FLOOD CHARACTERISTICS FOR THE NISQUALLY RIVER AND SUSCEPTIBILITY OF SUNSHINE POINT AND LONGMIRE FACILITIES TO FLOODING IN MOUNT RAINIER NATIONAL PARK, WASHINGTON

By Leonard M. Nelson

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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 units	By	To obtain SI units
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
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)

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.

FLOOD CHARACTERISTICS FOR THE NISQUALLY RIVER AND SUSCEPTIBILITY OF SUNSHINE POINT AND LONGMIRE FACILITIES TO FLOODING IN MOUNT RAINIER NATIONAL PARK, WASHINGTON

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ABSTRACT

Inundation from 25-, 50-, 100-, and 500-year floods at Sunshine Point and Longmire facilities and the Longmire visitors' center and ranger station generally is not a serious hazard as long as the existing dikes and banks of the Nisqually River and Tahoma Creek remain intact and flood capacities of the channels are maintained. However, average water velocities during floods are high (as much as 23 feet per second) and the channel, banks, and some dikes are composed of unstable materials. Sunshine Point campground is particularly susceptible to flooding and damage from Tahoma Creek, and to a lesser extent from the Nisqually River, if large amounts of debris or rock material accumulate in the channels and change the flood elevation or courses of either stream. At Longmire flood inundation or damage from the Nisqually River is much less, but flooding is still possible. There, high ridges upstream protect the several park facilities from the river, but accumulations of debris or rock in the channel could cause flooding from overtopping of dikes or riverbanks. Glacial outburst floods are a matter of serious concern at both Sunshine Point campground and Longmire. Glacial outbursts can and have produced very large flood discharges and transported large quantities of debris and rock materials. Although none have been known to transport these materials from Tahoma Glacier as far as Sunshine Point campground, one in 1955 from Nisqually Glacier (estimated at 70,000 cubic feet per second near the glacier) did appreciably increase the magnitude of the water discharge at Longmire. For safety, campers and visitors need to be advised about the potential flood hazards at both facilities.

INTRODUCTION

The headwaters of the Nisqually River drain the southern flanks of Mount Rainier. This report provides estimates of river discharges, water-surface elevations, average water velocities, and inundation maps for 25-, 50-, 100-, and 500-year flood peaks at the National Park Service facilities at Sunshine Point and Longmire in the Mount Rainier National Park, Washington. The report discusses the susceptibility of the Sunshine Point campground (hereafter referred to as Sunshine Point) and Longmire facilities to flooding.

This study was conducted by the U.S. Geological Survey in cooperation with the National Park Service to provide information needed by the National Park Service to develop safety and flood-protection measures. The study areas are 1/2- and 3/4-mi sections along the Nisqually River at Longmire and Sunshine Point, respectively, located 43 mi southeast of Tacoma in western Washington (fig. 1).

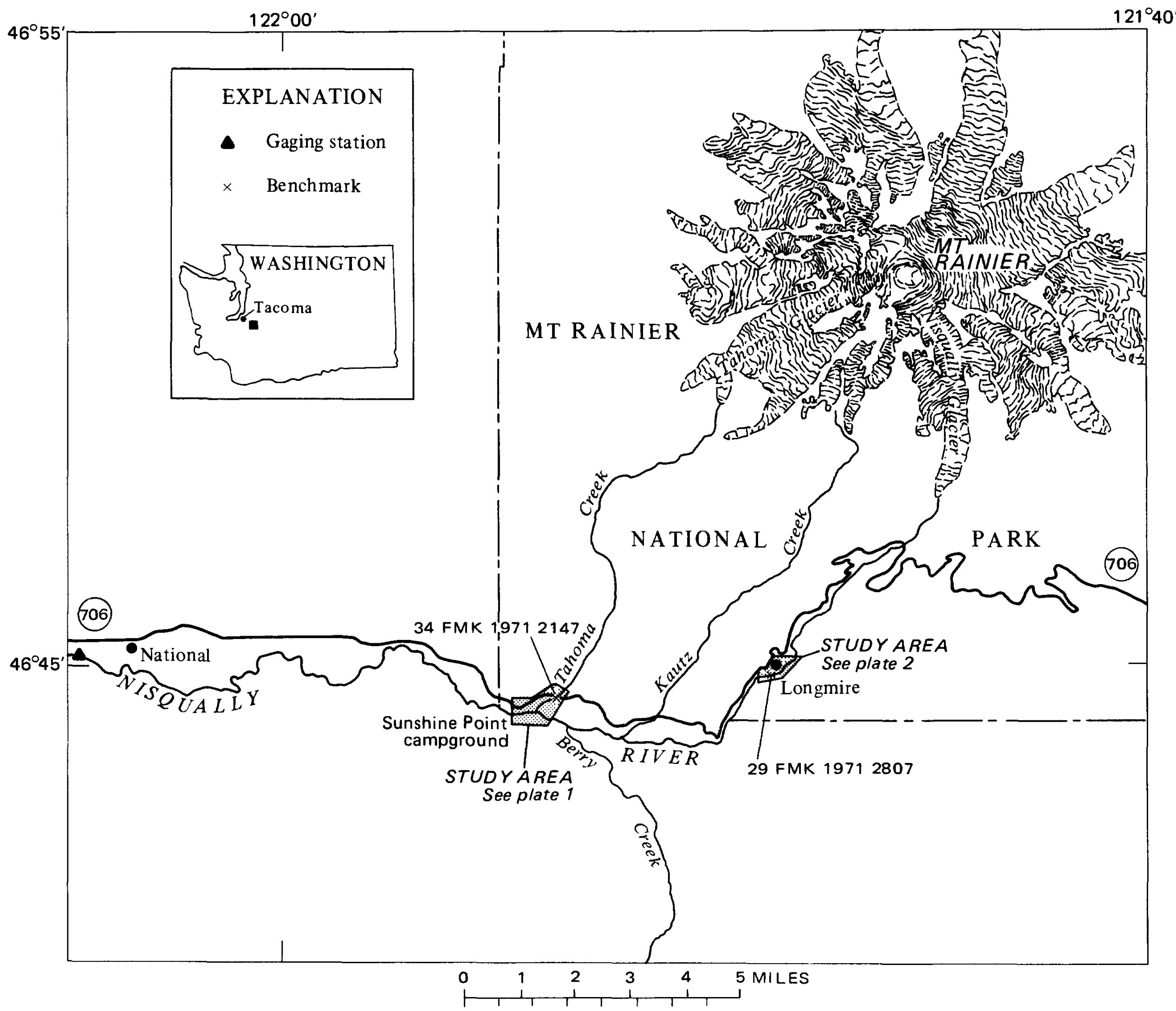

Figure 1. – Location of study areas.

Many of the National Park Service administration and maintenance buildings, homes for Park Service personnel, and the visitors' center and ranger station are located at Longmire. There also are additional accommodations including rooms, trailer spaces, and a campground available for park visitors from early May to mid-October. The visitors' center is open all year. Daily, thousands of tourists use the many trails, the visitors' center, and the many campgrounds in the park. The Sunshine Point campground is the only campground open all year in the park.

HYDROLOGY

The Longmire facilities and Sunshine Point campground are in an area of dense conifer forest that has an annual rainfall of about 100 inches (U.S. Weather Bureau, 1965). At higher elevations on Mount Rainier much of the precipitation falls as snow. Annual peak stream discharges generally occur during the winter months, November through February, as a result of intense precipitation from storms originating over the Pacific Ocean, but flooding can result from snowmelt.

Streamflow has been monitored continuously over a long period (1943-81) at only one gaging station on the upper Nisqually River, U.S. Geological Survey gaging station Nisqually River near National. The gaging station is located at river mile 57.8, 11.5 mi downstream of Sunshine Point and 17.4 mi downstream of Longmire. The highest discharge during the 39 years of record was 17,100 ft^3/s on December 2, 1977 (U.S. Geological Survey, 1981). Tahoma Creek and Kautz Creek are the two major tributaries draining from Mount Rainier between Longmire and Sunshine Point (fig. 1). Tahoma Creek enters at the upstream side of Sunshine Point campground and Kautz Creek enters midway between Longmire and Sunshine Point. A smaller tributary, Berry Creek, enters from the south between Longmire and Sunshine Point. None of these creeks has been gaged over a continuous period. The Nisqually River drains an area of 133 mi^2 at the gaging station, about 65 mi^2 at Sunshine Point, and 19.1 mi^2 at Longmire; Tahoma Creek contributes 14.0 mi^2, Kautz Creek 13.5 mi^2, and Berry Creek 9.8 mi^2.

Part of the precipitation falling upon the upper Nisqually River basin is stored in glaciers. At times water can form on or in the glaciers and create flooding in an infrequent phenomenon known as a glacier outburst, a sudden discharge of water from the glacier. These outburst floods, generally consisting of a small amount of water mixed with large volumes of rock debris, dissipate rapidly in the valley immediately downstream from the glacier, but the largest outbursts may travel many miles downstream. Glacier-outburst floods from the Nisqually Glacier have been documented by Richardson (1968). The estimates of the greatest outburst flows since 1926, as observed at the State Highway 706 crossing below the glacier, are listed below.

Date	Peak discharge (ft^3/s)	Rank in size of peak
October 1926	7,000	5
Do. 1932	(a)	2
Do. 1934	(a)	3
Do. 1947	(a)	4
Do. 1955	70,000	1
June 1968	5,000	6
July 1970	3,000	7

[a]Not determined.

The outburst of October 1955 had a small but measurable effect on the water level at the gaging station near National, where the river stage increased 1.7 ft.

One of the more spectacular outburst-flood events in the park was observed in October 1947 on Kautz Creek. Although the peak discharge may have been as much as 20,000 ft^3/s at the mouth of Kautz Creek where the deposit of boulders and debris was extensive, the flood had only a small effect on the water level or discharge (1,500 ft^3/s increase) of the Nisqually River at the gaging station near National.

On Tahoma Creek, the largest observed glacier outburst occurred in August 1967. Although the peak was an estimated 24,000 ft^3/s far upstream in the creek basin, little if any of the flood reached the creeks's mouth or the Nisqually River at Sunshine Point.

The stream channels in the study area are steep (gradients of reaches studied are 200 ft/mi for Nisqually River at Longmire, 80 ft/mi for the Nisqually River at Sunshine Point, and 150 ft/mi for Tahoma Creek at Sunshine Point). The channels are composed largely of well-rounded alluvial boulders and unstable large gravel, and the channels change shape and direction frequently. The flood plains are composed of these same materials covered with a thin mantle of soil. Riverbanks erode quickly when high discharges are directed against them. Where floods overtop the banks and inundate the flood plain, there are often appreciable deposits of boulders and gravel. Evidence of active erosion and deposition is plentiful in the study areas.

FLOOD CHARACTERISTICS

Peak Discharges

The 25-, 50-, 100-, and 500-year flood peaks have a 4-, 2-, 1-, and 0.2-percent chance of occurring in any one year. Peak discharges corresponding to the selected recurrence intervals were estimated by several methods for the Nisqually River and its tributary, Tahoma Creek. Tahoma Creek was included because it could potentially flood Sunshine Point facilities. Values were estimated from regression equations (relation between the discharge of rivers and their basin characteristics) suggested by Moss and Haushild (1978) and Cummans, Collings, and Nassar (1975); from regression equations used in the Pierce County flood study (Federal Emergency Management Agency, written commun., 1982); and also from frequency analysis of annual peak discharges recorded at the National gaging station. All values from the regression equations were found to be considerably lower than those for the station. Because none of the equations adequately represented peak discharges at the station, the station values were accepted as the more realistic at that location. However, it was necessary to adjust the station values to obtain estimates for the Nisqually River at Longmire and Sunshine Point and for Tahoma Creek.

The discharge values for 25-, 50-, 100-, and 500-year flood peaks for the Nisqually River at Longmire and at Sunshine Point and Tahoma Creek at Sunshine Point were determined by using equations from Moss and Haushild (1978, p. 43) as a mechanism for transferring and adjusting the values from the gaging station. The equations used were

$$\text{10-year floodflow} = 1.54DA^{0.89}P^{1.06},$$

$$\text{25-year floodflow} = 1.94DA^{0.89}P^{1.06},$$

$$\text{50-year floodflow} = 2.21DA^{0.89}P^{1.04}, \text{ and}$$

$$\text{100-year floodflow} = 2.49DA^{0.89}P^{1.04},$$

where
DA = drainage area of basin in square miles, and
P = annual precipitation, in inches.

The Moss and Haushild equations were chosen because they were the most recently developed from log-Pearson III frequency analysis of gaging-station records, which was the same method used in this study for analysis of records from the National gaging station. A ratio was obtained for each selected recurrence interval by dividing the values obtained from the gaging-station frequency analysis by values obtained using the Moss and Haushild equations. Discharge values for the Nisqually River at Longmire and Sunshine Point and Tahoma Creek were obtained from the Moss and Haushild regression multiplied by this ratio.

There was need for an additional adjustment, however. Discharge values for the National gaging station represented primarily rainfall or snowmelt floods, but not the outburst floods, which essentially dissipate before reaching the station. The probabilities of outburst floods were estimated for Longmire by using the Weibull formula (Chow, 1964, p. 28-29) and data from the seven largest outbursts (size ranks for three outbursts have been estimated) at Nisqually Glacier since 1926. The largest observed outburst from Nisqually Glacier (estimated 70,000 ft^3/s on October 25, 1955) was routed to Longmire using a U.S. Geological Survey flood-routing model (Land, 1981). The peaks of the smaller outbursts were assumed to have attenuated relatively little upon arrival at Longmire because they were small enough to be confined within the narrow river channel, which offers little temporary storage for floodwater.

The probabilities of the rainfall-flood peaks and the outburst-flood peaks were combined for the Nisqually River at Longmire using a method described by Crippen (1978). The discharge values obtained by combining probabilities are given in table 1, including values when outburst floods are neglected for Longmire, and also for the Nisqually River and Tahoma Creek at Sunshine Point. Outbursts obviously can have a sizable effect on the peak streamflow in the Nisqually River at Longmire, but probably not much farther downstream. Outburst floods from the Nisqually Glacier and Tahoma Glacier were neglected at Sunshine Point under the assumption that they would dissipate to insignificance compared to rainfall or snowmelt floods; the rate of attenuation in the routing model from Nisqually Glacier to Longmire tends to support that assumption.

TABLE 1.--Peak discharges for floods of selected recurrence interval on Nisqually River and Tahoma Creek, Washington

Site	Drainage area (mi^2)	Peak discharge (ft^3/s) for selected recurrence intervals			
		25-year	50-year	100-year	500-year
Nisqually River at Sunshine Point campground	65	8,400	10,200	12,300	15,300
Tahoma Creek at mouth	14.0	2,200	2,600	3,200	4,300
Nisqually River at Longmire	19.1	[a]3,100	[a]3,600	[a]4,200	[a]5,200
Nisqually River at Longmire	19.1	[b]3,200	[b]3,900	[b]4,900	[b]32,000

[a]Value obtained for rainfall floods only; not applied in this investigation.
[b]Value obtained by combining probabilities of rainfall and outburst floods; applied in this investigation.

Water-Surface Elevations

Twenty-three cross sections of the Nisqually River at Sunshine Point, 10 cross sections of Tahoma Creek near its mouth, and 20 cross sections of the Nisqually River at Longmire were surveyed in May and June of 1982 and used in the hydraulic analysis of riverine flooding. Typical cross sections are shown in figures 2 through 4. Vertical control for cross sections were obtained from the U.S. Geological Survey benchmarks (29 FMK 1971 2807 at Longmire and 34 FMK 1971 2147 at Tahoma Creek). The horizontal control for Longmire was taken from a U.S. Geological Survey map (Nisqually Glacier, Washington, 1976) and the horizontal control for Sunshine Point was estimated from a 7 1/2-minute topographic map (Mount Rainier 3NW). Elevations are given in feet above NGVD of 1929 and the Washington coordinate system (Lambert) was used for horizontal position identification.

Water-surface elevations were determined at each of 53 cross sections for the 25-, 50-, 100-year peak discharges, and for the 500-year peak discharge at all except cross-sections A through H at Longmire (tables 2-4) by using the U.S. Geological Survey step-backwater computer program (Shearman, 1976). The rounding of the values in tables 2 through 4 to the nearest foot causes elevations for different discharges to appear to be the same at some cross

TABLE 2.--Peak water elevations for floods of selected recurrence intervals on the Nisqually River at Sunshine Point campground

Cross section (location shown in figs. 5,6)	Peak elevation, in feet[a] above NGVD of 1929, for selected recurrence interval			
	25-year	50-year	100-year	500-year
AA	1,994	1,994	1,995	1,995
AB	2,000	2,000	2,001	2,001
AC	2,005	2,005	2,006	2,006
AD	2,011	2,011	2,011	2,012
AE	2,016	2,016	2,016	2,017
AF	2,020	2,020	2,020	2,021
AG	2,025	2,026	2,026	2,026
AH	2,031	2,031	2,031	2,032
AI	2,035	2,035	2,035	2,036
AJ	2,039	2,040	2,040	2,041
AK	2,043	2,043	2,044	2,044
AL	2,050	2,051	2,051	2,051
AM	2,055	2,055	2,055	2,056
AN	2,058	2,058	2,059	2,059
AO	2,061	2,061	2,062	2,062
AP	2,069	2,070	2,070	2,071
AQ	2,073	2,073	2,074	2,074
AR	2,077	2,078	2,078	2,079
AS	2,083	2,083	2,084	2,085

[a]Corresponding flood discharges are given in table 1.

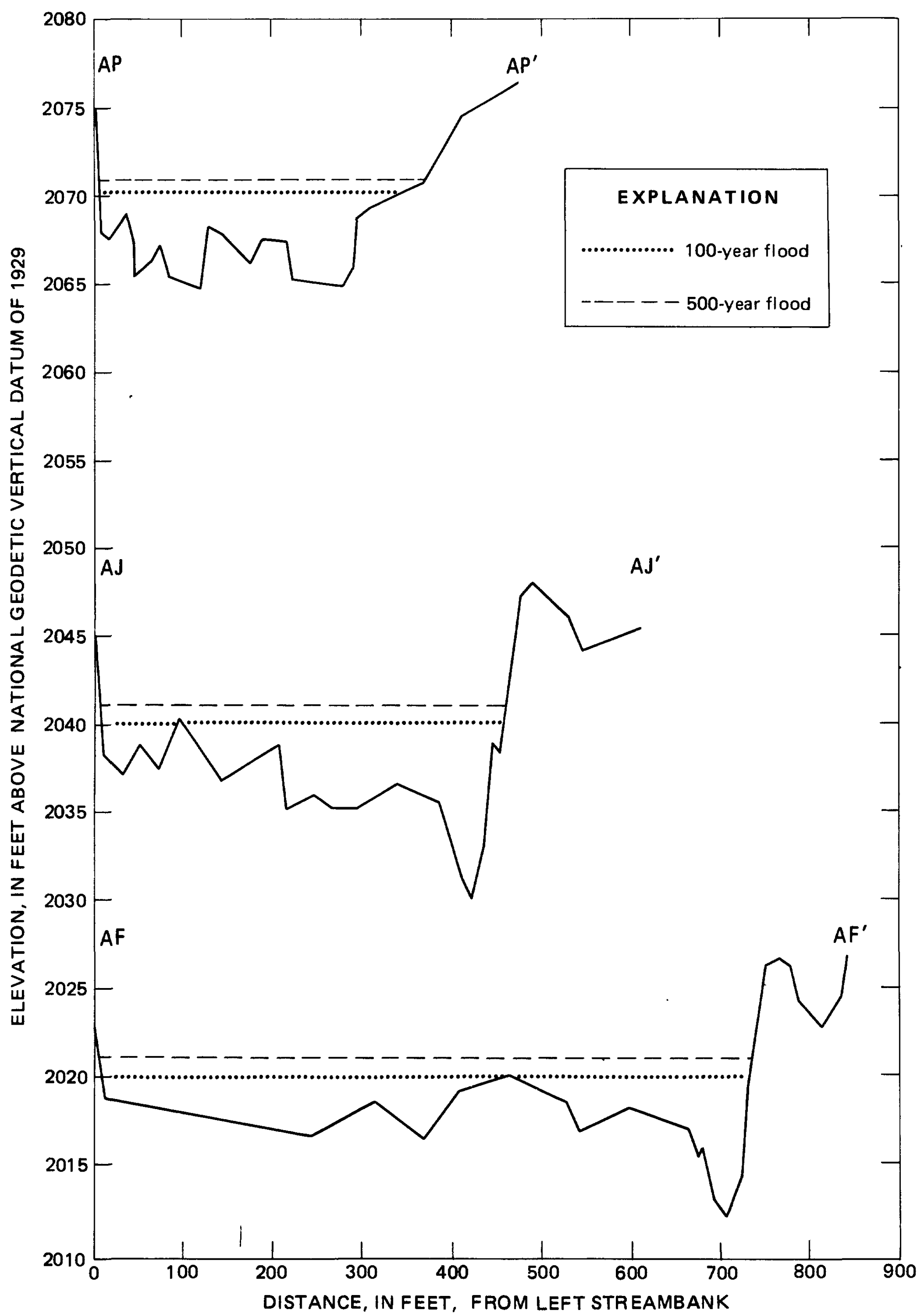

Figure 2.--Typical cross sections of the Nisqually River at Sunshine Point campground. Cross-section locations shown on plate 1.

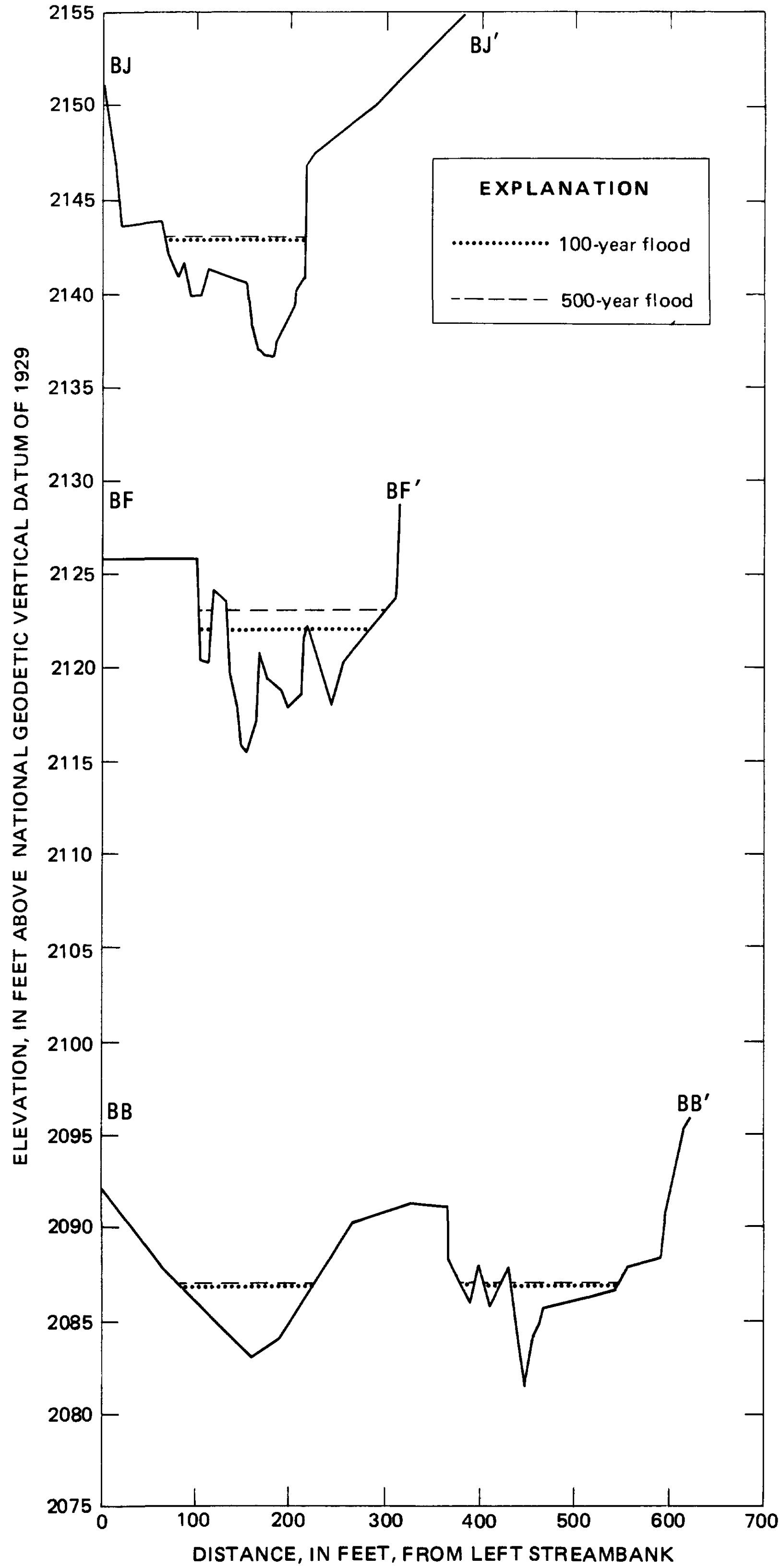

Figure 3.--Typical cross sections of Tahoma Creek at its mouth. Cross-section locations shown on plate 1.

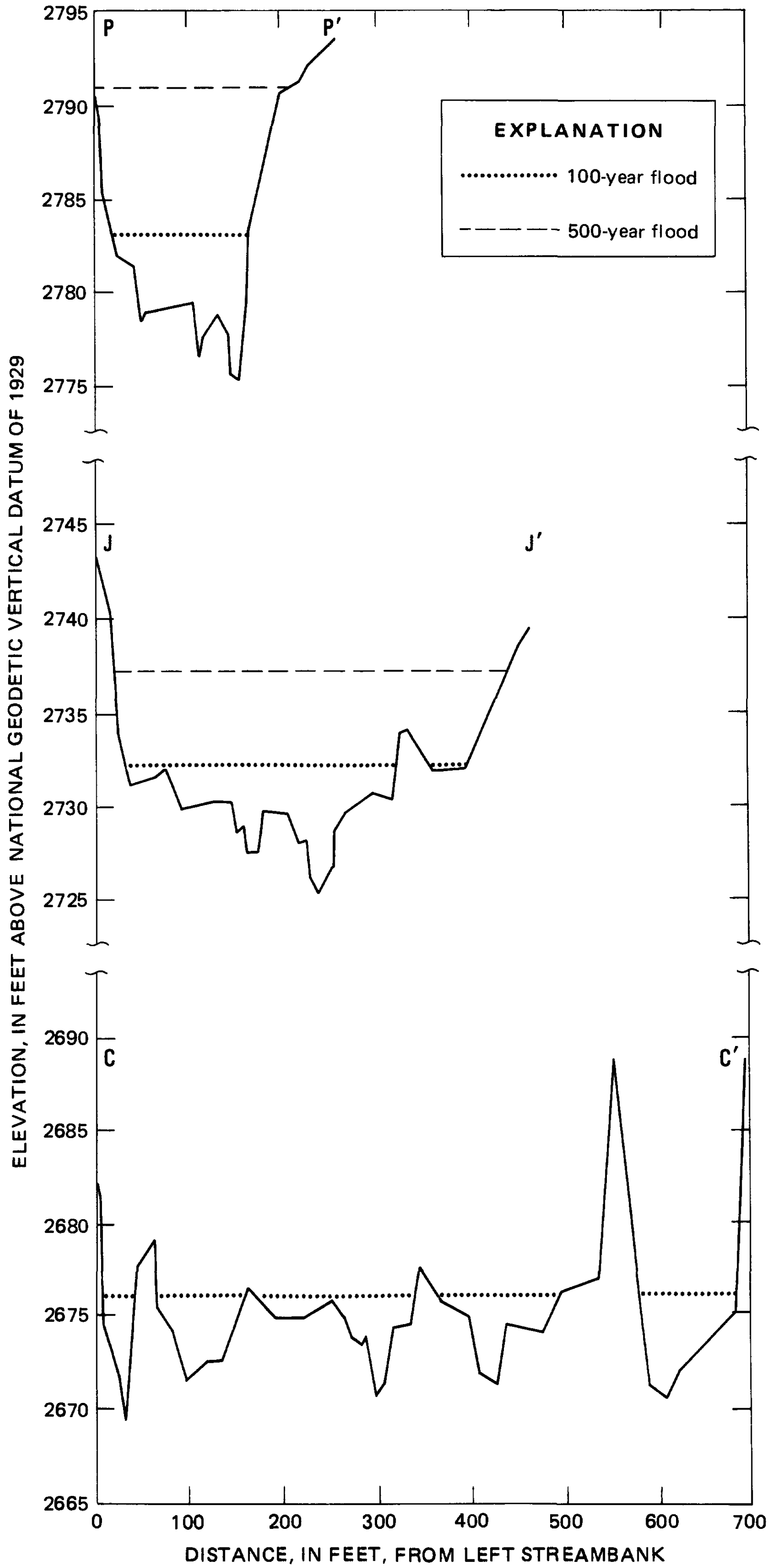

Figure 4.--Typical cross sections on the Nisqually River at Longmire. Cross-section locations shown on plate 1.

TABLE 3.--Peak water elevations for floods of selected recurrence intervals on Tahoma Creek near its mouth

Cross section (location shown in fig. 6)	Peak elevation, in feet[a] above NGVD of 1929 for selected recurrence interval			
	25-year	50-year	100-year	500-year
BA	2,082	2,082	2,082	2,083
BB	2,086	2,087	2,087	2,087
BC	2,096	2,096	2,096	2,097
BD	2,105	2,105	2,105	2,106
BE	2,111	2,112	2,112	2,112
BF	2,121	2,121	2,122	2,123
BG	2,130	2,130	2,130	2,131
BH	2,134	2,134	2,135	2,135
BI	2,137	2,137	2,138	2,138
BJ	2,142	2,142	2,143	2,143

[a]Corresponding flood discharges are given in table 1.

TABLE 4.--Peak water elevations for flood of selected recurrence intervals on the Nisqually River at Longmire

Cross section (location shown in fig. 7)	Peak elevation, in feet[a] above NGVD of 1929 for selected recurrence interval			
	25-year	50-year	100-year	500-year
A	2,660	2,661	2,661	(b)
B	2,668	2,668	2,669	(b)
C	2,675	2,675	2,676	(b)
D	2,683	2,683	2,683	(b)
E	2,689	2,690	2,690	(b)
F	2,702	2,702	2,703	(b)
G	2,710	2,710	2,710	(b)
H	2,721	2,721	2,721	(b)
I	2,726	2,726	2,727	2,730
J	2,732	2,732	2,732	2,737
K	2,743	2,743	2,744	2,749
L	2,754	2,755	2,755	2,761
M	2,761	2,762	2,762	2,768
N	2,768	2,768	2,769	2,774
O	2,776	2,776	2,777	2,784
P	2,782	2,782	2,783	2,791
Q	2,786	2,787	2,787	2,794
R	2,798	2,798	2,799	2,807
S	2,809	2,810	2,810	2,818
T	2,822	2,822	2,822	2,831

[a]Corresponding flood discharges are given in table 1.
[b]Elevation indeterminate due to unconfined overflow.

sections, although in reality the greater discharge produces a somewhat higher water elevation than does the lesser discharge. The computer program uses data for river cross-section geometry and elevation, channel slope between cross sections, and hydraulic friction (Manning's roughness coefficient, n) to balance the energy equation progressively from one cross section upstream to the next for a constant discharge along a given reach of river. The starting elevations at the most downstream cross section given for the Nisqually River at Sunshine Point (section AA, pl. 1) were obtained by convergence of water-surface profiles through several cross sections located farther downstream. The starting elevations for Tahoma Creek were obtained from section AO on the Nisqually River (pl. 1). Ten cross sections were synthesized from BA on Tahoma Creek (pl. 1). The sections were placed approximately 70 feet apart from section BA to the 100-year flood-peak boundary on the Nisqually River to determine the possible maximum elevations for floodflows on Tahoma Creek downstream of section BA. The floodflows were contained on the fan below section BA. The flood boundaries were drawn allowing the flow to spread over the fan through the many channels. The starting elevations at the most downstream cross section given for the Nisqually River at Longmire (section A) were obtained by convergence of water-surface profiles through several cross sections located farther downstream for all discharges except the 500-year flood peak. The 500-year peak elevations for cross-sections A through H (pl. 2) were not determined because the Nisqually River flows out of the main channel over both banks at those cross sections, and the amount of flow in the overflow areas could not be determined.

Channel roughness coefficients (Manning's n) used in the hydraulic computations were chosen on the basis of field observations and engineering subjective judgments. The roughness factors and computed elevations could not be verified because elevations for flood peaks in these reaches have not been recorded. Roughness factors of 0.050-0.075 were used for the main channel and 0.075-0.150 were used for the flood plains.

The elevations obtained by step-backwater computation for 25-, 50-, 100-, and 500-year peak discharges are based on unobstructed flow. Piles of forest debris and rocks observed during the 1982 survey indicate that flow could easily become obstructed at some places during flood, and peak water elevations may be somewhat higher than computed in such areas.

Boundaries of the 100-year flood are shown on topographic maps prepared especially for this investigation (pls. 1 and 2). The maps and elevation contours were prepared photogrammetrically from aerial photographs taken July 1982; contours are shown as dashed-line estimates where vegetation obscured a continuous clear view of the ground. In most places boundaries for 25-, 50-, and 500-year floods are within a few feet of coinciding with the 100-year flood-peak boundaries, and therefore are not shown on the maps, except as noted. Islands (parts of the cross sections in the channel that are above the elevation of floodflows) were not delineated on the flood-boundary maps because they are composed of materials that are easily eroded. The flood boundaries were determined by laterally extending elevations from flood-elevation profiles to intersect with ground contours corresponding to those elevations. The flood-elevation profiles (figs. 5, 6, and 7) were prepared by connecting with straight lines the computed flood elevations at each cross section along the length of each reach. Included with each flood-elevation profile is a profile of the thalweg, or lowest streambed elevation along the length of reach, which portrays maximum depth of floodwater.

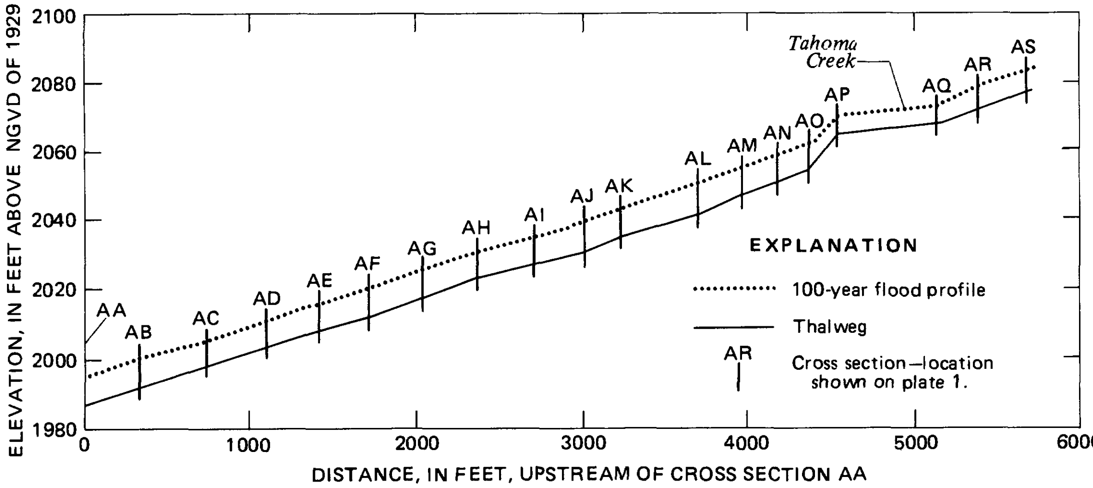

Figure 5.--Flood-elevation profile of the Nisqually River at Sunshine Point campground. Profiles for the 25-, 50-, and 500-year flood nearly coincide with the 100-year flood profile.

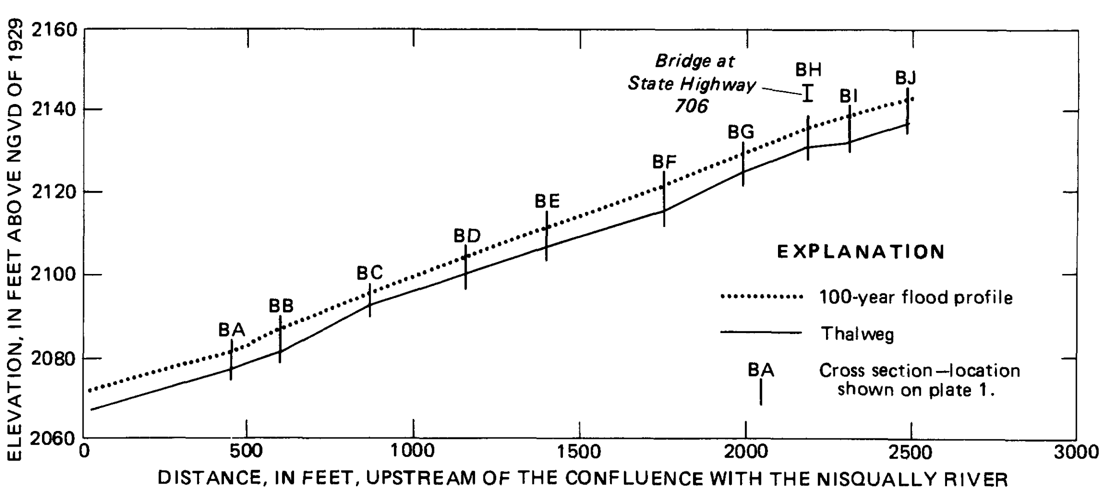

Figure 6.--Flood-elevation profile of Tahoma Creek at its mouth. Profiles for the 25-, 50-, and 500-year flood nearly coincide with the 100-year flood profile.

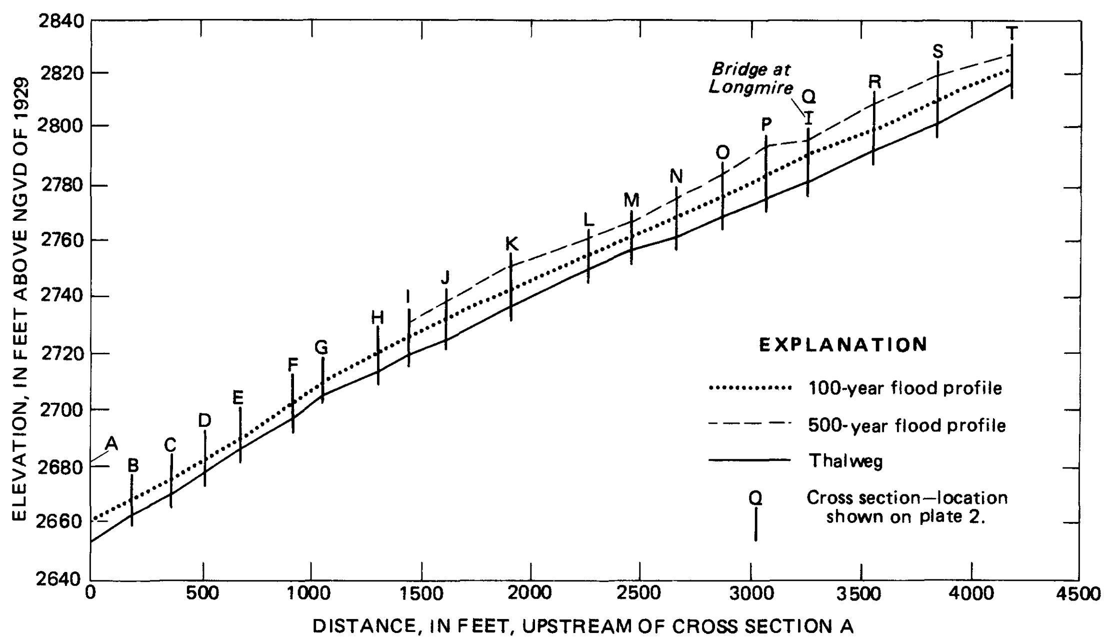

Figure 7.--Flood-elevation profiles of Nisqually River at Longmire. Profiles for the 25- and 50-year flood nearly coincide with the 100-year profile.

Average Water Velocities

Average water velocities at each cross section for the several flood-peak recurrence intervals are given in tables 5 through 7. The water velocities are quite high at most locations during floods because of the steep gradients. Such high velocities provide an appreciable force to move channel materials and change the channel's shape. Thus, it is considered dangerous to be in or near the flowing water during any floodflows, and most especially at Longmire if there is a large outburst flood. No deep or high-velocity areas were delineated in this investigation because all flow areas are considered hazardous.

TABLE 5.--Average water velocities for floods of selected recurrence intervals on the Nisqually River at Sunshine Point campground

Cross section (location shown in figs. 5,6)	Average water velocity (ft/s)[a] for selected recurrence interval			
	25-year	50-year	100-year	500-year
AA	6.1	6.5	6.9	7.5
AB	5.0	5.4	5.6	6.2
AC	6.1	7.0	7.4	8.1
AD	7.0	7.6	8.2	8.9
AE	5.6	6.1	6.5	7.2
AF	6.2	6.5	6.9	7.4
AG	7.3	7.6	8.0	8.7
AH	5.6	6.0	6.5	7.1
AI	7.1	7.6	8.0	8.7
AJ	6.9	7.4	7.9	8.7
AK	6.9	7.4	8.0	8.7
AL	7.5	7.7	7.7	8.3
AM	6.4	6.7	7.0	7.7
AN	7.8	8.5	9.3	10.2
AO	7.3	8.0	8.6	9.4
AP	7.5	7.9	8.2	9.4
AQ	5.3	5.6	5.9	6.4
AR	8.4	9.0	9.6	10.1
AS	5.8	6.1	6.3	7.2

[a]Corresponding flood discharges are given in table 1.

TABLE 6.--Average water velocities for floods of selected recurrence intervals on the Tahoma Creek near its mouth

Cross section (location shown in fig. 6)	Average water velocity (ft/s)[a] for selected recurrence interval			
	25-year	50-year	100-year	500-year
BA	4.2	4.2	4.4	4.8
BB	5.8	6.0	6.2	6.7
BC	6.5	6.7	7.0	7.4
BD	4.4	4.7	5.0	5.3
BE	5.8	6.1	6.6	7.3
BF	6.6	7.0	7.5	8.2
BG	4.9	5.2	5.6	6.3
BH	8.5	8.8	9.3	10.1
BI	6.4	6.7	7.1	7.8
BJ	7.1	7.5	8.1	9.0

[a]Corresponding flood discharges are given in table 1.

TABLE 7.--Average water velocities for floods of selected recurrence intervals on the Nisqually River at Longmire

Cross section (location shown in fig. 7)	Average water velocity (ft/s)[a] for selected recurrence interval			
	25-year	50-year	100-year	500-year
A	8.0	8.0	8.4	(b)
B	7.0	7.0	7.1	(b)
C	4.9	5.1	5.5	(b)
D	5.4	5.7	6.0	(b)
E	5.1	5.5	5.9	(b)
F	6.8	7.0	7.4	(b)
G	6.0	6.4	6.8	(b)
H	4.8	5.1	5.4	(b)
I	5.5	5.8	5.9	10.0
J	5.7	5.9	6.0	9.4
K	7.4	7.8	8.4	12.3
L	6.3	6.9	7.6	15.6
M	6.2	6.6	7.1	11.1
N	6.3	6.7	7.3	13.2
O	8.6	9.1	9.8	15.7
P	7.8	8.3	9.0	16.0
Q	7.4	7.9	8.6	22.6
R	6.6	7.2	7.8	15.6
S	6.9	7.4	8.2	17.6
T	7.3	7.6	8.2	10.3

[a]Corresponding flood discharges are given in table 1.
[b]Evaluation indeterminate due to unconfined overflow.

SUSCEPTIBILITY OF FACILITIES TO FLOODING

The computational analyses for this investigation indicate that the Sunshine Point and the Longmire campgrounds, visitors' center, and ranger station generally are free from extensive inundation during major floods. That conclusion is only valid if the riverbanks and dikes retain their present integrity and there is no accumulation of debris or bed material that would block or divert flow in the Nisqually River channel. However, the hydraulics, observed topography, and riverbank composition of the Nisqually River and Tahoma Creek indicate that water velocities are high during floods and play a major role in mobilizing the streambed, eroding the banks, and causing extensive deposits of debris and streambed material in the channel and on the flood plain. In addition, a large buildup of bed material at any channel location during recession from a flood could potentially cause water to flow over the banks in subsequent floods. Therefore, neither Sunshine Point nor Longmire facilities can be considered entirely free from flooding or flood damage. Some level of protection against the dikes or banks being topped or breached by floods is provided if the present practice of maintaining channel capacity by removing (bulldozing) deposited material from the main channel after large buildups is continued.

Of the two study sites, Sunshine Point is the more susceptible to flooding. It is bordered on two sides by unstable stream channels. After flowing under the State Highway 706 bridge a short distance upstream from Sunshine Point, Tahoma Creek flows onto an alluvial fan on the flood plain of the Nisqually River. Like the Nisqually River, the channel and flood plain of Tahoma Creek are composed largely of well-rounded alluvial cobbles and boulders, and the high velocity of the creek flow causes frequent streambed movement and channel alternations. Although Sunshine Point is protected on the Nisqually River side by a riprap armored dike, the dikes on the Tahoma Creek side are built only of streambed material. Because the downslope direction of Tahoma Creek is towards the Sunshine Point campground, it is possible that the Tahoma Creek dike could be breached or that a large buildup of bed material in the channel or on the alluvial fan could cause the creek, or perhaps even worse, a debris flow, to enter the campground. Although there is no recorded evidence of outburst floods from Tahoma Glacier reaching the mouth of the creek, the composition of the materials in the flood plain suggests that outbursts may at one time have traveled that far.

At Longmire, flooding or flood damage is much less than at Sunshine Point and the potential for flooding should remain low as long as channel flood capacity is maintained and the dikes and banks remain intact. A high ridge at the upstream side of the visitor center and the ranger station protects this area from the Nisqually River. Even so, there is potential that a very large outburst flood could top the dike that protects the river side of the area. Because outburst floods can transport large quantities of debris and rock materials, even over the tops of dikes, extensive damage could occur to the facilities at the Longmire visitors' center. The campground at Longmire is across the Nisqually River from those facilities and may be reached by a bridge; it also is protected by a high ridge. Although this investigation indicates that the campground is not highly susceptible to flooding, flooding could occur if the Nisqually River channel becomes blocked by any means. Any flow entering this campground could cause extensive damage, as the terrain there is all downslope.

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