peak-discharge equation
10	$Q = 1.54(A)^{0.89}(P)^{1.06}$
50	$Q = 2.21(A)^{0.89}(P)^{1.04}$
100	$Q = 2.49(A)^{0.89}(P)^{1.04}$

where,

Q = discharge, in cubic feet per second,
A = drainage area, in square miles, and
P = mean annual precipitation, in inches.

Cummans and others (1975) used peak-discharge data for 450 gaging stations in Washington to develop separate sets of flood-frequency equations for 12 regions across the State. Data for the two Hoh River gaging stations were included in the Cummans and others analysis. The drainage areas of the Hoh River above the ranger station and above gaging station 12041000 lie entirely within the Region II boundaries defined by Cummans and others. The drainage area above gaging station 12041200 lies mostly (90 percent) within Region II; however, 10 percent of it lies within Region III. The equations developed by Cummans and others to estimate flood-frequency discharges for these two regions are as follows:

Recurrence interval (years)	Peak-discharge equation for:	
	Region II	Region III
10	$Q = 0.158(A)^{0.85}(P)^{1.54}$	$Q = 0.082(A)^{0.85}(P)^{1.54}$
50	$Q = 0.186(A)^{0.86}(P)^{1.58}$	$Q = 0.098(A)^{0.86}(p)^{1.58}$
100	$Q = 0.194(A)^{0.86}(p)^{1.60}$	$Q = 0.102(A)^{0.86}(P)^{1.60}$

where Q, A, and P are defined in the same manner as in the equations developed by Moss and Haushild.

Flood-frequency discharges estimated from the two sets of regional regression equations for gaging stations 12041000 and 12041200 were compared with station discharges estimated by log-Pearson type III analysis of the annual peak discharges at the two gages (table 1) to determine which set of equations to use for the estimation of discharges for the Hoh River at the ranger station. Discharges estimated for station 12041200 from the regional equations were all within 7 percent of the station discharges except one which was within 14 percent. The discharges estimated from the regional equations for station 12041000 were all considerably greater (32 to 56 percent) than the station discharges for that gage. The 10-year frequency peak discharges estimated from the regional equations for this station differed from each other by only 3 percent; however, the 50- and 100-year discharges estimated from the Moss and Haushild equations were in closer agreement with the station discharges (+32 and +34 percent, respectively) than were those estimated from the Cummans and others equations (+50 and +56 percent, respectively). The equations of Moss and Haushild were selected for use in estimating discharges for the Hoh River at the ranger station because discharges estimated from them for the two Hoh River gaging stations generally were in better agreement with the station discharges than were discharges estimated from the Cummans and others equations.

Application of the Moss and Haushild equations to compute flood-frequency discharges for the Hoh River at the ranger station requires that values of drainage area and mean annual precipitation be determined for the drainage basin upstream from the ranger station. The drainage area of the Hoh River at the ranger station is 108 square miles (Richardson, 1962). Mean annual precipitation in the Hoh River drainage basin upstream of the ranger station ranges from approximately 120 inches along the northern basin boundary to about 240 inches at Mount Olympus (U.S. Weather Bureau, 1965). The mean annual precipitation for the basin was estimated to be 180 inches.

TABLE 1.--Comparison of flood-frequency discharges estimated by regional regression equations for two Hoh River gaging stations with those estimated by log-Pearson type III analysis of the annual peak discharges at the gages

Discharge computation method	Discharge at gaging station, in cubic feet per second					
	Station 12041000 recurrence interval			Station 12041200 recurrence interval		
	10-year	50-year	100-year	10-year	50-year	100-year
Log-Pearson type III analysis of annual peaks	29,600	39,700	44,100	47,900	64,100	70,800
Cummans and others (1975) regional regression equations	39,100	59,600	68,800	41,100	62,800	72,400
Percent difference from log-Pearson discharge)	+32	+50	+56	-14	-2	+2
Moss and Haushild (1978) regional regression equations	40,400	52,400	59,000	46,000	59,600	67,200
Percent difference from log-Pearson discharge	+36	+32	+34	-4	-7	-5

The flood discharges for the Hoh River at the ranger station as computed using the Moss and Haushild equations for the indicated recurrence intervals are as follows:

Recurrence interval (years)	Peak discharge (ft^3/s)
10	24,000
50	31,000
100	35,000

Step-Backwater Analysis

Water-surface elevations and mean flow velocities for 10-, 50-, and 100-year frequency peak discharges through the study reach were computed using the U.S. Geological Survey step-backwater computer program J635 (Shearman, 1977). The program is a one-dimensional, steady-state hydraulic computer model that uses river discharge, cross sections, and roughness coefficients in the computation of water-surface elevation and velocity at each cross section. The cross sections describe the shape, size, and ground elevations of the channel and flood plains, and the roughness coefficients define the resistance to flow through the channel and flood plains.

Fourteen cross sections, obtained by transit-stadia survey in October and November 1984, and spaced at intervals of approximately 500 feet, were used for the step-backwater analysis. Two cross sections are located downstream of the study reach and one (cross-section A) is located at the downstream boundary of the study reach. Step-backwater profiles were computed for these three cross sections to determine the "normal depth" (Davidian, 1984, p. 2) water-surface elevation at cross-section A. Step-backwater profiles started at water-surface elevations known to be higher and lower, respectively, than the normal depth water-surface elevation at the initial cross section are generally assumed to have reached normal depth at the cross section where they have converged to the same elevation. Normal depth water-surface elevations at the most downstream Hoh River cross section for each of the peak discharges modeled were estimated using the conveyance-slope method (Rantz, 1982, p. 334-337). Profiles computed using starting water-surface elevations 0.5 foot higher and lower, respectively, than the estimated normal depth elevations at that section converged to within 0.10 foot of each other at cross-section A.

Channel roughness coefficients, which were estimated by field inspection and reference to U.S. Geological Survey Water-Supply Paper 1849 (Barnes, 1967), range from 0.030 to 0.038. Flood-plain roughness coefficients, which range from 0.050 to 0.080, were estimated on the basis of field inspection and reference to a U.S. Department of Transportation guide for the selection of roughness coefficients (1984).

Plots of the cross sections located within the study reach are shown in figures 2-5. The left bank of each cross section is defined as the left side when looking in a downstream direction at the section. Also shown on the plots are the roughness coefficients or "n" values for the individual subareas in each cross section.

The validity of cross section and roughness coefficient data used in step-backwater analysis are often verified by comparing the actual high-water profile resulting from a flood peak of known discharge with the theoretical profile obtained from the step-backwater program. Profile verification could not be accomplished for the Hoh River at the ranger station because there is no documentation of either peak discharge or high-water-profile elevations for a past flood peak at that location.

Peak water-surface elevations and mean velocities at each cross section within the study area for 10-, 50-, and 100-year frequency flood discharges are given in table 2. A profile of the peak water-surface elevations for a 100-year flood is plotted in figure 6. The thalweg profile shown in figure 6 gives the lowest streambed elevation at each cross section. All elevations are referenced to NGVD of 1929. This datum was estimated from contour lines on a U.S. Geological Survey topographic map (Mount Tom, 1956) because of the absence of any permanent bench marks in the vicinity of the ranger station. The locations and descriptions of reference marks that were established during the transit-stadia survey of the cross sections are given on plate 1.

TABLE 2.--Water-surface elevations and mean flow velocities at Hoh River Cross sections for 10-, 50-, and 100-year flood discharges

[Elevations above NGVD of 1929, in feet; velocities, in feet per second]

	10-Year		50-Year		100-Year	
Cross-section[1]	Elevation	Velocity	Elevation	Velocity	Elevation	Velocity
A	568.0	4.6	568.7	5.1	569.1	5.2
B	568.8	7.4	569.7	7.8	570.1	7.9
C	571.4	9.7	572.2	11.0	572.5	11.7
D	574.4	8.4	575.5	9.1	576.0	9.4
E	576.1	7.4	577.1	8.1	577.6	8.4
F	579.9	8.6	580.6	9.6	581.0	10.0
G	584.2	5.9	585.0	6.4	585.4	6.6
H	587.6	7.9	588.2	8.6	588.5	8.9
I	593.0	8.3	593.6	9.2	593.9	9.8
J	596.2	7.6	596.9	8.3	597.3	8.7
K	600.1	5.9	600.9	6.1	601.3	6.2
L	603.2	7.9	603.9	8.1	604.2	8.3

[1]Cross-section locations are shown on plate 1.

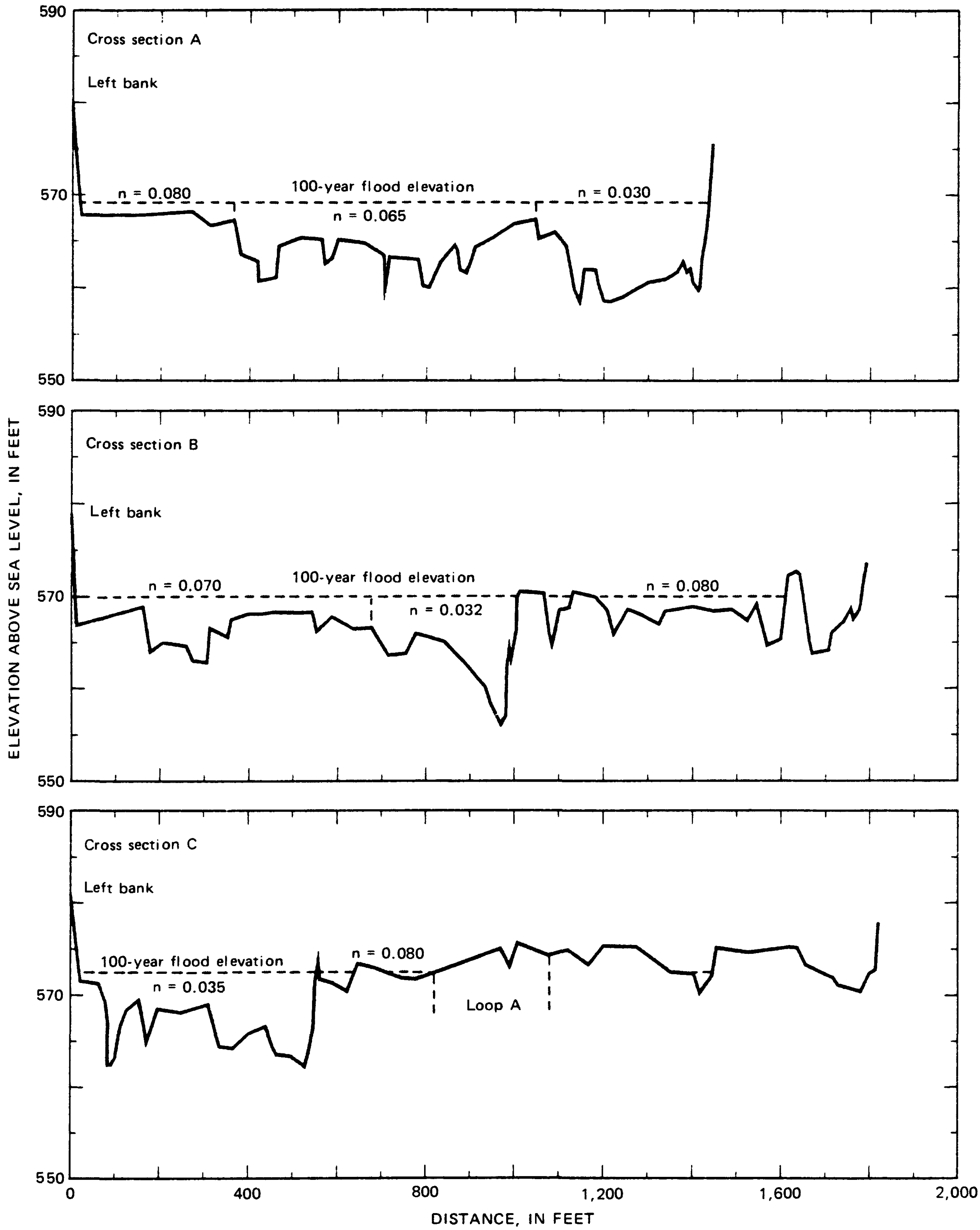

FIGURE 2.--Hoh River cross-sections A through C. See Plate 1 for location.

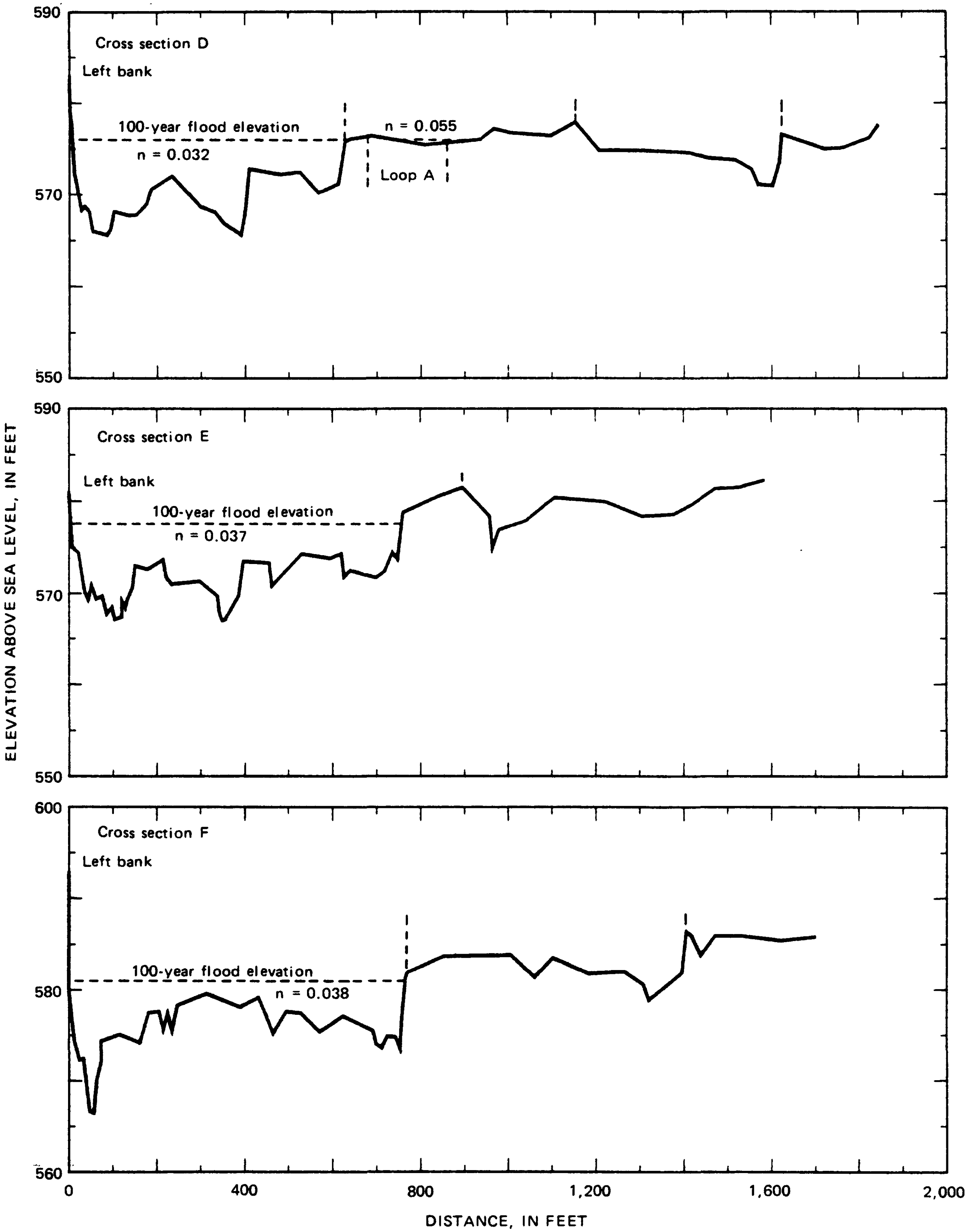

FIGURE 3.--Hoh River cross sections D through F. See Plate 1 for location.

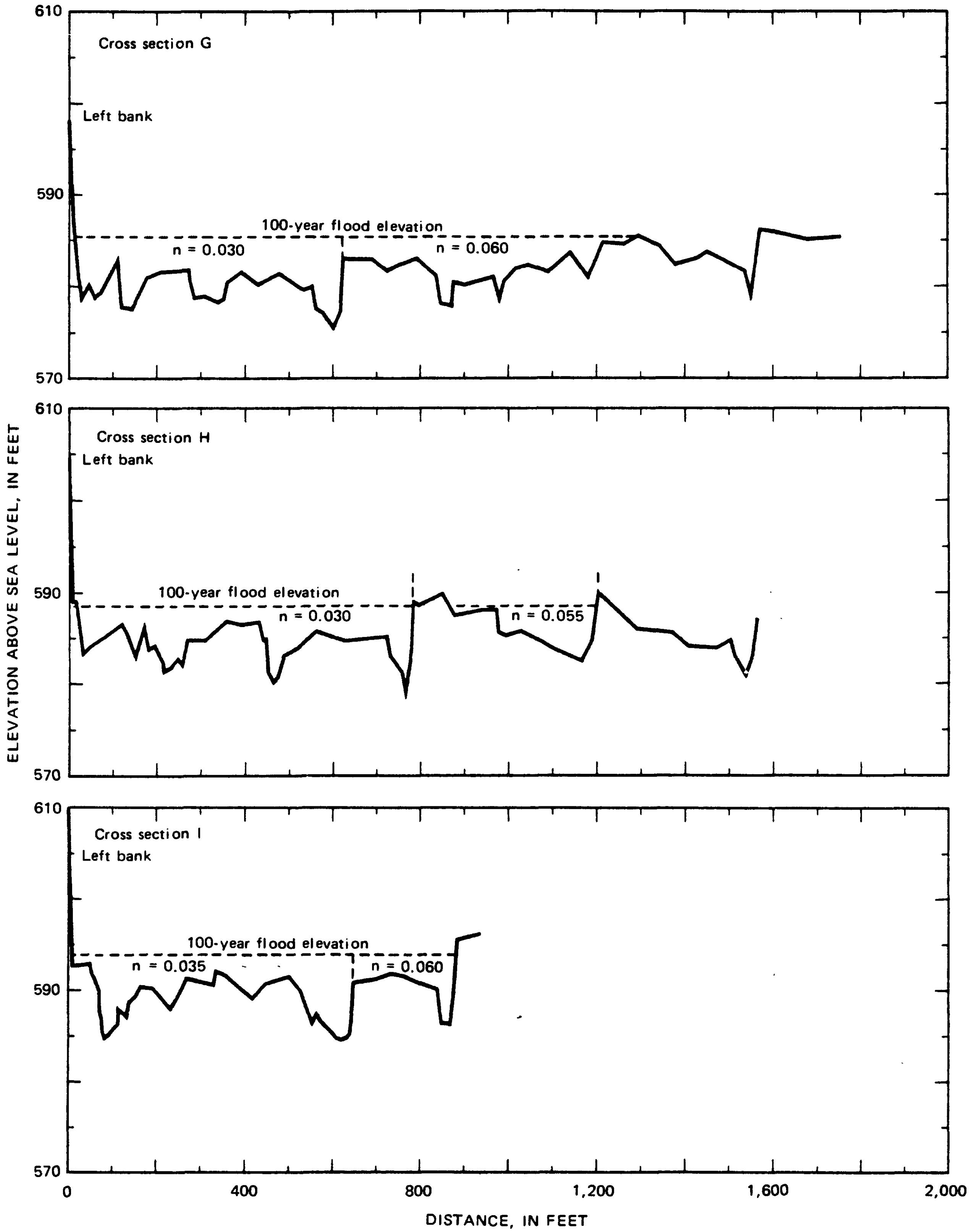

FIGURE 4.--Hoh River cross sections G through I. See Plate 1 for location.

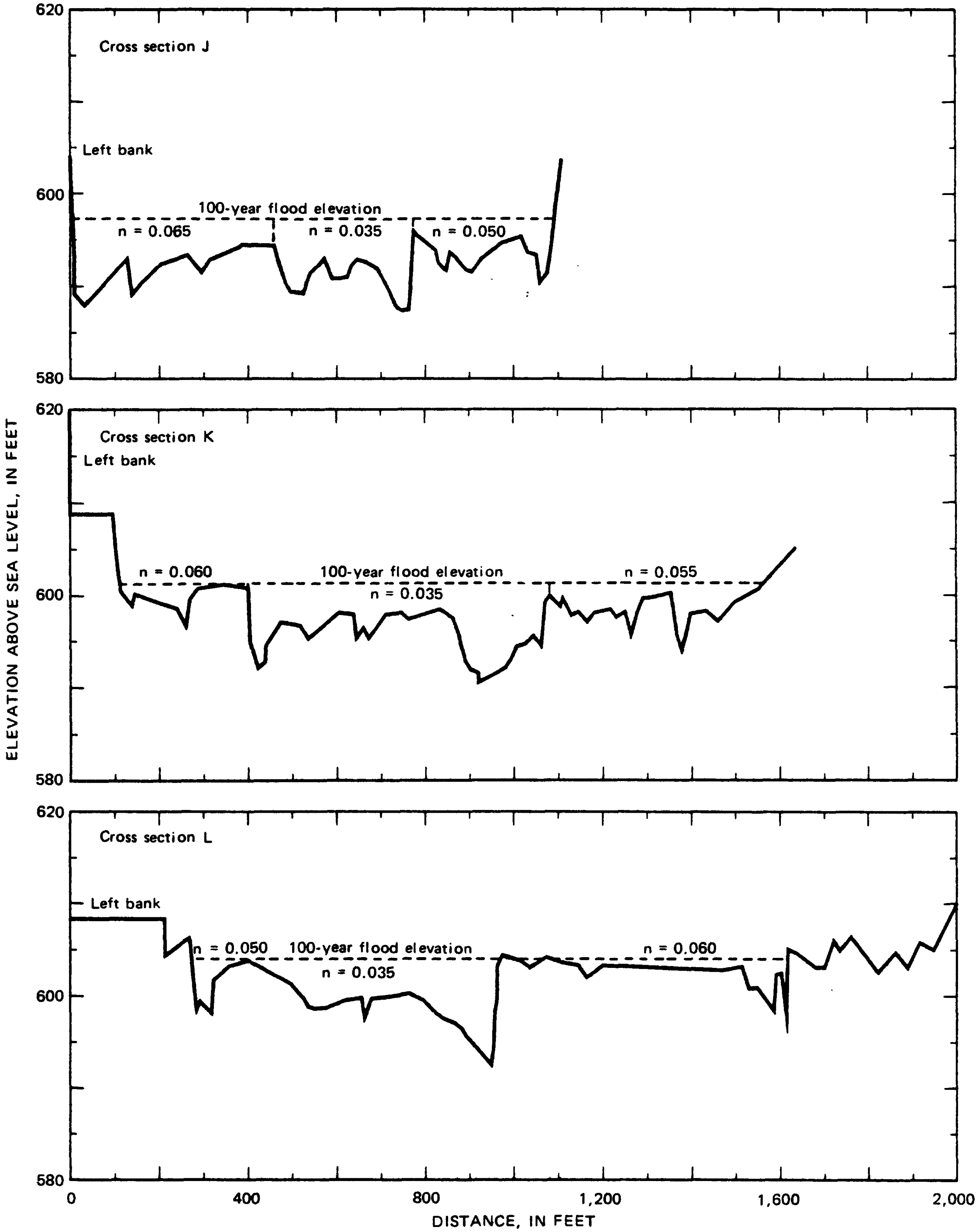

FIGURE 5.--Hoh River cross-sections J through L. See Plate 1 for location.

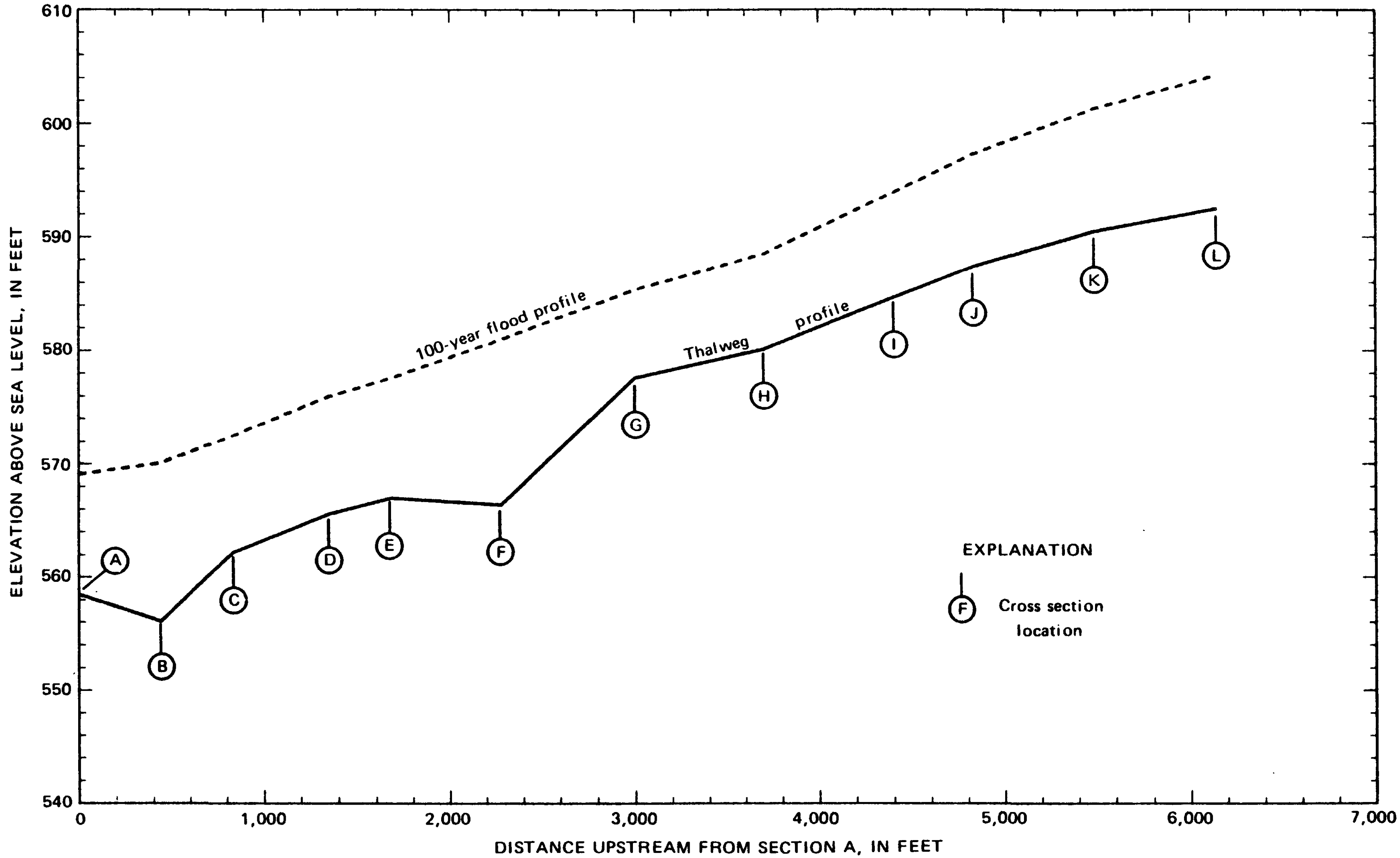

FIGURE 6.--Profile of 100-year flood elevations on the Hoh River in the vicinity of the ranger station complex.

Flood Inundation

Flood-inundation boundaries for a 100-year flood were delineated on an aerial photo base map of the Hoh River and flood plains. The base map, which is a mosaic enlargement of two aerial photographs obtained on March 7, 1985, has an approximate scale of 1:2400 (pl. 1).

Flood boundaries at the cross sections were established from water-surface elevations computed by step-backwater analysis and cross-section ground elevations. Between cross sections, flood boundaries were interpolated from water-surface elevations, topographic contour lines, surveyed ground elevations, and aerial photographs.

FLOOD-HAZARD ASSESSMENT

Flooding on the north bank flood plain along the upstream two-thirds of the study reach is confined to undeveloped areas by natural terraces (sections G through L) and banks stabilized with riprap (sections E and F). Flood elevations at section D would overtop the main channel bank and cause flooding with depths generally less than 2 feet in parts of loop A of the public campground. Most of the flooding in loop A would be confined to two historic meander channels. The smallest of the two channels lies approximately along the southeast-northwest centerline of the loop while the other channel lies along and mostly beyond the northeast boundary of the loop. The campsites, with few exceptions, are located on ground generally 2 to 3 feet higher than these channels. Campground loops B and C are not presently subject to flooding; however, continued unchecked bank erosion along upstream terrace faces could eventually result in either (1) flood-flows entering the overflow areas or flood-bypass channels that already exist in these loops or (2) the development of new channels through them. Some areas within the boundaries of inundation shown on plate 1, such as most of campground loop A, may be higher than the flood elevations determined, but cannot be delineated because of the lack of detailed topographic information.

Flooding in the vicinity of either the visitors center or the residential and maintenance areas is unlikely unless the small earthen dam at the upstream end of Taft Creek fails or floodwater enters the creek by means of the upstream tributary channel. Water-surface elevations at this dam, located about midway between cross sections J and K, and at the entrance to the Taft Creek tributary channel, located about midway between cross sections K and L, were estimated by interpolation between flood elevations at the adjacent cross sections. The estimated flood elevations at the dam were found to range from approximately 1 foot lower than the crest of the dam for a 10-year peak to about the same elevation as that of the dam crest for a 100-year peak. The strength of the earthen dam is not known. However, in view of the facts that it is composed of river sediments, its physical dimensions are relatively small, and flood elevations would likely be at or near its crest, the integrity of the dam to function as a flood-control structure is highly questionable. Nonetheless, for the purpose of this report, the small earthen dam was assumed to remain intact and prevent floodwaters from entering Taft Creek. Water-surface elevations at the entrance to the tributary channel for 10- and 100-year floods on the Hoh River were found to be 1.8 feet and 0.7 foot lower, respectively, than the lowest ground elevation at the entrance, which would prevent floodwaters from entering Taft Creek via this channel. Therefore, analysis of the flood characteristics of and potential inundation along the Taft Creek channel, which would have been beyond the scope of this study, was not included.

DEBRIS FLOW AND LANDSLIDE HAZARD ASSESSMENT

By Thomas C. Pierson

The rapid flowage of soil, rock debris, and water is termed "debris flow." Debris flows resulting from the liquefaction of landslide debris during intense rainstorms are a commonly occurring geologic process in steep terrain throughout the world, including the Olympic Mountains in northwestern Washington. Even though a debris flow may initially be small, liquefied debris flowing on open slopes or in channels can scour and incorporate material as it moves downslope. This characteristic often leads to debris flows that involve as much as a hundred times more volume than that which initially failed on the slope. Such debris flows may result in fatalities if dwellings or campgrounds are situated too close to the mouths of steep (and usually harmless-looking) drainages. The distance that debris flows can move out "on the flat" away from the steep slopes is a function of composition, velocity, volume (discharge), and flow resistance along the flow path. As yet, there is no certain way of predicting runout distance, although the spatial distribution of older debris-flow deposits at the mouths of steep drainages gives a clue to the magnitude of flows in the past.

Any debris flow or landslide hazard at the Hoh Ranger Station would come from the steep ridge to the north. The Hoh valley is too wide and flat to convey any debris flows from farther upstream, at least debris flows of the magnitude typically encountered in such terrain. The north ridge is high (2,500 feet above the valley floor) and steep (average slope about 35°). Bedrock is the Western Olympic Lithic Assemblage (Tabor and Cady, 1978), which is composed of medium- to thick-bedded sandstone and minor granule conglomerate with interbedded (about 40 percent) siltstone and argillite. Where measured nearby, the bedding is steeply dipping (50° to 90° and generally to the SW) and strike is generally NW-SE. In addition, rocks in this unit may be highly sheared in places. Soils mantling these slopes appear to be relatively shallow, non-cohesive, and colluvial in origin. In short, the bedrock is relatively weak and the soil mantle is a type that can fail during intense rainstorms, particularly in soil-filled bedrock hollows at the heads of drainages.

Figure 7 shows a few debris fans at the mouths of small creeks coming off the north ridge. Two of these fans were examined in the field (Nos. 4 and 6) and appear to be composed of old debris-flow deposits. The presence of mature Douglas fir and western hemlock growing on the deposits indicates that the deposits have been there at least 400 to 500 years. Aerial photos show that several of the creeks immediately upstream of the ones mapped have had debris flows descend their channels recently, probably within 5 to 10 years of when the photos were taken (September 9, 1976). Drainages 1 and 2 also have had recent debris flows, probably within 15 years of the photo date. Most of these debris flows extend no more than about 100 yards away from slope out onto the terrace.

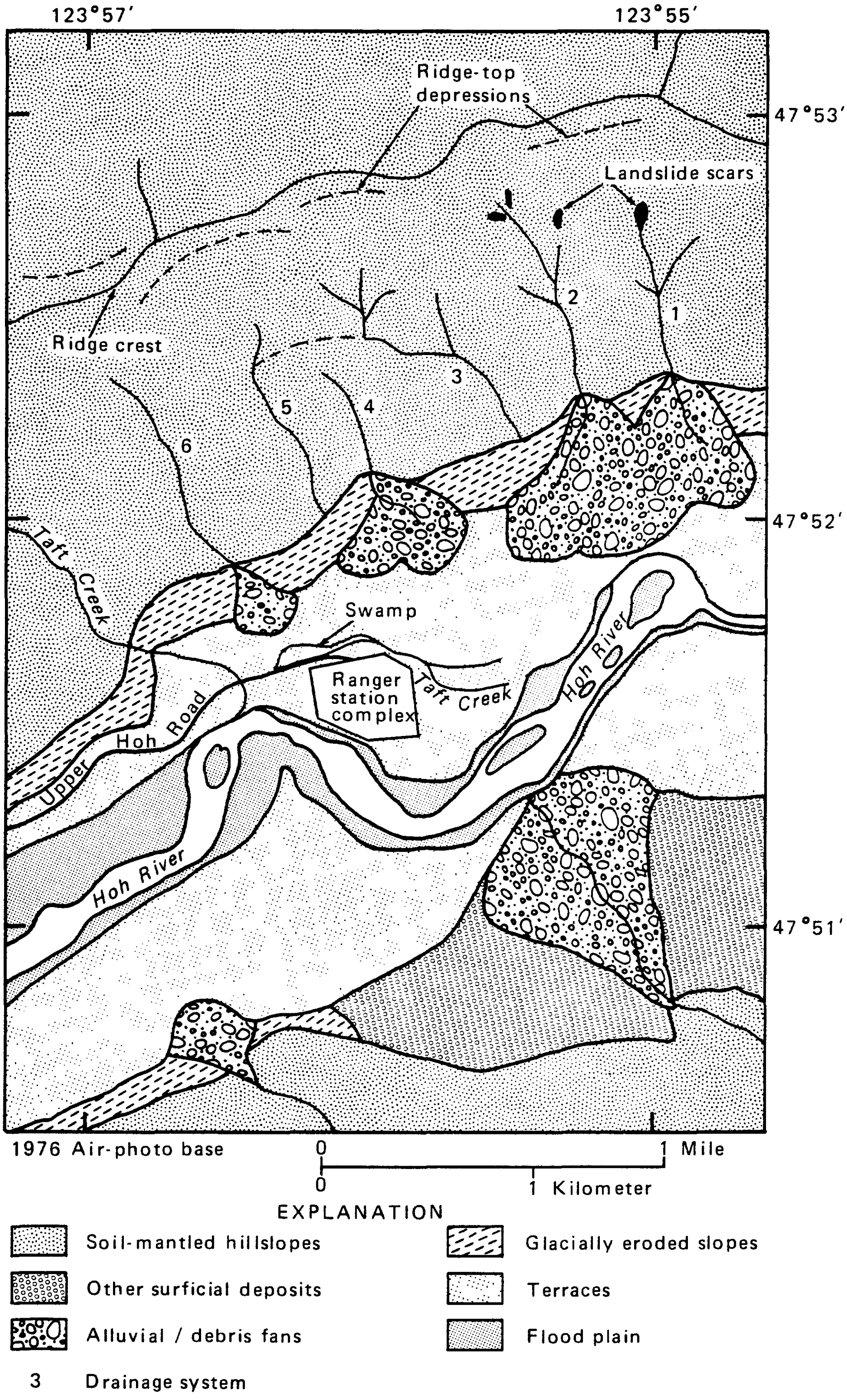

FIGURE 7.--Location of debris flow fans, landslide scars and ridge-top depressions in the vicinity of the Hoh River ranger station complex.

The risk to the ranger station complex from debris flows of the magnitude that have occurred in the past does not appear to be great. Flows on the order of 100 to 1,000 cubic yards could reasonably be expected to come down drainages 1 through 6 during an extreme storm event, but deposits from past flows (at least those since the last glaciation) indicate they would probably travel no more than about 100 yards from the base of the steep slope. The only structure located within the approximate range of these past flows is the ranger station and visitors center building, which is situated about 100 yards from the base of the hillside. To reach most of the developed areas, a flow would have to travel across at least 100 to 200 yards of flat, heavily forested terrace and then cross the 60 to 80 yard wide old meander or flood-bypass channel on the north side of the ranger station complex. To do this, a flow would have to be extremely large. The meander channel would act as a moat or debris-catch basin and provide additional protection for the ranger station complex.

Another potential hazard to consider is that from deep-seated slope failure in the weak bedrock that makes up the north ridge. Aerial photos show several linear features up near the ridge crest that appear to be ridge-top depressions of the type described by Tabor (1971). Ridge-top depressions apparently result from large-scale creep of bedrock. In most of the cases studied by Tabor elsewhere in the Olympic Mountains, shear is distributed over a wide zone and there is no discrete rupture surface. Tabor believes that most were formed soon after the withdrawal of lateral support by valley glaciers at the end of the last glaciation, and that most appear to be relatively stable today. However, rock creep of this type can be a precursor to catastrophic failure of large rock masses (Radbruch-Hall, 1978), and indeed large landslide deposits are scattered throughout the Olympic Mountains (Tabor and Cady, 1978). Such areas of weak creeping rock can be shaken loose by earthquakes.

In order to assess the potential landslide hazard posed by these features, the terrain at and around the depressions should be examined on the ground by a geologist. If any sign of currently active movement is found, such as ground cracking, tipped trees or shear zones, the risk of catastrophic failure is real, and detailed engineering studies should be carried out. As figure 7 shows, the ranger station complex could be directly in the path of such a rock avalanche. If no evidence of recent movement is found, the slope could reasonably be assumed to be stable. To assess the risk during earthquakes, a stability analysis could be carried out by an engineering geologist to compute the degree of stability under dynamic loading from potential earthquakes of various magnitudes.

SUMMARY AND CONCLUSIONS

Federal regulations require buildings and public facilities on Federal land to be located beyond or protected from inundation by a 100-year flood. Peak flood discharges of 10-, 50-, and 100-year recurrence intervals (24,000, 31,000, and 35,000 ft^3/s, respectively) were estimated for the Hoh River at the ranger station complex in the Olympic National Park from regional regression equations developed by Moss and Haushild (1978). Fourteen cross sections of the Hoh River channel and flood plains in the vicinity of the ranger station complex were obtained by transit-stadia survey. Water-surface elevations and mean flow velocities at the cross sections for each of the three flood-frequency discharges were computed by step-backwater analysis (table 2). Boundaries of inundation for a 100-year flood, which were determined from computed water-surface elevations and ground elevations, were delineated on a map of the study area (pl. 1). Portions of loop A of the public campground would be flooded by a 100-year flood--probably to average depths of about 2 feet or less. It is unlikely that either the visitors center or the residential and maintenance areas would be flooded unless the small earthen dam at the upstream end of Taft Creek were to fail and significant quantities of flow were to enter the creek.

Potential hazards to the ranger station complex from debris flows and landslides were assessed superficially. The risk from debris flows of the magnitude that have occurred in the past does not appear to be great. Inspection of aerial photos of the ridge immediately to the north of the ranger station area indicates the apparent presence of several ridge-top depressions that could suggest the possibility of potentially catastrophic landslide failures. However, many similar-looking depressions elsewhere in the Olympic Mountains that have been examined on the ground are considered to be relatively stable. A comprehensive assessment of the potential landslide hazards associated with the ridge-top depressions north of the ranger station would therefore require at least a field inspection by a geologist.

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