SEDIMENT TRANSPORT IN THE LOWER PUYALLUP, WHITE, AND CARBON RIVERS OF WESTERN WASHINGTON

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CONVERSION FACTORS

For the convenience of readers who may prefer to use metric 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 metric units
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
ton	0.9078	ton (metric)
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
	0.02832	cubic meters per second (m^3/s)
cubic yard (yd^3)	0.7646	cubic meter (m^3)

Sea level: In this report "sea level" refers to the 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 Sea Level Datum of 1929.

SEDIMENT TRANSPORT IN THE LOWER PUYALLUP, WHITE, AND CARBON RIVERS OF WESTERN WASHINGTON

By William G. Sikonia

EXECUTIVE SUMMARY

In 1983, the Pierce County Public Works Department initiated a study of flood protection on the lower Puyallup, White, and Carbon Rivers that flow from the slopes of Mount Rainier in western Washington (fig. E1). Since 1974, the Pierce County and Inter-County River Improvement agencies, as well as private parties, have removed above-water parts of gravel bars from the river system. The removal has been done when the gravel bars appeared to be reducing the cross-sectional areas or increasing the average bottom elevations enough to affect flood-carrying capacity substantially. The U.S. Geological Survey, in cooperation with the Pierce County Public Works Department and the State of Washington Department of Ecology, conducted a substudy of the flood-protection study to obtain information on sediment deposition, scour, and movement in the river channels. This information could then be used to determine locations and characteristics of sediment deposits that might affect channel flood-carrying capacity, and to estimate the effects of alternatives for the control of the deposition.

Three potential alternatives for managing sediment deposition were compared using Hydrologic Engineering Center - Six (HEC-6), a computer program useful for modeling one-dimensional river flow, sediment transport, and streambed aggradation or degradation. The three alternatives were (1) to continue gravel mining by the procedure of scalping gravel bars (an appropriately descriptive term for the removal of deposited material from above the water line during periods of low flow), (2) to install sediment traps, and (3) not to intervene at all with sediment control measures on the river system. Measured cross sections, hydrographs, and sediment data collected from 1984 through March 19, 1986, provided data for input and verification of the computer model. (The starting date was July 27, 1984, on the White River, and August 16, 1984, for the Puyallup and Carbon Rivers.) The modeled time interval included four storms that produced moderately high river flows and corresponding moderately high sediment transport rates. The storms occurred June 7-10, 1985, October 25-26, 1985, January 18-20, 1986, and February 23-27, 1986. Actual stream hydrographs from the modeling period were used as input to the model. Stream cross sections measured at the start of the modeling period were used as the initial conditions of the channels. Sediment particle-size data collected during the modeling period were used to set input particle sizes in the streambeds, and transport rates measured for the same period were used to set input sediment discharges at the upstream ends of the modeled sections of the rivers. Using actual, instead of synthetic, data facilitated direct comparison of modeled and observed values. For selected locations on the rivers and selected times during the modeling period, comparisons were possible between modeled and measured bed-elevation changes, transport rates, and particle-size distributions.

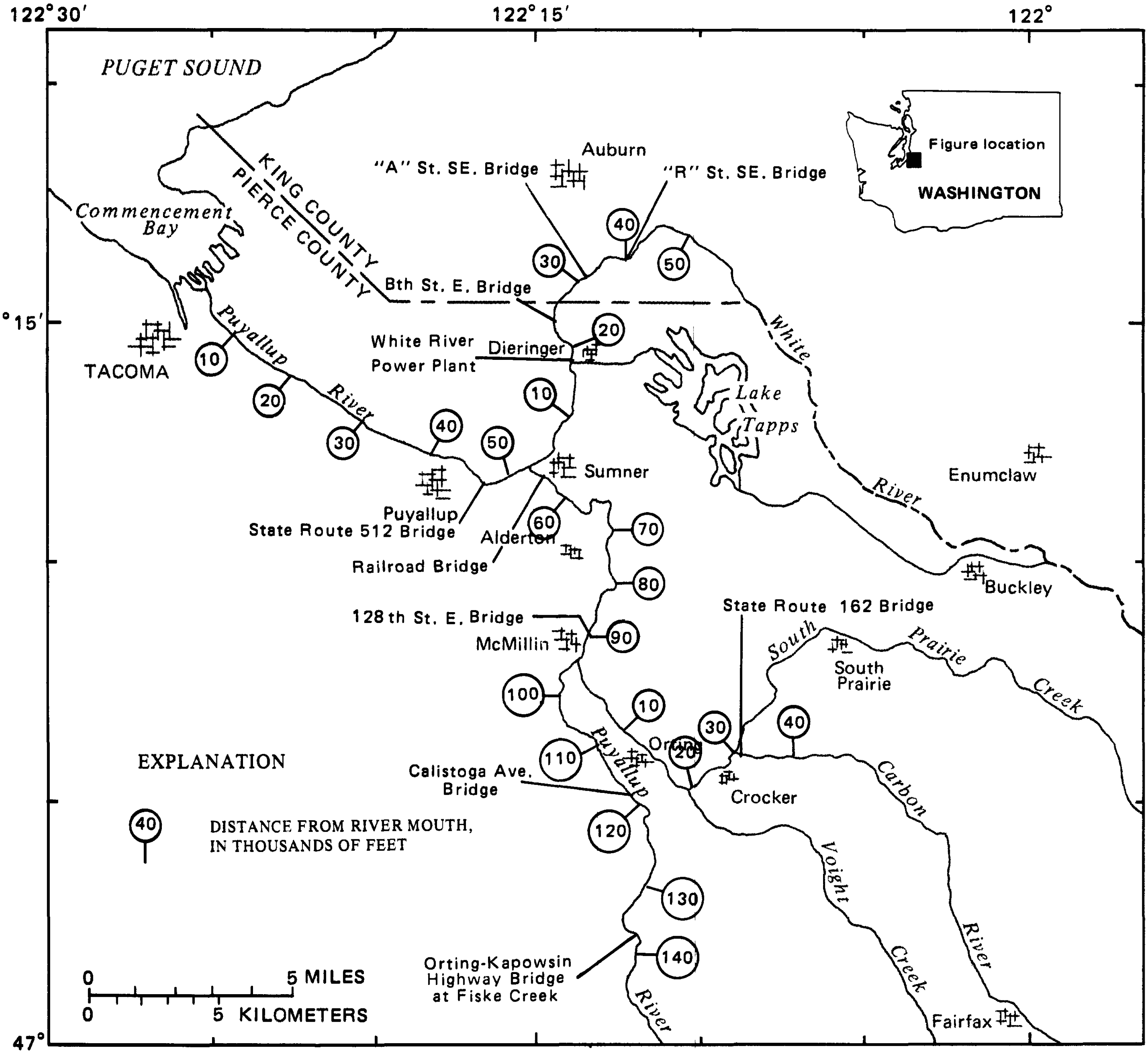

FIGURE E1.--Location of the lower Puyallup, White, and Carbon Rivers, river coordinates, selected bridges, and the White River Power Plant.

This study indicates that gravel transport is only a small part of the total sediment transport, which also includes transport of finer materials. The study further indicates that gravel transport cannot be influenced effectively by changes at a fixed upstream location, such as at a sediment trap; rather, gravel transport is influenced only near the local area at which the sediment control measure is applied. The transport and deposition of sand and finer material need to be considered in forming a complete understanding of the sediment transport process in the river system, and in formulating sediment control plans.

In analyzing the river system by a computer model such as HEC-6, one needs to be aware of limitations imposed by model accuracy. Model discharge and field-measured discharge for silt compared within a factor of 2.5, for sand, within a factor of 2.2, and for gravel, within a factor of 1.9 or 7, depending on whether a questionable field measurement was included in the comparison. The factor either multiplies or divides the best estimate (noted by × or ÷). For example, if the modeled sand discharge is 10,000 tons per day, root-mean-square error bounds would be 10,000 ÷ 2.2 = 4,500 tons per day, to 10,000 × 2.2 = 22,000 tons per day. Differences between modeled streambed elevations and those from field surveys were within ±0.5 foot.

A general-purpose location map for figures E2 through E6, which will be presented in this executive summary, is shown in figure E1. River coordinates, selected bridges, and the White River Power Plant, which will be referenced in the text and tables, are shown in figure E1. The river coordinates shown in figure E1 are the distances in thousands of feet from the mouth of the Puyallup River at Commencement Bay; for the White and Carbon Rivers, the distances are in thousands of feet from their junctions with the Puyallup River. The same map base was used in constructing figures E1 through E6. In figures E2 through E6, areas of panels A through L of figure A2, Appendix A, are shown. The larger scale of the figure A2 panels allows detailed location of physical features and river coordinates. Panel references will be given in the text and tables to aid in locating a feature within a particular panel on these figures, and to indicate which panel of figure A2, Appendix A, to reference for more detail. The cross-reference location map, figure E1, may not be explicitly given in a text reference to figures E2 through E6, but its use will be implied for the purpose of locating river coordinates or features along the rivers.

Non-Intervention Alternative

The non-intervention alternative is based on the assumption that gravel-bar scalping operations would cease and that sediment traps would not be installed. Both cross-section surveys and computer model results indicated that in much of the modeled system, scour rather than deposition took place. The non-intervention alternative, therefore, would be appropriate on these reaches. There were, however, areas of deposition that would not be ameliorated by the non-intervention approach.

Gravel Mining Alternative

Modeling indicated that gravel and coarser material were deposited in some river reaches (fig. E2). Scalping of gravel bars could be the most appropriate alternative to be applied to these reaches (fig. E3). The modeling results indicated that the scalping of gravel bars would be an effective method of maintaining channel capacity if restricted to reaches where deposition was occurring, provided that only the amount of aggradation is removed over the long term. Locations of substantial gravel deposition are given in table E1. These locations would be the primary areas for a continued program of gravel-bar scalping. The sum of the rate of deposition for sand and finer materials and the rate for gravel and coarser materials given in table E1 defines the rate of deposition for all size classes, because the total deposit is removed by the process of gravel-bar scalping. The total deposition rates in table E1 provide guidelines from modeling for the amount of gravel removal that would have resulted in steady-state channel conditions during the modeling period. Actual scalping volumes could vary from deposited volumes during a particular time interval, such as the modeling period, if only a longer-term average balance between deposits and removal is sought. That is, gravel removal in excess of the volumes in table E1 might have occurred at some sites to remove sediments deposited before the start of the modeling period.

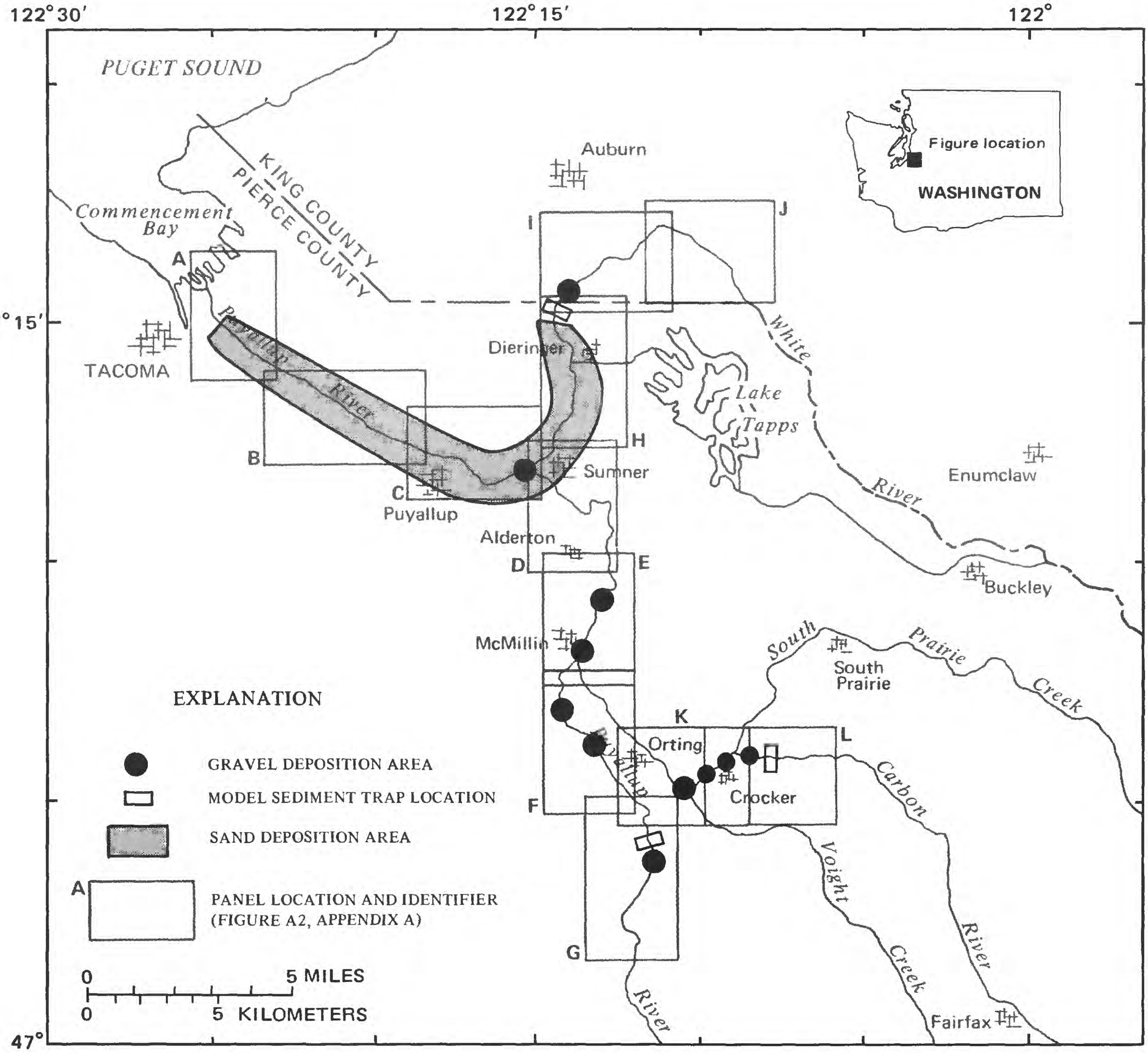

FIGURE E2.--Depositional areas for sand and finer material, and those for gravel and coarser material, from the computer model.

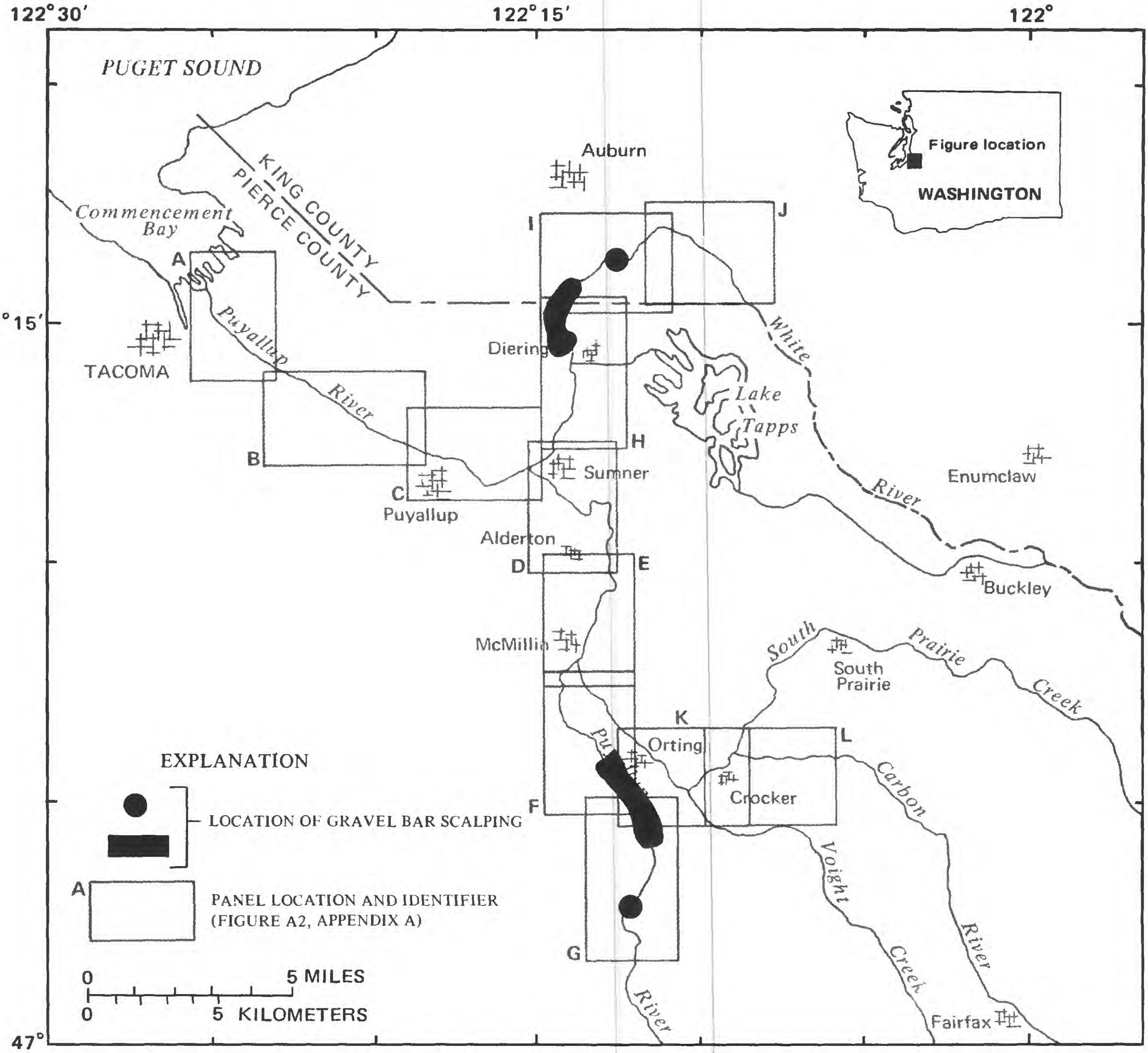

FIGURE E3.--Locations of gravel bar scalping during the modeling period.

Table E1.--River reaches with substantial deposition of gravel and coarser material[1]

[g, deposition of gravel and coarser material; s, sand and finer material; t, all size classes]

River	Limit of reach, in feet from river mouth		Average rate of deposition (+) or scour (-), in cubic yards per foot of river length per year			Reach description[2]
	Downstream	Upstream	g	s	t	
Puyallup	124,000	126,000	4.3	0.4	4.7	In sediment control site /a/ near Orting, Washington (panel G)
Do.	123,200	124,000	1.1	-0.3	0.8	In sediment control site /a/ near Orting, Washington (panel G)
Do.	108,200	110,300	1.4	0.7	2.1	Between mouth of Carbon River and Orting, Washington (panel F)
Do.	100,200	102,200	1.7	0.5	2.2	Between mouth of Carbon River and Orting, Washington (panel F)
Do.	91,200	93,200	1.7	0.6	2.3	Near mouth of Carbon River (panel E)
Do.	83,700	86,100	1.2	0.0	1.2	Near McMillan, Washington (panel E)
Do.	53,500	54,400	3.4	-0.9	2.5	Near mouth of White River (panel C)
White	29,600	31,500	1.2	0.9	2.1	Near Auburn, Washington (panel I)
Carbon	32,400	33,300	2.5	0.0	2.5	Near Crocker, Washington (panel L)
Do.	28,200	30,000	2.4	-1.2	1.2	Near Crocker, Washington (panel K)
Do.	24,300	26,200	1.1	-0.5	0.6	Near Crocker, Washington (panel K)
Do.	18,600	21,900	2.2	0.0	2.2	Near Orting, Washington (panel K)

[1] Deposition rates were averaged during the time interval from July and August 1984 to March 19, 1986. The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

[2] The reference after each reach description is to a panel area shown in figure E2 (gravel deposition areas) or figure E4 (control sites); the same panel of figure A2, Appendix A, shows the area in more detail.

Sediment Trap Alternative: Effect on the Transport of Sand and Finer Material

In other river reaches, where sand and finer material was deposited, computer modeling indicated that sediment traps were effective in removing silt and sand from the sediment load transported farther downstream; a secondary effect of this reduced transported load was somewhat reduced silt and sand deposition downstream. (The reduction is an indirect effect of the reduced transported load because changes in transported load, rather than the transported load itself, determine deposition; for example, a large sediment load can be carried completely through a river reach with no deposition.) Table E2 shows the effect of sediment traps on the deposition of sand and finer material. The modeling results indicated that the traps had markedly different effects on the transport and deposition of sand and finer material than on gravel and coarser material.

Table E2.--Effect of sediment traps on deposition of sand and finer material, showing average annual deposition in the indicated reaches from July and August 1984 to March 19, 1986[1]

River	Limits of sediment trap, in feet from river mouth: Downstream	Limits of sediment trap, in feet from river mouth: Upstream	Limits of deposition reach, in feet from river mouth: Downstream	Limits of deposition reach, in feet from river mouth: Upstream	Annual volume of sand and finer material, in cubic yards per year[2]: Deposition in reach without trap	Deposition in reach with trap	Reduction in deposition due to trap	Required maintenance removal from trap
Puyallup[3]	122,070	123,130	7,700	58,200	51,000	[4] 8,000	[4] 43,000	46,000
White[5]	27,510	28,560	500	27,500	52,000	19,000	33,000	110,000
White[3]	27,510	28,560	500	27,500	56,000	21,000	35,000	114,000
Carbon[3]	34,370	35,430	no significant deposition of sand and finer material					25,000

[1] The starting date was August 16, 1984, for the Carbon and Puyallup Rivers. The starting date for the White River was July 27, 1984, but the slightly shorter period starting August 16, 1984, is also given because of the influence of the White River trap on the Puyallup River.

[2] All four columns refer only to sand and finer material, and exclude annual volumes of gravel and coarser material.

[3] August 16, 1984, to March 19, 1986.

[4] Includes reduction of sand and finer load due to traps on the White and Carbon Rivers, as well as on the Puyallup River.

[5] July 27, 1984, to March 19, 1986.

On the White River, a model sediment trap was located from 27,510 to 28,560 feet upstream from the mouth (fig. E2, panel H). The trap location was within sediment transport control site /b/ (table E3; fig. E4, panels H and I), upstream of the 8th Street East Bridge located between Dieringer and Auburn (fig. E1). Sand and finer material were deposited on the reach from 500 to 27,500 feet upstream from the mouth (fig. E2, panels D and H). This deposition reach extends from the river's mouth to upstream of the 8th Street East Bridge and includes "hot spot" locations B1, B2, B3, and part of C1 (table E4; fig. E5, panels D and H). (The "hot spot" locations as defined herein include communities, developments, existing public utilities, structures, and flood-control works that require measures to reduce flood damages.) Deposition of sand and finer material in this reach was reduced from 52,000 to 19,000 cubic yards per year by the model sediment trap, a reduction of 33,000 cubic yards per year. However, this reduction was at the expense of maintenance removal of a much larger 110,000 cubic yards per year of sand and finer material from the model sediment trap. That is, the model indicated that most of the sand and finer material removed by the trap would have been transported into the lower Puyallup River and Commencement Bay, instead of being deposited in the White River below the trap.

Table E3.--Sediment transport control sites, by priority (Anderson, 1986)

Control site	River	Distance from mouth (feet)	Cross section	Location[1]
/a/	Puyallup	122,020-128,030	P135-P141	Orting area, upstream of city of Orting limits (panel G)
/b/	White	25,970- 29,620	W66- W70	Dieringer-Auburn area, upstream of 8th Street East Bridge (panels H, I)
/c/	Carbon	upstream of 31,450	upstream of C33	Crocker area, about 0.6 mile upstream of State Route 162 Bridge (panel L)
/d/	White	39,650- 43,240	RM7.51-RM8.19	Auburn area, upstream of the "R" Street Southeast Bridge (panel I)
/e/	White	32,790- 37,440	RM6.21-RM7.09	Auburn area, upstream of the "A" Street Southeast Bridge (panel I)
/f/	Puyallup	upstream of 137,050	upstream of P150.2	Orting area, upstream of Orting-Kapowsin Highway Bridge at Fiske Creek (panel G)

[1] The reference after each location is to a panel area shown in figure E4; the same panel of figure A2, Appendix A, shows the area in more detail. See figure E1 for locations of bridges.

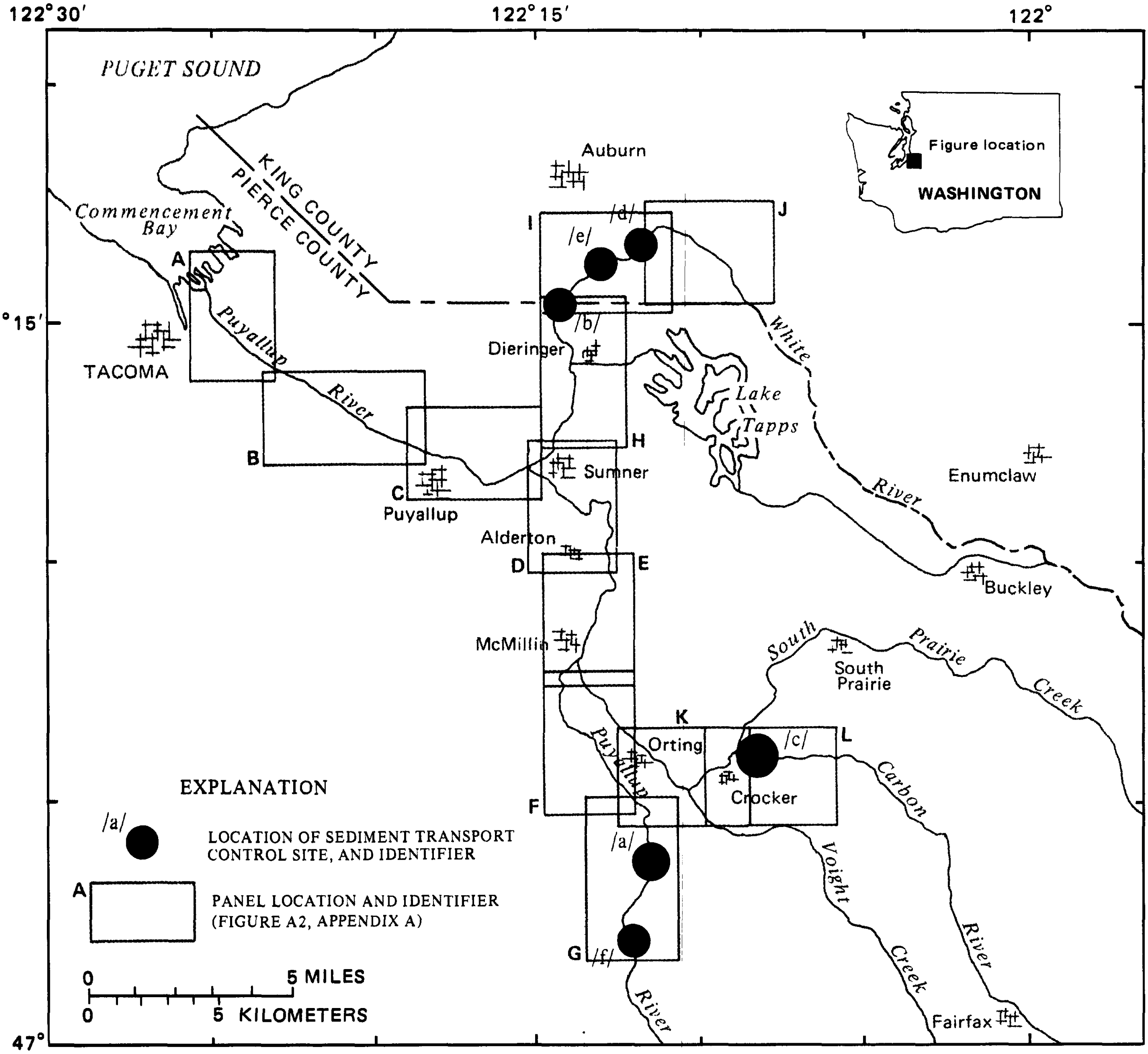

FIGURE E4.--Sediment transport control sites /a/ through /f/ (Anderson, 1986).

Table E4.--"Hot spot" locations, by priority (Anderson, 1986)

Hot Spot	River	Distance from mouth (feet)	Cross section	Location[1]
A1	Puyallup	110,300-115,200	P122-P127	Orting area, downstream of Calistoga Avenue Bridge (panel F)
A2	Puyallup	115,480-122,020	P128-P135	Orting area, upstream of Calistoga Avsnue Bridge (panels F, G)
A3	Puyallup	122,020-125,980	P135-P139	Orting area, 1.3 to 2.0 miles upstream of Calistoga Avenue Bridge (panel G)
A4	Carbon	9,440- 19,760	C10- C20	Orting area (panels F, K)
B1	Lower White	5,970- 9,620	W46- W51	Sumner area (panels D, H)
B2	Lower White	9,620- 19,230	W51- W60	Dieringer area, downstream of White River Power Plant (panel H)
B3	Lower White	19,230- 25,970	W60- W66	Dieringer area, downstream of 8th Street East Bridge (panel H)
C1	Middle White	25,970- 29,620	W66- W70	Dieringer-Auburn area, upstream of 8th Street East Bridge (panels H, I)
C2	Middle White	29,620- 39,650	W70 -RM7.51	Auburn area, downstream of "R" Street Southeast Bridge (panel I)
D1	Puyallup	48,050- 49,550	P58- P60	Puyallup area, upstream of State Route 512 Bridge (panel C)
D2	Puyallup	53,510- 55,550	P64- P66	Puyallup area, at mouth of White River (panel C)
D3	Puyallup	56,560- 62,540	P68- P74	Puyallup area, upstream of railroad bridge (panel D)
D4	White	450- 1,480	W39- W40	Sumner area, at mouth of White River (panel D)
E1	Puyallup	84,990- 89,660	P97-P101	McMillan area, downstream of 128th Street East Bridge (panel E)
E2	Puyallup	89,660- 93,240	P101-P105	McMillan area, upstream of 128th Street East Bridge to mouth of Carbon River (panel E)
F1	Upper White	39,650- 55,860	RM7.51 -RM10.58	Auburn area, upstream of "R" Street Southeast Bridge (panels I, J)

[1] The reference after each location is to a panel area shown in figure E5; the same panel of figure A2, Appendix A, shows the area in more detail. See figure E1 for locations of bridges and the White River Power Plant.

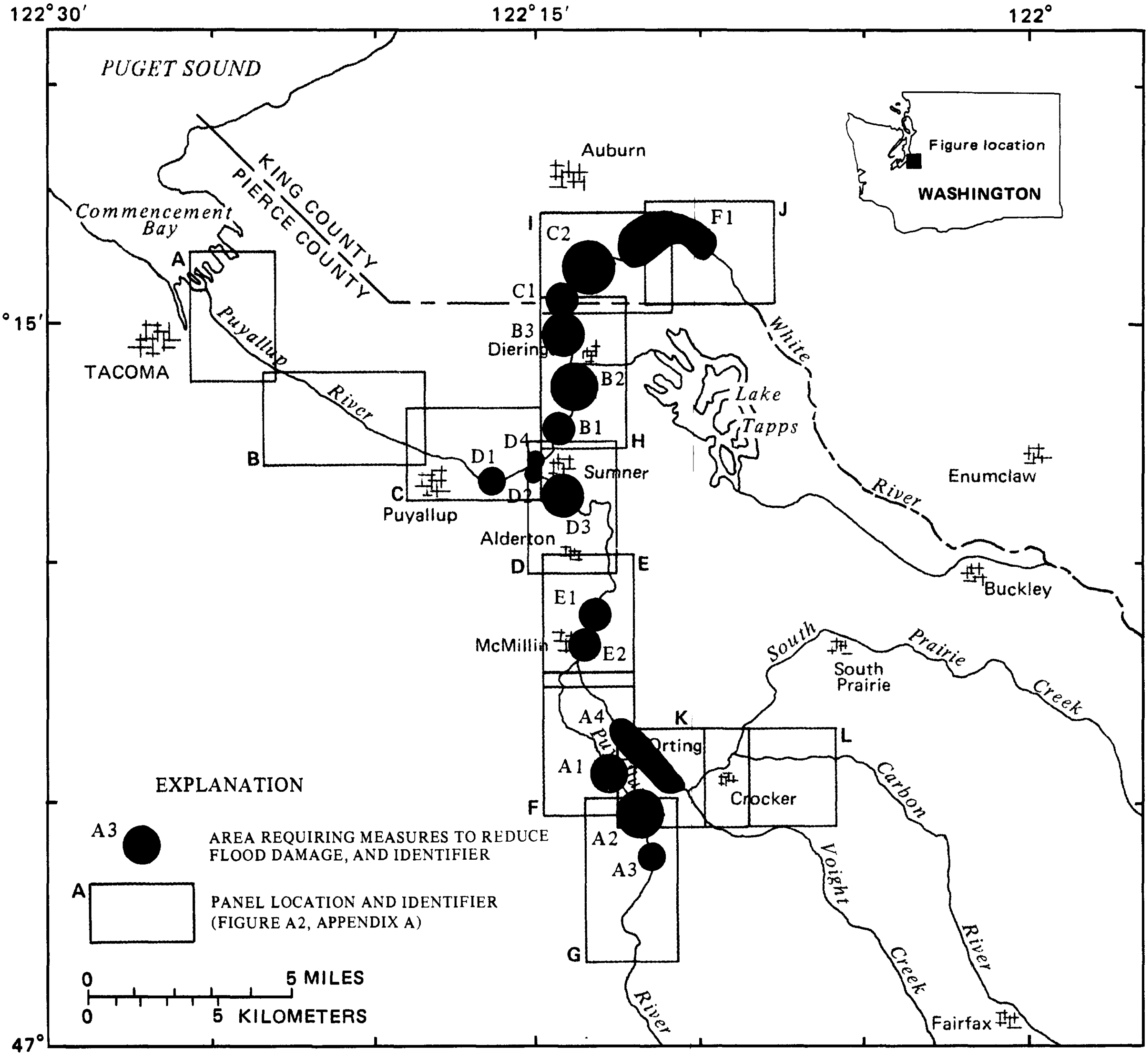

FIGURE E5.--Location of communities, developments, existing public utilities, structures, and flood control works that require measures to reduce flood damage.

A model trap on the Carbon River was located from 34,370 to 35,430 feet from the river's mouth (fig. E2, panel L), in sediment control site /c/ (table E3; fig. E4, panel L), upstream of the State Route 162 Bridge located about a half mile north of the city of Crocker (fig. E1). However, the Carbon River did not have any reaches where deposition of sand and finer material was larger than 0.7 cubic yards per foot of length along the river, per year. Therefore, the model results indicate that traps for the purpose of sand removal probably are not needed on the Carbon River, unless the purpose is to remove sand that would be transported into the Puyallup River and Commencement Bay.

On the Puyallup River, deposition of sand and finer material occurred from 7,700 to 58,200 feet upstream from the mouth (fig. E2, panels A, B, C, and D). This deposition reach extends from the Port of Tacoma to upstream of the mouth of the White River and includes "hot spots" D1, D2, and part of D3 (table E4; fig. E5, panels C and D). The model sediment trap on the Puyallup River was located between 122,070 and 123,130 feet from the mouth (fig. E2, panel G). This trap location is within sediment transport control site /a/, upstream of the city of Orting (table E3; fig. E4, panel G). Deposition of sand and finer material in the reach was reduced from 51,000 to 8,000 cubic yards per year by the combined effect of sediment traps on the Puyallup, White, and Carbon Rivers, a reduction in annual deposition of 43,000 cubic yards.

It is perhaps more instructive to consider the combined deposition reaches for sand and finer material on both the lower White and Puyallup Rivers (fig. E2, panels A, B, C, D, and H). In addition to the reduction of 43,000 cubic yards on the Puyallup River, the model indicated a reduction of 35,000 cubic yards per year in deposition of sand and finer material on the White River from August 16, 1984, to March 19, 1986 (table E2), for a total reduction of 78,000 cubic yards per year. This modeled reduction was at the expense of the removal of 46,000 cubic yards per year from the trap on the Puyallup River, 114,000 cubic yards per year from the trap on the White River, and 25,000 cubic yards per year from the trap on the Carbon River, for a total annual removal in the three traps of 185,000 cubic yards. Thus, modeling indicated that most of the sand and finer material removed by the traps would have been transported, in the absence of the traps, into Commencement Bay, rather than being deposited in the lower White and Puyallup Rivers.

Sediment Trap Alternative: Effect on the Transport of Gravel and Coarser Material

The computer model results indicated that the influences of sediment traps on gravel transport were much more restricted to the local reach downstream and upstream from the trap (fig. E6, panels G, H, I, and L), in contrast to the effects on sand and finer material. The effects just downstream of the traps are shown in table E5, and the effects just upstream of the traps in table E6.

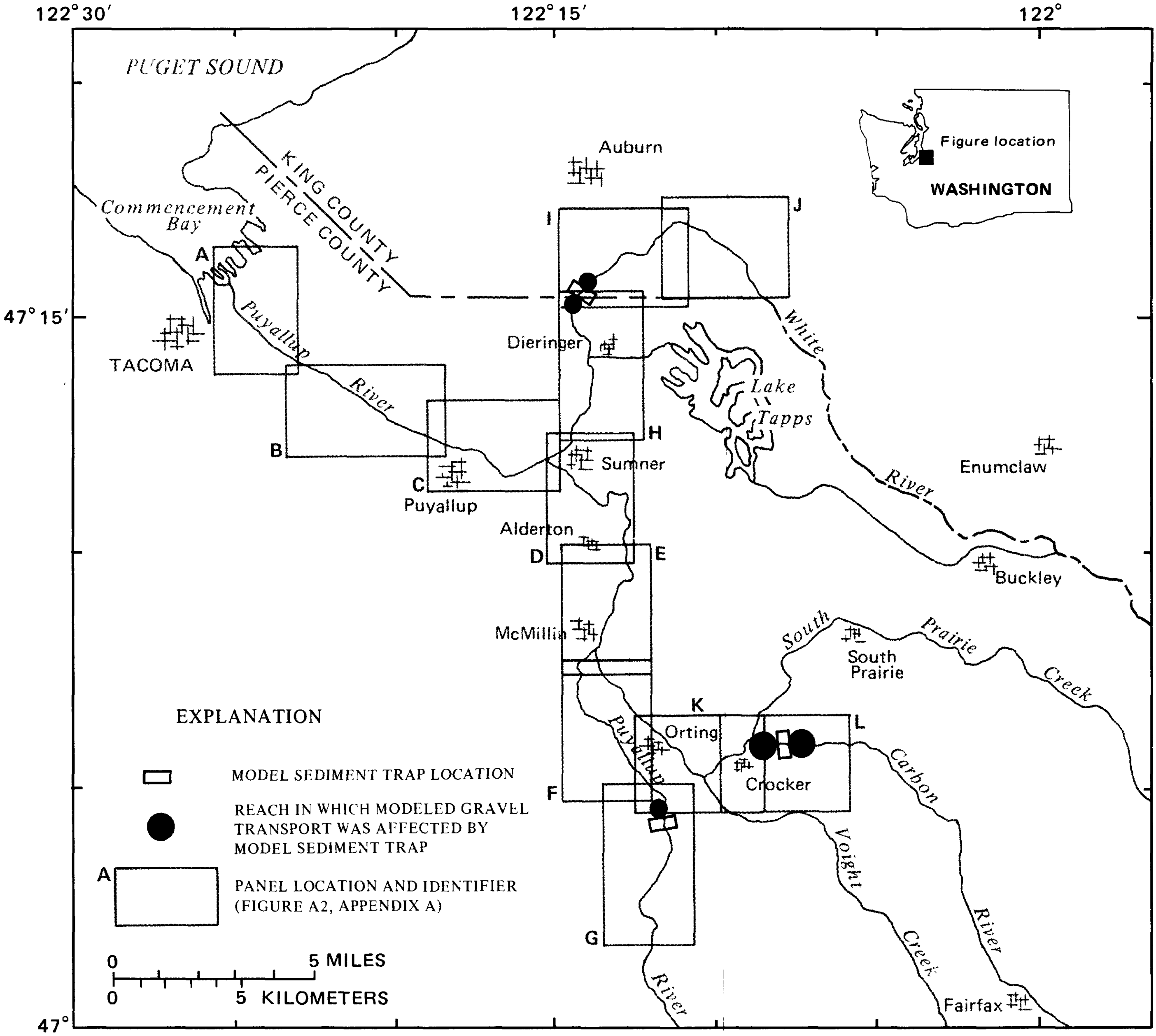

FIGURE E6.--Reaches in which modeled transport of gravel and coarser material was affected by sediment traps.

Table E5.--Downstream effect of sediment traps on deposition of gravel and coarser material, showing average annual deposition in the indicated reaches from July and August 1984 to March 19, 1986[1]

River	Limits of sediment trap, in feet from river mouth: Downstream	Limits of sediment trap, in feet from river mouth: Upstream	Limits of deposition reach, in feet from river mouth: Downstream	Limits of deposition reach, in feet from river mouth: Upstream	Annual volume of gravel and coarser material, in cubic yards per year[2]: Deposition (+) or scour (-) in reach without trap	Deposition (+) or scour (-) in reach with trap	Reduction in deposition and (or) increase in scour due to trap	Required maintenance removal from trap[3]
Puyallup	122,100	123,100	120,200	122,100	200	-200	400	700
White	27,500	28,600	26,000	27,500	-400	-1,300	900	1,200
Carbon	34,400	35,400	28,100	34,400	-600	-3,100	2,500	2,000

[1] The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

[2] All four columns refer only to gravel and coarser material, and exclude annual volumes of sand and finer material.

[3] The column refers to the total required maintenance removal of gravel and coarser material from the trap; this quantity is duplicated in table E6, and the values from the two tables should not be added.

Table E6.--Upstream effect of sediment traps on deposition of gravel and coarser material, showing average annual deposition in the indicated reaches from July and August 1984 to March 19, 1986[1]

River	Limits of sediment trap, in feet from river mouth: Downstream	Limits of sediment trap, in feet from river mouth: Upstream	Limits of deposition reach, in feet from river mouth: Downstream	Limits of deposition reach, in feet from river mouth: Upstream	Annual volume of gravel and coarser material, in cubic yards per year[2]: Deposition (+) or scour (-) in reach without trap	Deposition (+) or scour (-) in reach with trap	Reduction in deposition and (or) increase in scour due to trap[3]	Required maintenance removal from trap[4]
Puyallup	122,100	123,100	123,100	123,100	0	0	0	700
White	27,500	28,600	28,600	29,600	500	300	200	1,200
Carbon	34,400	35,400	35,400	39,000	-700	-300	-400	2,000

[1] The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

[2] All four columns refer only to gravel and coarser material, and exclude annual volumes of sand and finer material.

[3] The negative value for the Carbon River indicates a decrease in scour.

[4] The column refers to the total required maintenance removal of gravel and coarser material from the trap; this quantity is duplicated in table E5, and the values from the two tables should not be added.

On the White River, the sediment trap increased the scour of gravel and coarser material just downstream of the model sediment trap from 400 to 1,300 cubic yards per year, an increase of 900 cubic yards per year (table E5). The downstream reach extended from 26,000 to 27,500 feet upstream from the mouth of the White (fig. E6, panel H), and included part of "hot spot" C1 in the 8th Street East Bridge area between Dieringer and Auburn (table E4; fig. E5, panel H). Just upstream of the model trap, deposition was reduced from 500 cubic yards per year to 300 cubic yards per year, a reduction of 200 cubic yards per year (table E6). The upstream reach extended from 28,600 to 29,600 feet above the river's mouth (fig. E6, panel I), and included part of "hot spot" C1 upstream of the 8th Street East Bridge (table E4; fig. E5, panel I). Operation of the trap required the maintenance removal of 1,200 cubic yards per year of gravel from the trap. (Note that the last column is duplicated in tables E5 and E6, and already refers to the total removal of gravel and coarser material from the trap; the entries from the tables should not be added to arrive at total removal.)

The addition of the trap caused increased deposition within the length of the trap, which was balanced by reduced deposition in the nearby upstream reach, and increased scour in the nearby downstream reach. In a local reach that extended from 26,000 to 29,600 feet from the river's mouth and included the trap, total deposition of gravel and coarser material was about the same as it had been without the trap, namely, 100 cubic yards per year. No significant change in the discharge, aggradation, or deposition of gravel and coarser material occurred upstream or downstream of the local reach. Note that the restriction of influence of the trap to a reach of 3,600 feet surrounding the trap was because of the local nature of gravel transport, and did not depend on trap size; a larger trap would not have increased the reach of influence.

On the Carbon River, the effect of a model sediment trap on deposition of gravel and coarser material was similar. Downstream of the model trap, in the reach near the town of Crocker extending from 28,100 to 34,400 feet from the river's mouth (fig. E6, panel L), scour increased from 600 to 3,100 cubic yards per year, an increase of 2,500 cubic yards per year. In the upstream reach extending from 35,400 feet to 39,000 feet from the river's mouth (fig. E6, panel L), scour actually decreased just slightly, from 700 cubic yards per year to 300 cubic yards per year. The decrease in scour was the reverse of what was expected, and may be a result of the nearness of the upstream model boundary. The local reach of influence affected by the trap extended from 28,100 to 39,000 feet. Scour of gravel and coarser material in this reach remained about 1,500 cubic yards per year with or without the trap. The affected reach does not include any "hot spots" because the overall trend there is scour, rather than deposition. Operation of the sediment trap required the removal of 2,000 cubic yards per year of gravel and coarser material.

On the Puyallup River, the downstream reach affected by the model trap extended from 120,200 feet from the river's mouth to the downstream end of the trap at 122,100 feet (fig. E6, panel G). This reach includes part of "hot spot" A2 in the Orting area upstream of the Calistoga Avenue Bridge (table E4; fig. E5, panel G). Deposition of 200 cubic yards per year in this downstream reach was changed by the presence of the trap to scour of 200 cubic yards per year, an increase in scour of 400 cubic yards per year. Gravel transport was not affected upstream of the trap. Deposition remained at about 500 cubic yards per year in the surrounding local reach extending from 120,200 to 123,100 feet from the mouth, whether or not the trap was present. The effect of the trap was to cause increased deposition within its length, which was accounted for by reduced deposition and increased scour in the nearby downstream reach. Operation of the sediment trap required the removal of 700 cubic yards per year of gravel and coarser material.

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By William G. Sikonia

ABSTRACT

In 1983, the Pierce County Public Works Department began a study of flood protection for the lower Puyallup, White, and Carbon Rivers of western Washington. This report presents the results of a substudy directed at obtaining information on sediment deposition, scour, and movement in the river channels in response to potential alternatives for sediment control measures. The information was applied to investigate means of maintaining the flow carrying capacity of the river channels. Three alternative approaches for managing sediment deposition on the rivers were compared using a computer model of sediment transport. The three alternate courses of action were (1) to continue gravel mining by the procedure of scalping gravel bars, (2) to install sediment traps, or (3) not to intervene at all with sediment-control measures on the river system. Gravel-bar scalping consisted of the removal of deposited material from above the water line during periods of low flow. Measured cross sections, hydrographs, and sediment data collected from July and August 1984 to March 19, 1986, provided data for input and verification of sediment transport computer model Hydrologic Engineering Center - Six (HEC-6).

Cross-section surveys and computer model results indicated that the rivers were degrading rather than aggrading throughout much of the study area. Accordingly, non-intervention would appear to be the most appropriate of the three alternatives for such reaches, because the other two courses of action mitigate aggradation, rather than degradation. Deposition of gravel and coarser material, as well as of sand and finer material, did occur in some reaches. Model results indicated that gravel was deposited at rates of 1 to 3 cubic yards per foot of river distance, per year, in scattered, localized reaches on the three rivers. These specific locations would be logical areas for gravel-bar scalping operations. To maintain bed elevations, the long-term average rate of gravel removal by scalping needs to equal the long-term average rate of deposition at the specific location. Sediment traps were shown by this model study to be an effective but inefficient course of action for removal of sand and finer material. Sediment traps modeled in the study reduced deposition of sand and finer material in the lower White and Puyallup Rivers by 78,000 cubic yards per year during the modeling period from August 16, 1984, to March 19, 1986. However, this reduction would require maintenance removal of a combined total of 185,000 cubic yards per year of sand and finer material from model sediment traps on all three of the rivers.

This volume is much larger than the reduction in deposition, because most of the trapped material would have been transported completely through the river system to Commencement Bay in the absence of the traps, rather than being deposited enroute. Model sediment traps modified gravel transport only in local reaches near the traps. On the White River, for example, gravel transport was modified only for 1,500 feet downstream of the model trap, and 1,000 feet upstream. Gravel deposition downstream of the local reach of influence was not affected by the trap.

INTRODUCTION

The Puyallup River and its major tributaries -- the White and Carbon Rivers -- together with smaller tributaries of these three rivers, form a drainage system in western Washington that flows from the slopes of Mount Rainier into Commencement Bay (fig. 1). A report by E. A. Prych (1987) described the overall study of flood protection for the lower Puyallup River basin that was initiated by the Pierce County Public Works Department in 1983; a specific goal within the general investigation was to obtain information on sediment deposition, scour, and movement in the river channels. This information could then be used to determine locations and characteristics of sediment deposits that might affect channel flood-carrying capacity, and to estimate the effects of alternatives for the control of the deposition. These alternatives had been proposed (Sato, 1986) for the purpose of maintaining channel flood-carrying capacity. The U.S. Geological Survey, in cooperation with the Pierce County Public Works Department and the State of Washington Department of Ecology, conducted a study of sediment transport in the lower reaches of the rivers to provide this sediment-related information. The results of this substudy of the general investigation of flood protection are the subject of this report.

Background

Since 1974, the Pierce County and Inter-County River Improvement agencies, as well as private parties, have removed gravel bars from the river system. The removal has been done when the gravel bars appeared to be reducing the cross-sectional areas or increasing the average bottom elevations of the channels enough to affect flood-carrying capacity substantially. The term scalping was used to describe removal of deposited material from above the water line. Gravel-bar scalping was done only during the season when the work would be least disruptive to salmon and steelhead trout, usually during late July through early October.

In a study prepared under subcontract to Entranco Engineers, Inc.[1], for the Seattle District U.S. Army Corps of Engineers, the consulting firm R. W. Beck and Associates considered various alternatives as sediment-control measures (Sato, 1986). The measures were intended to maintain or increase the channel capacities by reducing gravel buildup in the channel at areas where flooding was thought to pose a threat. The present practice of gravel-bar scalping was considered in the analysis. The measures were ranked according to evaluation criteria such as effectiveness of gravel removal, ease and cost of construction, maintenance and operation, effect of the sediment-control alternative on surface-water profiles, and effects of the alternative on fish. The ranking assigned a relative advantage, with weight +1, a relative disadvantage, with weight -1, and no particular advantage or disadvantage, with weight 0, to each of the evaluation criteria, for each of the sediment-control alternatives. The ranking was based on engineering judgment. The sum of the weights for each sediment-control alternative provided the ranking. The firm of R. W. Beck rated sediment traps as the most effective measure of sediment control, followed by the present gravel-bar scalping operation.

[1]Use of firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

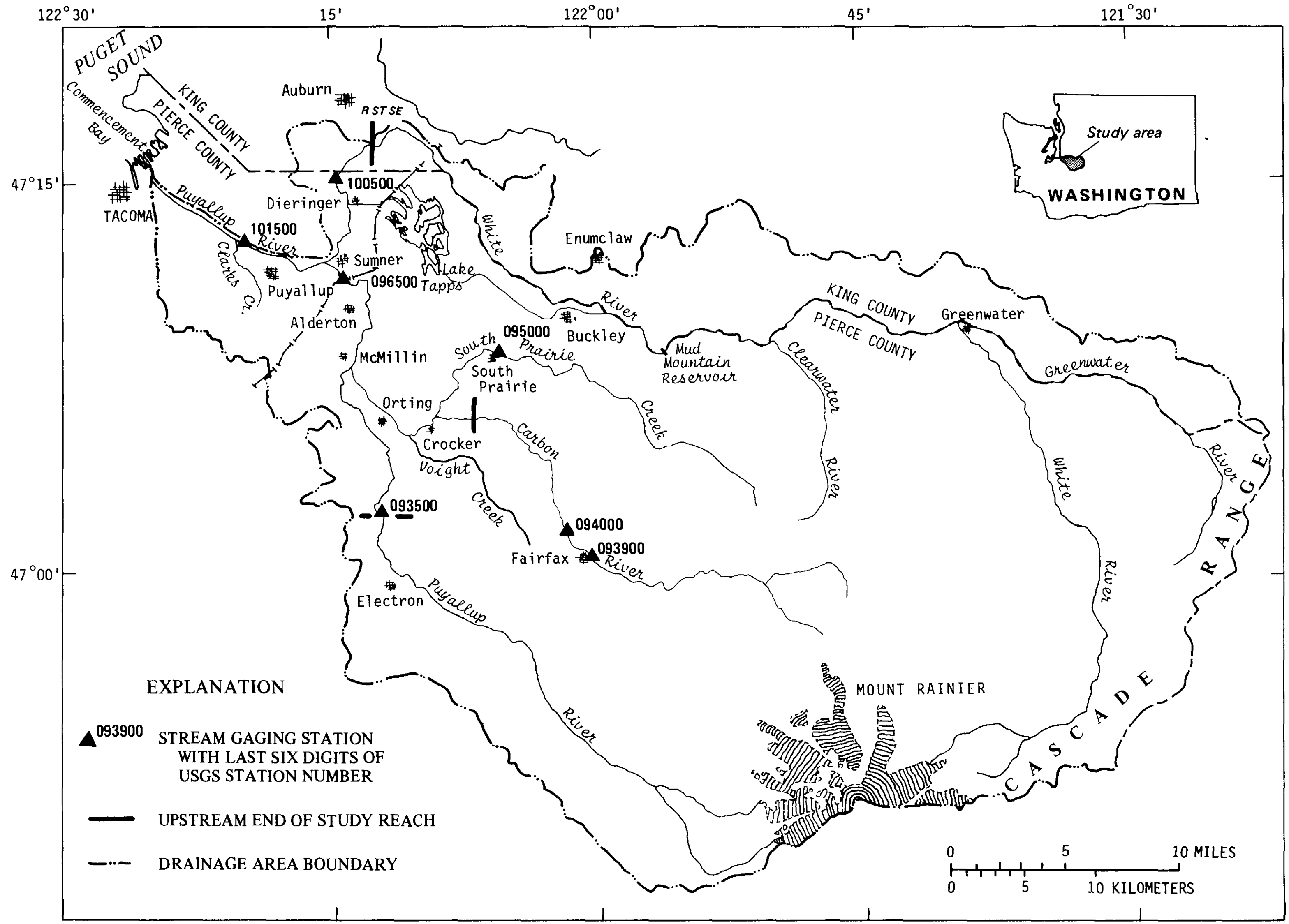

FIGURE 1.--Puyallup River basin, showing location of study area, and selected stream gaging stations.

Purpose and Scope

This report presents the results of a substudy to determine sediment transport within the lower Puyallup basin under the assumptions of specified alternative sediment-control measures. Two of the three alternatives were active sediment control measures (Sato, 1986) -- namely, retaining the present practice of gravel mining by gravel-bar scalping, or installing sediment traps on the Puyallup, White, and Carbon Rivers. The third alternative was to not intervene with sediment-control measures on the river system. Measured cross sections, hydrographs, and sediment data from July and August 1984 to March 19, 1986, provided data for input and verification of sediment transport computer model HEC-6. The data and computer modeling are intended to provide information on the sediment-transport processes and for evaluating the alternative sediment management practices.

Description of River Reaches of the Study

The study reaches (fig. 1, and in more detail in figs. A1 and A2 of Appendix A) included the lower 137,100 feet of the Puyallup River from the mouth in Commencement Bay to near the location of a stream-gaging station a few miles upstream of the city of Orting. The lower 39,700 feet of the White River was included, from the river's mouth to the "R" Street Southeast Bridge. The White River joins the Puyallup River at 54,100 feet upstream from the mouth of the Puyallup. The outlet for the Lake Tapps Diversion joins the White River at 19,200 feet upstream from the mouth of the White River. The lower 39,000 feet of the Carbon River was included from the river's mouth to 7,500 feet upstream from the town of Crocker. The Carbon River joins the Puyallup River at 93,800 feet upstream from the mouth of the Puyallup. Voight Creek and South Prairie Creek enter the Carbon River at 19,900 feet and 30,300 feet, respectively, upstream from the mouth of the Carbon. The modeling included flow from these streams as tributary input to the Carbon River. The upstream boundaries of the White and Carbon Rivers differ from those used in the flood-capacity study (Prych, 1987). The upstream boundary of the White River was set at 39,700 feet upstream from the river's mouth for this study because a sediment-discharge measurement station was located there. The upstream boundary of the Carbon River was reset upstream for this study to include a sediment trap from 34,370 to 35,430 feet from the river's mouth.

DESCRIPTION OF THE SEDIMENT TRANSPORT MODEL

The computer program Hydrologic Engineering Center - Six (HEC-6) of the U.S. Army Corps of Engineers (1977) was used in this study to model sediment transport, deposition, and scour. In this report, we will refer to this computer program, which is based on mathematical equations representing the physics of open-channel flow and sediment transport, as a "model." We will describe the process of using this model as "modeling," and will refer to "modeled" results arising from its use. Some modifications to the HEC-6 model were made; see Appendix C for details concerning these changes.

Streamflow

Streamflow was modeled using a quasi steady-state approximation in which a continuous hydrograph was treated as a sequence of discrete, constant-discharge events. Open-channel flow was described through the step-backwater approach using the flow-continuity equation

$$\frac{\partial Q}{\partial x} = q_{\ell}, \tag{1}$$

and the flow-energy equation

$$\left(h + \frac{\alpha Q^2}{2gA^2}\right)_{k-1} = \left(h + \frac{\alpha Q^2}{2gA^2}\right)_{k} + H_L, \tag{2}$$

where

Q = water discharge,
x = longitudinal river coordinate,
q_{ℓ} = lateral water inflow per unit length along river,
h = water-surface elevation,
α = velocity-head correction factor,
g = acceleration of gravity,
A = cross-sectional area,
k = cross-section index, and
H_L = head loss, consisting of friction and form losses, between sections k-1 and k.

Tributaries could not be included together with the main stem in a single computer run, because HEC-6 was not designed to solve a branching network of rivers simultaneously. Instead, the river system was approximated by modeling the tributaries to the Puyallup River -- the Carbon and White Rivers -- separately. Output from these tributary runs determined sediment discharges at the mouths of the tributaries for the entire modeling period. Tributary sediment and water discharges were then added as inflows, at the location of the junctions of each tributary with the Puyallup River, for a computer run of the main stem of the Puyallup River. The HEC-6 model uses a step-backwater method to compute water-surface elevation up the single river stem being considered, for a given downstream water discharge. Thus, a downstream boundary condition for the streamflow part of the calculation required that the downstream water-surface elevation be specified in some way during the modeling. For the Carbon and White Rivers, rating tables that specified water-surface elevation as a function of tributary discharge were used as the downstream boundary condition. The tables were developed by first running the main stem model using the known water discharges from the tributaries that occurred during the modeling period. Water-surface elevations in the main stem, at the junction of the tributary, were then plotted against the tributary discharge, and a rating table was developed. Because water-surface elevations at the mouth of a tributary depend on flow in the main stem as well as in the tributary, the correspondence between downstream tributary discharge and the water-surface elevation at the junction is not unique, so the rating table approach is an approximation. However, the tables were based on typical distributions of flows between the main stem and tributaries that occurred during the modeling period. The approximation will affect potential sediment transport to some extent in the downstream most part of the tributaries, because water-surface slope and flow velocity at times will be somewhat too high or too low there.

The downstream water-surface elevation in the Puyallup River was determined by the tide level in Commencement Bay for use as the downstream boundary condition. Because the model used a quasi steady-state approximation, it was not possible to follow the tidal fluctuation. Instead, the boundary condition was set at mean lower low water, -6.51 feet with respect to the National Geodetic Vertical Datum of 1929. It was more appropriate to use mean lower low water, rather than mean tide level, for the quasi steady-state approximation because otherwise the constantly higher water surface allowed unrealistic deposition at the mouth of the Puyallup River. The lower water-surface elevations during the tidal cycle seem to control scour and deposition, and thereby the elevation of the streambed, just upstream of the river mouth.

Sediment Transport

The sediment size classes used in the model ranged from clay and silt to small boulders (table 1). The smallest size class consisted of eight standard clay and silt classes lumped together to include all material less than 0.062 millimeters. To simplify the presentation of output, the computational classes were grouped into silt, sand, gravel, cobble, and boulder size ranges.

Sediment discharges were specified by the Yang sediment transport equation (Yang, 1973; 1984). Yang's equation for sand is

$$\log C_{ts} = 5.435 - 0.286 \log \frac{\omega d}{\nu} - 0.457 \log \frac{U_*}{\omega}$$
$$+ \left(1.799 - 0.409 \log \frac{\omega d}{\nu} - 0.314 \log \frac{U_*}{\omega}\right) \log \left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right), \qquad (3)$$

and his equation for gravel is

$$\log C_{tg} = 6.681 - 0.633 \log \frac{\omega d}{\nu} - 4.816 \log \frac{U_*}{\omega}$$
$$+ \left(2.784 - 0.305 \log \frac{\omega d}{\nu} - 0.282 \log \frac{U_*}{\omega}\right) \log \left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right) \qquad (4)$$

where

C_{ts} = total potential sand concentration in parts per million by weight,
C_{tg} = total potential gravel concentration in parts per million by weight,
ω = average terminal fall velocity of sediment particles.
d = median sediment particle diameter,
μ = viscosity of water,
ρ = density of water,
ν = μ/ρ = kinematic viscosity of water,
P = length of wetted perimeter,
R = A/P = hydraulic radius,
S_b = bed slope,
g = acceleration of gravity,
γ = ρg = specific weight of water,
τ_0 = $\gamma R S_b$ = shear stress,
U_* = $\sqrt{\tau_0/\rho}$ = shear velocity,
V = average flow velocity,
V_{cr} = critical velocity,
S = energy slope, and
log = logarithm to the base 10.

Table 1.--Sediment size classes used in the computer model

Class name	Size range (millimeters)	Size group name
Clay and silt	0.00024 - 0.062	Silt
Very fine sand	0.062 - 0.125	Sand
Fine sand	0.125 - 0.25	
Medium sand	0.25 - 0.5	
Coarse sand	0.5 - 1	
Very coarse sand	1 - 2	
Very fine gravel	2 - 4	Gravel
Fine gravel	4 - 8	
Medium gravel	8 - 16	
Coarse gravel	16 - 32	
Very coarse gravel	32 - 64	
Small cobbles	64 - 128	Cobbles
Large cobbles	128 - 256	
Small boulders	256 - 512	Boulders

The dimensionless critical velocity appearing in equations 3 and 4 can be computed by

$$\frac{V_{cr}}{\omega} = \frac{2.5}{\log\left(\frac{U_* d}{\nu}\right) - 0.06} + 0.66, \tag{5}$$

when

$$1.2 < \frac{U_* d}{\nu} < 70 \tag{6}$$

and

$$\frac{V_{cr}}{\omega} = 2.05, \tag{7}$$

when

$$70 \leq \frac{U_* d}{\nu}. \tag{8}$$

For sediment, the upstream boundary condition in the HEC-6 model is given by tables of sediment discharges for selected water discharges. These were constructed for each of the three rivers from measured sediment data (see the section "Preparation of Model Input Data"). The computer modeling of the Carbon and White Rivers produced downstream sediment hydrographs for the entire modeling period that were subsequently used as sediment inflows, at the location of the junction of each tributary with the Puyallup River, for a model run of the main stem of the Puyallup River.

Justification of the Use of Yang's Sediment Transport Equations

Yang's equations 3 and 4 were chosen over other equations for a number of reasons. The equations were derived using an energy approach, based on well-established theories of fluid mechanics and turbulence that led directly to their expression in terms of the velocity-slope product VS. The equations are simple and require only a small amount of data. The basic assumptions are applicable generally, and thus not specialized to some particular river or sediment transport problem. The coefficients in the equations were established by multiple regression using a large number of data sets, even though in principal they could have been calculated theoretically from flow and sediment characteristics. The equations give total load, and this is desirable because the distinction between bedload and suspended load is difficult to make and quite often artificial. The use of equations 3 and 4 guarantees that sediment is treated in a parallel manner throughout its size range.

Extensive comparisons of equation 3 with other sediment transport equations have been made by Yang (1973, 1975, 1977, 1987), Yang and Stall (1976, 1978), and Yang and Molinas (1982). The American Society of Civil Engineers Task Committee on Relations Between Morphology of Small Streams and Sediment Yield (American Society of Civil Engineers, 1982) presented the results of a study by Alonso (1980) that ranked Yang's equation 3 first among eight formulas selected for analysis. Yang's equation 3 was characterized as giving the best overall predictions. The eight selected for Alonso's study had already been selected from among 30 formulas on the basis of the following criteria: "The selected formula should: (1) be framed so that it is easy to apply in computer simulation, (2) give the total load of bed material, knowing the hydraulic and geometric properties of the flow, and (3) provide reliable estimates when applied to channels of any size in which the sediment particles are transported by the fluid." Another comparison of sediment transport equations was carried out on the North Fork Toutle and Toutle Rivers in Washington by Stephen Hammond of the Cascades Volcano Observatory, U.S. Geological Survey (Hammond, 1988). Yang's equation 3 again yielded computed values of sediment discharge among the best of the equations studied.

Fewer comparisons among equations apply to equation 4 for gravel. Yang (1984) restricted calibration of equation 4 to data obtained from laboratory flumes, due to difficulties in obtaining reliable field measurements of bedloads in real rivers. Nevertheless, Yang was able to demonstrate that independent variables used in other common gravel discharge equations, namely shear stress, stream power, or water discharge, are probably not ideal variables. Multivalued relations occurred between these variables and gravel discharge, whereas Yang's unit stream power yielded a one-to-one correspondence. Yang (1984) calibrated equation 4 by multiple regression using 166 sets of laboratory flume data. Yang (1987) also indicated the need for further verification and testing of equation 4 as additional reliable data sets become available from both the laboratory and from field observations on real rivers.

The comparisons of sediment transport equations in these studies by Yang (1973, 1975, 1977, 1987), Yang and Stall (1976, 1978), Yang and Molinas (1982), Alonso (1980), and Hammond (1988) were based on direct comparison of transport rates calculated from the formulas with observed transport rates from field or laboratory measurements. Other studies have also been made that compare observed and computed bed-profile changes. In these studies, the observed profiles were determined by field surveys, and the computed profiles were determined by models that incorporated the sediment-transport formulas. Yang (1987, section V.B.) presented the results of a model study by the U.S. Army Corps of Engineers, Los Angeles District. A plot of the Lower Santa Ana River showed that profiles computed using HEC-6 with Yang's equation 3 agreed well with the surveyed results (Yang, 1987, fig. 16). The Los Angeles District Corps of Engineers confirmed that equation 3 yielded the most reasonable results among the equations available in HEC-6 for their study, and transmitted copies to the author of the relevant sections from the unpublished Lower Santa Ana River report (J. Evelyn, U.S. Corps of Engineers, oral commun., 1988). Other published Corps of Engineers reports also showed that the Yang's equation 3 gave the best estimated values compared to measured data (U.S. Army Corps of Engineers, 1983; 1984). A comparison of Yang's equation 3 with other sediment transport equations was also made in a U.S. Geological Survey study of bed degradation below Cochiti Dam on the Rio Grande River (Mengis, 1981). Where the bed material was in the sand-size range, bed profiles computed by using the Yang equation 3 agreed closely with those obtained by field observation. In yet another modeling study, Molinas and others (1986) applied both Yang equations 3 and 4 in a development of scour at Mississippi River Lock and Dam No. 26 replacement site near St. Louis, Missouri; again, computed bed profiles agreed closely with those from field surveys.

Armoring and Streambed Layers

The HEC-6 model has the capability to consider active and inactive streambed layers. For computer runs, the inactive layer consisted initially of material in a layer 30 feet thick below the armoring, or active, layer. The active, or armor, layer consisted of material at the river-streambed interface. The thickness of the active layer was adjusted dynamically within a computer run always to be eight times the diameter of the smallest non-moving-particle size (see Appendix C). This critical particle size was determined using equation 5 or 7 to find the particle size for which the critical velocity V_{cr} equaled the average flow velocity V. Within any time step, scour was restricted to material within the active layer only. HEC-6 was modified for this study to include an additional layer, designated the inactive deposition layer, between the active and inactive layers (Bennett and Nordin, 1977; see Appendix C).

Initially within each computer run, the inactive deposition layer contained no material. During aggradation, sediment was transferred to the inactive deposition layer from the active layer to maintain the dynamically defined active-layer thickness. During degradation, material was first transferred from the inactive deposition layer to the active layer to maintain the active-layer thickness. If total depletion of the inactive deposition layer occurred, further material was transferred from the inactive layer to the active layer. All of these transfers of material were tracked by particle size class. Armoring within the model took place because the finer sizes tended to be scoured out of the active layer, leaving particles larger than the critical size that were resistant to further scour. Because scour could only take place from the active layer, which was close to the effects of the moving water at the streambed, the inactive deposition and inactive layers were protected from further scour by the active layer. Thus, the active layer armored the river bed. The choice of the inactive layer depth was somewhat arbitrary, because the presence of the inactive deposition layer meant that newly deposited material would never be mixed with material in the inactive layer. The sole purpose of the inactive layer was as a reservoir of sediment material having the original subsurface size distribution. The depth only had to be chosen deep enough so that scour during the modeling period would not cut completely through it.

Sediment Mass Conservation

Equations 3 and 4 relate water-flow variables and potential sediment discharge. Armoring, deposition or scour, potential sediment discharge, and the sediment mass conservation equation were then combined to yield actual sediment discharge. The sediment mass conservation equation is

$$\frac{\partial G}{\partial x} + B\frac{\partial y}{\partial t} = 0, \tag{9}$$

where

G = volumetric sediment-transport rate in cubic feet per day,
B = movable bed width,
y = movable bed elevation,
t = time in days, and
x = distance along the channel.

Tributaries were treated as point source inputs at the nodes, and thus distributed lateral inflows do not appear in equation 9, which was applied between nodes.

Deposition and Scour

Deposition or scour is assumed to add or remove a layer of constant thickness across the user-defined movable bed portion of the channel, during any modeling time increment Δt. Because this layer is of constant thickness, and because only changes of elevation appear in equation 9, the choice of the location within the movable bed to use as a reference for the movable bed elevation is somewhat arbitrary. Thus, y can be chosen as the thalweg elevation, that is, as the minimum elevation on each cross section. An approximation within HEC-6 is that the movable bed width at each cross section is fixed throughout the entire run, rather than being dynamically adjusted for changing water-surface elevations. For the rivers in this study, fixed movable bed widths could be reasonably chosen because the streambeds are in well-defined channels confined between banks, valley walls, or levees.

Gravel Mining and Dredging

Gravel-bar scalping was modeled for this study by a gravel mining option within the HEC-6 computer program. Cross sections at which gravel mining took place, and the rate of gravel mining at that location in tons per day, were identified in model input. The program allowed that the time interval and cross sections could be modified within the modeling period. Thus, it was possible to take into account the fact that the actual gravel-bar scalping locations and associated rates of removal varied during the modeling period. The process was modeled simply by removing the specified volumes from the active and inactive layers of the streambed. This procedure lowered the streambed uniformly across the movable bed at each cross section where gravel mining occurred.

Maintenance removal of deposited material from sediment traps was modeled by a dredging option within the HEC-6 program. The basic difference between modeled dredging and gravel mining was that whereas the volume of material removed was specified for gravel mining, the desired streambed elevation was specified for dredging, irrespective of the volume of material that had to be removed to achieve that elevation.

Justification of the Use of the Sediment Transport Model

HEC-6 was chosen as the model for this study because it appeared to be the best suited among those available. The model has been widely used in various applications. Insight into the model's capabilities in comparison with other models can be obtained from an evaluation done by the National Academy of Sciences for the Federal Emergency Management Agency (National Research Council, 1983). Hydraulic computations within it are based on HEC-2, a fixed-bed model also developed by the Corps of Engineers. HEC-2 is in wide use to determine flood elevations, and its input data format has become something of a standard. The models are well supported by the Hydrologic Engineering

Center of the U.S. Army Corps of Engineers in Davis, California, through which the Corps provides source code, documentation, and training in model use. HEC-6 provides for tracking of individual size classes, armoring, channel aggradation or degradation, gravel mining, and dredging, all of which were needed in this study. HEC-6 is restricted to steady flow, that is, to flow in which the discharge at any instant along a river's length is constant between points of inflow from tributaries.

An unsteady flow model would have been preferable to improve routing of flood peaks through the river system; however, to our knowledge, no such model exists that is suitable to the steep slopes of the upper reaches of the study area. The only unsteady models of which we are aware are based on the four-point implicit numerical scheme. However, in trials for the Puyallup-White-Carbon Rivers modeled in this study, a hydraulic model based on this numerical method performed only poorly, or for some river conditions, not at all. Adding the complications of sediment transport and channel aggradation and degradation to a model based on the four-point numerical scheme would result in a model that would probably not work at all in this situation. Thus, we must wait for further development of a sediment-transport model based on a robust unsteady-flow hydraulic model to be able to route flood peaks down the river system.

In the meantime, the steady-flow step-backwater computations in HEC-6 do provide a numerically solid framework for sediment-transport calculations. Because the model solves only for steady flow, it was necessary to approximate time-changing discharge hydrographs by a sequence of steady-flow events of short time duration. This procedure forces discharge hydrographs at cross sections throughout a reach to be identical between tributaries, instead of lagged in time as one proceeds downstream. Precise timing of water and sediment discharges within flow events was not important in this study, so this forced simultaneity was not of concern. Sediment aggradation or deposition may have been somewhat affected because discharges within individual reaches actually would have varied slightly as a flood wave passed. Influences of this effect in this study were probably diminished because only time-integrated accumulations over the study period were of concern, rather than the close following of bed-elevation changes through a storm event. Note that mass conservation of sediment was obtained through equation 9 using the approximation of steady-flow events, even though this procedure in general did not conserve water because the required $\partial A/\partial t$ term is absent in equation 1. That is, water associated with changes in channel storage from one steady-state condition to the next was not conserved. The approximation nevertheless succeeded in this application because water discharges were used only to drive sediment transport through the sediment-transport equation. The durations of the short steady-flow events varied in this study from a day in non-storm periods to an hour during storms. These time increments were chosen to allow adequate feedback of channel geometry changes to the hydraulic equations.

PREPARATION OF MODEL INPUT DATA

Channel data were specified at cross sections at intervals of approximately 2,000 feet along the longitudinal river coordinate (see table A1 in Appendix A for the exact locations). Geometry was specified by elevation data along a lateral coordinate at each cross section. Manning's "n" friction coefficient was specified at each cross section. Measured sediment data are organized in tabular form in Appendix A. Table A2 shows the location of the data collection sites, and tables A3 through A13 present measured particle-size distributions and discharges at those sites. Streambed-material size distribution in the inactive layer was approximated at cross sections throughout the river system by spatial interpolation from several locations where measurements of bed-material size distribution were made (table A6).

Incoming-Sediment Discharge Tables: Introduction

Incoming sediment discharge values were required at the upstream boundaries of the modeled sections of the Puyallup, White, and Carbon Rivers. For the computer model, these discharges were approximated by use of rating tables that related sediment discharge in each size class to water discharge. The rating tables were constructed from measurements of suspended-sediment discharge and bedload discharge. Sediment-discharge measurements on the Puyallup River were made at Orting, 115,100 feet upstream from the river's mouth (tables A9 and A13 in Appendix A; fig. A2, panel F, in Appendix A). This measurement location was 22,000 feet downstream from the model boundary at 137,100 feet from the river's mouth (fig. A2, panel G, in Appendix A). On the White River, the sediment-discharge measurements were made at Auburn, 39,800 feet upstream from the river's mouth, next to the upstream boundary of the modeled section at 39,700 feet from the river's mouth (tables A10 and A13 in Appendix A; fig. A2, panel I, in Appendix A). The sediment-discharge measurements were taken at the Carbon River at Crocker, at 31,300 feet from the river's mouth, or 7,700 feet downstream from the model boundary at 39,000 feet from the river's mouth (tables A11 and A13 in Appendix A; fig. A2, panel L, in Appendix A).

Construction of sediment rating tables for the upstream boundaries will be described in the next five sections. A preview of the development is as follows. Transport curves of total suspended-sediment discharge and total bedload discharge were constructed first for the measurement locations (to be described in the section "Sediment Transport Curves at the Measurement Locations"). Rating tables that specified sediment discharge in each size class then were constructed from these transport curves (to be described in the sections "Size Distribution of Suspended Sediment," "Size Distribution of Bedload," and "Rating Tables for the Measurement Locations"). Finally, the rating tables, which were applicable to the downstream measurement locations, were adjusted so that the resulting tables were applicable to the upstream boundary locations (to be described in the section "Adjustment of the Rating Tables to the Upstream Boundaries").

Sediment Transport Curves at the Measurement Locations

We begin with the construction of the transport curves of total suspended-sediment discharge and total bedload discharge, for each of the three rivers at the measurement locations (figs. 2, 3, and 4). Suspended-sediment discharge was determined from the measured data of tables A9, A10, and A11 (Appendix A) by means of the equation

$$Q_{ss} = Q_w \times C_{ss} \times 0.0027, \tag{10}$$

where

Q_w = water discharge, in cubic feet per second,
Q_{ss} = suspended sediment discharge, in tons per day, and
C_{ss} = suspended sediment concentration, in milligrams per liter.

The suspended-sediment concentration C_{ss} was the total suspended-sediment concentration from rows labeled "ave" in tables A9, A10, A11. Suspended sediment samples for these tables were collected using a P-61 or D-74 sampler. The observed suspended sediment points (squares) in figures 2, 3, and 4 are the data points from tables A9, A10, A11. Bedload discharge Q_{bl} was read directly from the rows labeled "xsect" in table A13 (Appendix A). Bedload samples for this table were collected with a Helley-Smith bedload sampler. The observed bedload points (crosses) in figures 2, 3, and 4 are the data points from table A13. The suspended sediment and bedload transport curves in figures 2, 3, and 4 were interpolated between and extrapolated beyond measured values by straight lines on the log-log graphs. For the White River, field observations provided only a single bedload data point, necessitating an approximate approach for the construction of the bedload curve. To extend the curve, slopes from the bedload curves of the Puyallup River (slope = 1.868) and the Carbon River (slope = 2.322) were averaged. This resulted in a bedload slope of 2.095 that was used for the White River bedload curve, approximated by a straight line on the log-log plots. At least one more data point would be desirable. However, it will be shown in analysis of the results that the transport of gravel and coarser material is a local phenomenon, and that bedload in downstream reaches is virtually independent of the incoming load, except in a local reach near the upstream boundary. Thus, it is not necessary to specify precisely the incoming bedload curve. Nevertheless, the suspended and bedload measurements in figures 2, 3, and 4 are sparse, and more field measurements would be desirable.

Size Distribution of Suspended Sediment

The transport curves were next used to determine rating tables that gave sediment discharges in each particle size class at a specified set of water discharges. The suspended- and bedload-sediment discharges were allocated to size classes according to the measured particle-size distributions given in tables A9, A10, A11, and A13 in Appendix A. The details of the method of allocation follow. This section describes particle-size distributions for suspended-sediment loads, and the next section "Size Distribution of Bedload" describes the distributions for the bedloads.

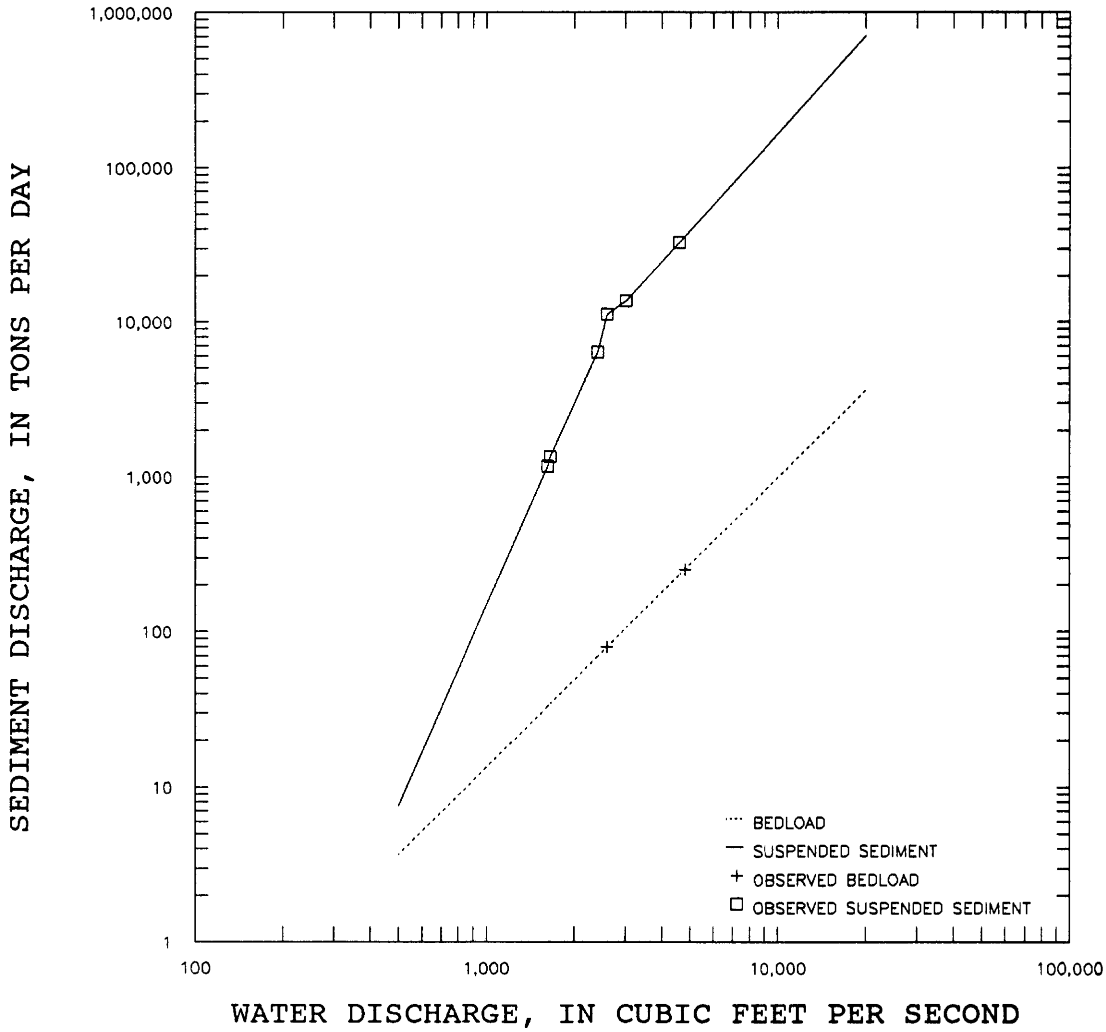

FIGURE 2.--Sediment discharge as a function of water discharge for the Puyallup River at Orting.

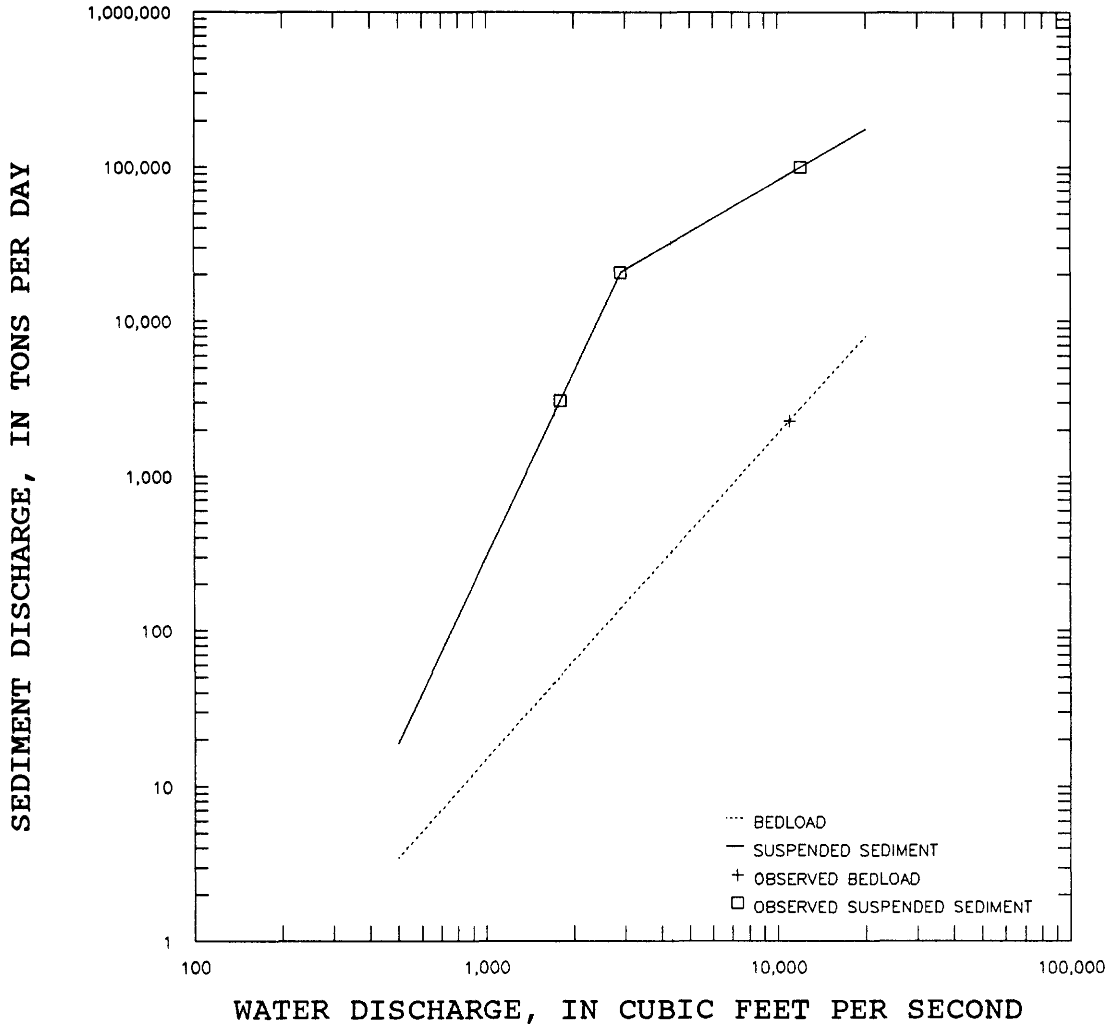

FIGURE 3.--Sediment discharge of a function of water discharge for the White River at Auburn.

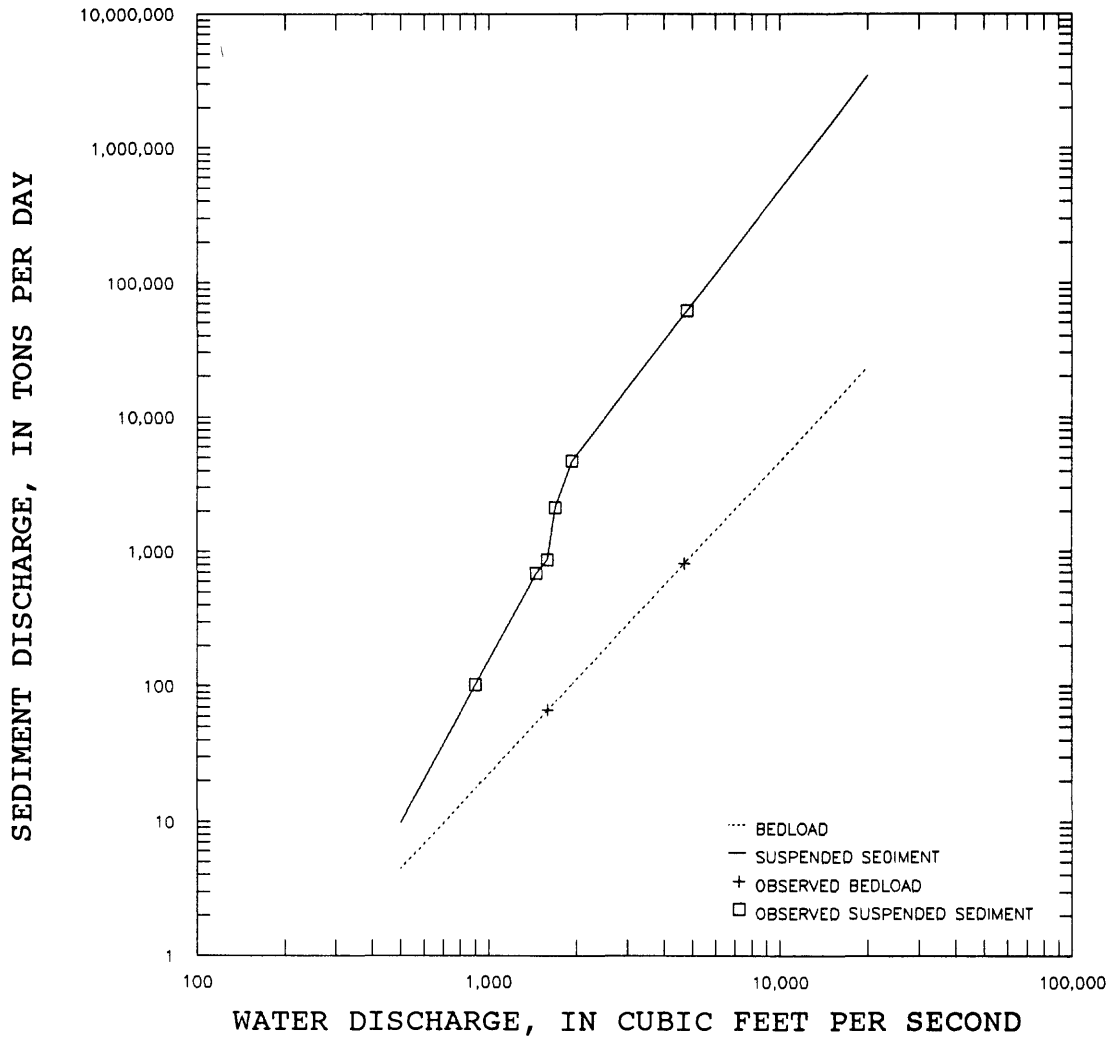

FIGURE 4.--Sediment discharge as a function of water discharge for the Carbon River at Crocker.

Rows in suspended sediment tables A9, A10, and A11 labeled "ave" show cross-sectional average concentrations obtained by sediment-discharge weighting of the samples taken across the width of the river. For some sampling times, another row labeled "comp" gives the results of size analysis for a single sample composited from duplicates of the individual samples taken across the width of the river. The average derived by discharge-weighting ("ave") was considered somewhat more reliable than by compositing ("comp"). Therefore, for this study, the size information in the "ave" rows was considered primary, and was used to determine the percentages of material to allocate to fines (sizes less than 0.0625 millimeters) and to sand (sizes between 0.0625 and 2 millimeters).

Let the subscript "a" refer to the discharge-weighted average "ave", let "P" denote percentage by weight, and let "C" denote concentration, in milligrams per liter. Then the percentage of fines was computed by

$$P_{fines} = 100 \times (C_{fines})_a \ / \ (C_{total})_a \tag{11}$$

and the percentage of sand was therefore

$$P_{sand} = 100 - P_{fines}. \tag{12}$$

At sampling times having an associated composite sample, the discharge-weighted rows "ave" in tables A9, A10, and A11 had only a total concentration entry. The concentrations of fines and sand were missing, and so equation 11 could not be used. In such cases, the concentration of fines from the composited sample replaced the discharge-weighted fines concentration in equation 11, to yield

$$P_{fines} = 100 \times (C_{fines})_c \ / \ (C_{total})_a, \tag{13}$$

where the subscript "c" refers to the composited average "comp."

It was then necessary to further distribute material in the sand size group among its five size classes. At some of the sampling times, the complete size distribution could be read directly from the discharge-weighted "ave" rows in tables A9, A10, and A11. At other sampling times, this information was contained in the "comp" rows, and for these cases, allocating sand to its component classes was done according to the sand distribution in composited samples. The total sand-group percentage that had been computed using equations 13 and 12 differed slightly, in general, from the total sand-group percentage of the composite sample, because the discharge-weighted total concentration was usually slightly different from the total concentration of the composite sample. Therefore, percentages from the composite averages in tables A9, A10, and A11 were scaled so that the total sand-group percentage was that of the discharge-weighted average, by the equation

$$(P_i)_a = (P_i)_c \times (P_{sand})_a \ / \ (P_{sand})_c. \tag{14}$$

In equation 14, the subscript "i" refers to the i'th sand class.

Other sampling times had only the distribution between the fines and sand-size groups given by equations 11 or 13, and 12. For such times, the missing size distributions were approximated from sampling times for which complete distributions had been determined. Percentages within the sand size group were scaled by an equation similar to equation 14:

$$(P_i)_a = (P_i)_t \times (P_{sand})_a \; / \; (P_{sand})_t. \tag{15}$$

In equation 15, the subscript "t" refers to the approximating size distribution that was transferred from another sampling time. In carrying out the transfer of size distributions, extrapolation was not attempted beyond the minimum or maximum discharges for which complete distributions were known. Size distributions of samples having discharges above this maximum were approximated by the distribution of the maximum. Similarly, size distributions of samples having discharges below this minimum were approximated by the distribution of the minimum. One sample with an incomplete size distribution had a water discharge between two samples with known distributions. In this single case, the approximating size distribution was determined by interpolation in units of $\log_{10}(Q_w)$:

$$(P_i)_t = (1 - \Phi)\, P_{i1} + \Phi\, P_{i2} \tag{16}$$

where

$$\Phi = \frac{[\log_{10}(Q_w) - \log_{10}(Q_{w1})]}{[\log_{10}(Q_{w2}) - \log_{10}(Q_{w1})]} \,. \tag{17}$$

Here, Q_w is the water discharge of the sample with the incomplete size distribution; Q_{w1} and Q_{w2} indicate water discharges of samples with known percentages P_{i1} and P_{i2} in the i'th sand class; and $\log_{10}$ denotes logarithm to the base 10.

For the Puyallup River at Orting (table A9 of Appendix A), complete size distributions were available at streamflows of 3,020 and 4,600 cubic feet per second. The complete distribution at 3,020 cubic feet per second was used to distribute material within the sand-size group according to equation 15, for samples at 1,620; 1,650; 2,400; and 2,600 cubic feet per second. The measured percentages of fines for each of these samples was still determined by equation 11 or 13, and the measured total percentage in all five classes of the sand group by equation 12, without need for the size distributions transferred from 3,020 cubic feet per second. The size distribution from 1,620 cubic feet per second was then transferred to the extrapolated rating table entry at 500 cubic feet per second, and the distribution at 4,600 cubic feet per second was transferred to the extrapolated rating-table entry at 20,000 cubic feet per second.

For the White River at Auburn (table A10 of Appendix A), percentages for each size class were available at 2,900 and 12,000 cubic feet per second. The distribution at 2,900 cubic feet per second was used to allocate the sand sizes according to equation 15 for the sample at 1,800 cubic feet per second. The size distribution for 1,800 cubic feet per second was then transferred to the extrapolated rating-table entry of 500 cubic feet per second, and the distribution from 12,000 cubic feet per second was transferred to the extrapolated rating-table entry at 20,000 cubic feet per second.

For the Carbon River at Crocker (table A11 of Appendix A), complete size distributions were available at water discharges of 1,700 and 4,800 cubic feet per second. The size distribution at 1,700 cubic feet per second was used to allocate sand sizes by equation 15 for samples at 900; 1,460; and 1,600 cubic feet per second. The percentage in each size class for the sample at 1,930 cubic feet per second was determined by interpolating the percentages in the samples at 1,700 and 4,800 cubic feet per second linearly in units of $\log_{10}(Q_w)$, and then applying equation 15. Then the size distribution from 900 cubic feet per second was transferred to the extrapolated rating-table entry at 500 cubic feet per second, and the distribution from 4,800 cubic feet per second was transferred to the extrapolated rating-table entry at 20,000 cubic feet per second.

Size Distribution of Bedload

Measured particle-size distributions in bedload were obtained from rows in table A13 of Appendix A labeled "xsect". The percentages in these rows are cross-sectional averages obtained by sediment-discharge weighting of the samples taken across the width of the river. Every bedload sample had a complete size distribution, so it was not necessary to transfer this information to samples themselves, as was done for suspended sediment. An approximation was needed for the bedload-size distribution on the White River at lower discharges, because there was no field-measured distribution. This was done by averaging the size distributions measured for the Puyallup River at a water discharge of 2,600 cubic feet per second and for the Carbon River at a water discharge of 1,600 cubic feet per second. This size distribution was used for the White River at a water discharge of 2,040 cubic feet per second, which is halfway between the 2,600- and 1,600-cubic-foot discharges on log paper.

The rating tables give total sediment discharge at specified water discharges. Each of the discharges chosen for the tables must have an associated sediment discharge that is a total of suspended-sediment discharge and bedload discharge. The sampling discharges for suspended sediment were chosen as the water discharges to include in the rating tables. High and low discharges were added to the tables to insure that they would cover the complete range covered during the modeling.

Bedload discharge was then required for each of the selected water discharge entries in the rating-tables in order to obtain the total sediment discharge. Total bedload discharges at the rating-table water discharges were read from figures 2, 3, and 4. Size distributions were transferred to the entries in a manner analogous to the procedure described above for transferring the size distributions for suspended-sediment discharges. That is, constant size distributions were used above and below the water-discharge ranges represented in the bedload samples, and distributions were interpolated in units of $\log_{10}(Q_w)$ between sampled water discharges.

For the Puyallup River at Orting, the bedload-size distribution measured at 2,600 cubic feet per second was used for rating table entries at 500; 1,620; 1,650; 2,400; and 2,600 cubic feet per second. The bedload-size distribution at 4,800 cubic feet per second was used for the rating table extension to 20,000 cubic feet per second. Distributions at the rating table entries of 3,020 and 4,600 cubic feet per second were interpolated in units of $\log_{10}(Q_w)$ from bedload measurements at 2,600 and 4,800 cubic feet per second.

On the White River at Auburn, the bedload-size distribution at 2,040 cubic feet per second that had been approximated by averaging distributions from the Puyallup and Carbon Rivers was used for rating table entries at 500 and 1,800 cubic feet per second. The measured bedload distribution at a water discharge of 11,000 cubic feet per second was used for the rating table entries at 12,000 and 20,000 cubic feet per second. The bedload-size distribution for the rating table entry at 2,900 cubic feet per second was interpolated in units of $\log_{10}(Q_w)$ from the distributions at 2,040 and 11,000 cubic feet per second.

On the Carbon River at Crocker, the bedload distribution at a water discharge of 1,600 cubic feet per second was used for table entries at 500; 900; 1,460; and 1,600 cubic feet per second. The bedload-size distribution measured at a water discharge of 4,700 cubic feet per second was used at rating table entries of 4,800 and 20,000 cubic feet per second. Rating table entries at 1,700 and 1,930 cubic feet per second were interpolated in units of $\log_{10}(Q_w)$ from bedload-size distribution measurements at 1,600 and 4,700 cubic feet per second.

Rating Tables for the Measurement Locations

The suspended-sediment discharges and bedload discharges thus determined were then added by size class to yield the rating table entries. In general, each bedload sample had a water discharge that was approximately equal to that for a suspended-sediment sample made at about the same time. A rating table entry where this occurred closely approximated a simultaneous measurement of both suspended-sediment discharge and bedload discharge at the same water discharge. See the first seven entries in table 9 for sampling times when near-simultaneity of bedload and suspended load measurement occurred.

Adjustment of the Rating Tables to the Upstream Boundaries

The final step in the process of constructing incoming-load rating tables required adjusting the rating tables so that they would apply to the upstream boundaries, rather than the downstream measurement locations. The measurement location for the White River was at the upstream boundary, so no change was necessary for it. The adjustment for the Puyallup and Carbon Rivers was carried out as follows. A computer run was made with the unadjusted downstream rating tables entered as initial estimates of the incoming-load rating tables at the upstream boundaries of these two rivers. The modeled sediment discharges at the actual measurement locations were then compared with the table values. Discharges in the incoming-load rating tables were adjusted by multiplicative factors, one each for the silt, sand, and gravel size groups. Silt and sand discharges were simply scaled up or down according to this factor of discrepancy between measured and computed values at the downstream locations. The factors for silt and sand discharges for the Puyallup River were 0.72 and 0.94, respectively, and for the Carbon River, 0.73 and 0.49. The local nature of gravel transport precluded an adequate relation between gravel transport at the upstream boundary and the measurement location 22,000 feet downstream for the Puyallup River and 7,700 feet downstream for the Carbon River. Factors for gravel transport of 2.00 for the Puyallup River and 1.49 for the Carbon River were used instead, to reduce scour produced by the computer model at the upstream boundaries when the unadjusted input gravel discharges were used. The resultant sediment-discharge rating tables that were used as upstream boundary conditions are shown in tables 2, 3, and 4.

Rating Tables for Tributary Inflow

Besides sediment rating tables at the upstream model boundaries, it was also necessary to provide sediment rating tables for tributary inflow. The Lake Tapps Diversion enters the White River at Dieringer. Because of settling of sediment within Lake Tapps, and because of efforts to prevent sediment from entering the diversion in the first place, the sediment discharge in this tributary was set to zero (table 5). Voight Creek and South Prairie Creek both join the Carbon River near Crocker. No sediment data were collected on Voight Creek. Determination of the rating table for the Voight Creek tributary was not critical, since the flow was approximated as only 10 percent of the flow at the mouth of the Carbon River. The sediment-discharge rating table was approximated by the table for the Carbon River at Crocker measurement location, as derived by the procedure described in the previous sections, excluding the adjustment to the upstream Carbon River boundary (table 6).

Field measurements of sediment discharge on South Prairie Creek were restricted to suspended sediment only, and were rather tightly grouped between 560 and 730 cubic feet per second. These measurements were not sufficient in themselves to construct a rating table. They were used instead to provide a shift for the Carbon River rating table; the shift specified the South Prairie Creek sediment discharges as a multiple of the measured Carbon River discharges. For the stream discharges of 730, 680, and 560 cubic feet per second, the measured suspended-sediment discharges on South Prairie Creek (table A12 in Appendix A) were 162, 376, and 33.3 tons per day, respectively. The corresponding values from the Carbon River at Crocker transport curve (fig. 4) were 44.6, 33.6, and 15.6 tons per day. A multiplicative shift was equivalent to an additive shift on the log plot of figure 4. The best least-square fit to the three measured discharges was obtained by minimizing

$$\begin{aligned} \phi = {} & [\log_{10}162 - (\log_{10}44.6 + K)]^2 \\ & + [(\log_{10}376 - (\log_{10}33.6 + K)]^2 \\ & + [(\log_{10}33.3 - (\log_{10}15.6 + K)]^2 \end{aligned} \tag{18}$$

with respect to logarithmic shift K, which gave a multiplicative shift 10^K of 4.43. The discharges from figure 4 were thus multiplied by 4.43 to obtain total discharges for South Prairie Creek.

Table 2.--Sediment discharge rating table at the upstream model boundary for the Puyallup River

Water discharge, in cubic feet per second	Sediment discharge, in tons per day, for sediment size class[1]													
	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand	Very fine gravel	Fine gravel	Medium gravel	Coarse gravel	Very coarse gravel	Small cobbles	Large cobbles	Small boulders
1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0002	0.0002	0.0002	0.0002	0	0	0
500	.67	1.0	2.8	4.1	1.5	.20	.0074	.0074	.015	.0074	.32	0	0	0
1,620	101	145	320	388	139	13	.066	.066	.13	.066	3.0	0	0	0
1,650	157	159	349	425	151	15	.068	.068	.14	.066	3.0	0	0	0
2,400	774	738	1,610	1,934	689	61	.14	.14	.28	.14	6.0	0	0	0
2,600	1,989	1,189	2,579	3,099	1,106	96	.16	.16	.32	.16	7.0	.0002	0	0
3,020	1,855	1,548	3,380	4,050	1,434	131	.42	.42	.84	1.7	9.2	12	0	0
4,600	8,675	4,989	7,526	5,368	1,881	3.3	2.4	1.9	4.2	13	18	98	0	0
20,000	185,360	106,495	160,500	114,177	40,010	51	36	30	66	218	282	1,646	0	0

[1] See table 1 for sediment size classes. Sediment discharges were derived from measured values from figure 2 and tables A9 and A13 for the Puyallup River at Orting. Sediment discharges in this table equal those in a table applicable to the Orting measurement location, multiplied by the following factors: silt discharge x 0.72, sand discharges (in each of the five size classes) x 0.94, and gravel and coarser discharges (for each of the eight size classes) x 2.00. Sediment discharges have not been rounded, but rather show what was used as model input.

Table 3.--Sediment discharge rating table at the upstream model boundary for the White River

Water discharge, in cubic feet per second	Sediment discharge, in tons per day, for sediment size class[1]													
	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand	Very fine gravel	Fine gravel	Medium gravel	Coarse gravel	Very coarse gravel	Small cobbles	Large cobbles	Small boul-ders
1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0	0	0
500	4.6	2.4	5.8	6.9	2.1	.084	.0070	.0070	.0070	.0070	.48	0	0	0
1,800	763	386	872	889	233	1.2	.10	.10	.10	.10	7.1	.0001	0	0
2,900	5,376	2,530	5,694	5,731	1,494	3.5	1.1	2.0	4.1	6.5	23	2.7	0	0
12,000	34,044	15,137	23,946	19,743	6,623	1,181	77	165	355	583	760	253	0	0
20,000	60,004	26,698	42,337	35,046	11,805	2,173	224	481	1,034	1,699	2,212	737	0	0

[1] See table 1 for sediment size classes. Sediment discharges were derived from measured values from figure 3 and tables A10 and A13 for the White River at Auburn. Since the upstream model boundary on the White River was at the sediment measurement location, sediment discharges in this table equal those in a table applicable to the White River at Auburn. Sediment discharges have not been rounded, but rather show what was used as model input.

Table 4.--Sediment discharge rating table at the upstream model boundary for the Carbon River

Water discharge, in cubic feet per second	Sediment discharge, in tons per day, for sediment size class[1]													
	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand	Very fine gravel	Fine gravel	Medium gravel	Coarse gravel	Very coarse gravel	Small cobbles	Large cobbles	Small boulders
1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0	0	0
500	1.8	.74	1.5	2.3	.78	.064	.027	.021	.021	.021	1.5	0	0	0
900	11	8.8	16	19	5.9	.25	.10	.079	.079	.079	6.1	0	0	0
1,460	127	52	90	103	29	.78	.33	.24	.24	.24	18	0	0	0
1,600	167	65	112	128	36	.93	.40	.30	.30	.30	22	.0001	0	0
1,700	573	136	231	254	69	1.1	.69	.80	1.3	1.6	27	.58	0	0
1,930	652	406	663	669	185	1.5	1.4	2.7	4.2	5.7	34	2.5	0	0
4,800	11,355	6,744	8,547	5,387	2,149	12	45	106	179	253	267	122	0	0
20,000	633,948	376,424	476,764	299,566	119,357	335	1,231	2,917	4,921	6,961	7,347	3,339	0	0

[1] See table 1 for sediment size classes. Sediment discharges were derived from measured values from figure 4 and tables A9 and A13 for the Carbon River at Crocker. Sediment discharges in this table equal those in a table applicable to the Crocker measurement location, multiplied by the following factors: silt discharge x 0.73, sand discharges (in each of the five size classes) x 0.49, and gravel and coarser discharges (for each of the eight size classes) x 1.49. Sediment discharges have not been rounded, but rather show what was used as model input.

The size distributions of the Carbon River measurements were used for the South Prairie Creek table entries (table 7) at stream discharges of 900; 1,600; 1,700; 1,930; 4,800; and 20,000 cubic feet per second; that is, for these discharges, the South Prairie Creek rating table is a simple multiple of 4.43 times the rating table for the Carbon River at the measurement location at Crocker. The rating table entry for a stream discharge of 680 cubic feet per second used the size distribution from the South Prairie Creek measurements directly. The percentage of fines at 680 cubic feet per second was averaged from the three measurements at 560, 680, and 730 cubic feet per second. Subtraction of the fines percentage from 100 percent yielded the percentage in the whole sand group. The size distribution among the five sand classes was then determined by equation 15, with "t" denoting the complete size distribution from the measurement at 680 cubic feet per second. The size distribution at 680 cubic feet per second was then also used at the low extrapolated rating table entry at 500 cubic feet per second.

An enhanced program of sediment-discharge data collection would be desirable if a continued modeling and field observation program is contemplated. It would be preferable to locate sampling sites at all upstream boundaries of the modeling study, to eliminate the adjustment of incoming discharges to that location from downstream sites. Additional samples, particularly on the White River and South Prairie Creek, and on all rivers at high water discharges, would be beneficial.

Stream Discharge Hydrographs

Discharge hydrographs for the period 1984 to 1987 were obtained from several gaging stations on the river system. The hydrographs were approximated by histograms on a daily basis, except during five storms on June 7-10, 1985; October 25-26, 1985; January 18-20, 1986; February 23-27, 1986; and November 22-26, 1986. During these storms, the discharge histograms were constructed on an hourly basis. See Appendix B for discharge hydrographs at various locations in the river system. The first four storms were included in the modeling period that extended from 1984 through March 19, 1986. The starting date of the modeling period was July 27, 1984, on the White River, and August 16, 1984, for the Puyallup and Carbon Rivers. The fifth storm was included in the extended modeling period (discussed in Appendix D), that had the same starting dates, but ended July 31, 1987.

Table 5.--Sediment discharge rating table for tributary inflow from the Lake Tapps Diversion into the White River

Water discharge, in cubic feet per second	Sediment discharge, in tons per day, for sediment size class[1]													
	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand	Very fine gravel	Fine gravel	Medium gravel	Coarse gravel	Very coarse gravel	Small cobbles	Large cobbles	Small boulders
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[1] See table 1 for sediment size classes. Because of settling in Lake Tapps, as well as efforts to keep sediment from flowing into the diversion at all, the outflow sediment discharges were set at zero.

Table 6.--Sediment discharge rating table for tributary inflow from Voight Creek into the Carbon River

Water discharge, in cubic feet per second	Sediment discharge, in tons per day, for sediment size class[1]													
	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand	Very fine gravel	Fine gravel	Medium gravel	Coarse gravel	Very coarse gravel	Small cobbles	Large cobbles	Small boulders
1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0	0	0
500	2.5	1.5	3.0	4.7	1.6	.13	.018	.014	.014	.014	1.0	0	0	0
900	15	18	32	39	12	.51	.070	.053	.053	.053	4.1	0	0	0
1,460	174	106	184	211	59	1.6	.22	.16	.16	.16	12	0	0	0
1,600	229	132	228	261	73	1.9	.27	.20	.20	.20	15	.0001	0	0
1,700	785	277	472	519	140	2.2	.46	.54	.85	1.1	18	.39	0	0
1,930	893	828	1,353	1,366	378	3.0	.93	1.8	2.8	3.8	23	1.7	0	0
4,800	15,555	13,763	17,442	10,994	4,386	25	30	71	120	170	179	82	0	0
20,000	868,422	768,213	972,987	611,338	243,586	684	826	1,958	3,303	4,672	4,931	2,241	0	0

[1] See table 1 for sediment size classes. Sediment discharges were derived from measured values from figure 4 and tables A9 and A13 for the Carbon River at Crocker. Sediment discharges in this table equal those in a table applicable to the Carbon River at the Crocker measurement location. Sediment discharges have not been rounded, but rather show what was used as model input.

Table 7.--Sediment discharge rating table for tributary inflow from South Prairie Creek into the Carbon River

Water discharge, in cubic feet per second	Sediment discharge, in tons per day, for sediment size class[1]													
	Silt	Very fine sand	Fine sand	Medium sand	Coarse sand	Very coarse sand	Very fine gravel	Fine gravel	Medium gravel	Coarse gravel	Very coarse gravel	Small cobbles	Large cobbles	Small boulders
1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0	0	0
500	15	11	12	15	5.3	.58	.080	.060	.060	.060	4.6	0	0	0
680	49	37	40	39	13	1.2	.16	.12	.12	.12	9.4	0	0	0
900	66	80	142	173	53	2.3	.31	.23	.23	.23	18	0	0	0
1,600	1,014	585	1,010	1,156	323	8.4	1.2	.89	.89	.89	66	.0001	0	0
1,700	3,478	1,227	2,091	2,299	620	9.7	2.0	2.4	3.8	4.9	80	1.7	0	0
1,930	3,956	3,668	5,994	6,051	1,675	13	4.1	8.0	12	17	102	7.5	0	0
4,800	68,909	60,970	77,268	48,703	19,430	111	133	315	532	753	593	363	0	0
20,000	3,847,109	3,403,183	4,310,332	2,708,227	1,079,086	3,030	3,659	8,674	14,632	20,697	21,844	9,928	0	0

[1] See table 1 for sediment size classes. Sediment discharges were derived from measured values from figure 4, tables A9 and A13 for the Carbon River at Crocker, and table A12 for South Prairie Creek at Crocker. Sediment discharges in this table are 4.43 times the discharges in a table applicable to the Carbon River at Crocker measurement location. An exception is that the size distributions at stream discharges of 500 and 680 cubic feet per second were derived from suspended sediment measurements of table A12 for South Prairie Creek. Sediment discharges have not been rounded, but rather show what was used as model input.

Sediment Traps

Sediment traps were modeled by modifying cross section input data at the selected locations. The model traps emulated physical traps with the R. W. Beck design (Sato, 1986). Part of the river bed was lowered in the appropriate model cross sections to form basins approximately 160 feet wide by 1,000 feet long by 8 feet deep (table 8). The basins did not extend across the full width of the river. The rock stabilizers in the R. W. Beck design were modeled as 50-foot reaches of small-boulder bed material that prevented excessive scour at the trap ends. The longitudinal stabilizers of the design were unnecessary because the model did not allow lateral scour into the sides of the basin. The model traps were located in sediment control sites /a/, /b/, and /c/ (Anderson, 1986; see fig. 8 and table 14). The Puyallup River trap (fig. A2, panel G, in Appendix A) was upstream of the city of Orting limits. The model trap on the White River (fig. A2, panel H, in Appendix A) was located upstream of the 8th Street East Bridge, and the one for the Carbon River (fig. A2, panel L, in Appendix A) was upstream of the State Route 162 Bridge. The traps were re-excavated within the model runs to depths of 8 feet after each of the four storms.

Table 8.--Sediment trap locations and dimensions

River	Limits of sediment trap, in feet from river mouth		Length, in feet	Width, in feet	Depth, in feet
	Downstream	Upstream			
Puyallup	122,070	123,130	1060	160	8
White	27,510	28,560	1050	150	8
Carbon	34,370	35,430	1060	160	8

DESCRIPTION OF MODEL OUTPUT

Use of the computer model provided sediment discharges by size groups through each cross section at selected times during the period modeled. The model also predicted, by size grouping, the time-integrated discharges, or equivalently the total quantity of sediment, that passed through the sections. Differences in volumes passing successive cross sections during the modeling period provided time-integrated deposition or scour within each river reach. The distributions by size grouping of material in the armor layer and combined armor and inactive layers were also provided. Scour or fill during the modeling period was indicated by bed-elevation change at each cross section. The scour or fill at a given cross section was assumed to take place in a uniform layer within the movable bed.

The section "Preparation of Model Input Data" indicated that (1) actual stream hydrographs from the modeling period were used as input to the model; (2) stream cross sections measured at the start of the modeling period were used as the initial conditions of the channels; (3) sediment particle-size data collected during the modeling period were used to set input particle sizes in the streambeds; and (4) transport rates measured during the modeling period were used to set input sediment discharges at the upstream ends of the modeled sections of the rivers. Using actual, instead of synthetic, data facilitated direct comparison between modeled and observed values. For selected locations on the rivers and selected times during the modeling period, comparisons were possible between modeled and measured bed-elevation changes, transport rates, and particle-size distributions. The model contained only a single sediment-related adjustable parameter, namely the factor N describing thickness of the armor layer as a multiple N of the smallest nonmoving particle size (see Appendix C, change no. 1). All other parameters in the sediment transport equations were fixed for this study using published values based on more general sets of sediment transport data (Yang, 1973; 1984). The hydraulic parameters for the model were the Manning's coefficients, which were determined in the earlier flood-capacity study by calibration with data from 1974 or 1977 (Prych, 1987), and were not adjusted for this study of sediment transport. Opportunity to calibrate the sediment transport model in the usual sense was quite limited -- that is, the single parameter N could not be used to adjust all model-generated outputs to match the measurements during a calibration period. The value of 8 used for the parameter N seems to give a reasonable thickness for the armor layer, and is the value used by Bennett and Nordin (1977). The comparison of modeled and measured results during the modeling period has perhaps more of the characteristics of verification, in the usual sense applied to models, than calibration.

Comparison of Computed and Measured Instantaneous Sediment Discharge

Several sediment-discharge measurements at various points in the river system provided a test of the model's correspondence to the real system (table 9; see tables A7 through A13, Appendix A, for measured sediment discharges used in table 9). Some care had to be taken in determining how to make the comparison of computed and modeled discharges. Model stream discharges were approximations of the real stream discharges because of the enforced simultaneity of storm discharges over reaches within the HEC-6 model, and because discharges at some locations were derived from measurements elsewhere (table B1). In general, the model discharges at any given time t during the modeling period did not equal the discharges measured at that same instant. Sediment discharge is, on a logarithmic scale, sensitive to changes in stream discharge (see figs. 2, 3, and 4). Therefore, when the comparisons in table 9 were made, time was approximately the same as when the field measurement had been made, but shifted slightly across the rising or falling model stream hydrograph so that the model stream discharge equaled the discharge associated with the field measurement. This procedure should give the most appropriate comparison between modeled and field-measured sediment discharges. Table 9 indicates reasonable correspondence between the measured and computed sediment discharges. The current state of both field measurement techniques and modeling is such that factors-of-two correspondence between observed and computed discharge is usually considered satisfactory, especially for gravel transport. For the storm on February 25, 1986, the computed gravel discharge is considered satisfactory, whereas the measured value is probably too low. The measured gravel discharge was estimated from the amount of material collected by a Helley-Smith bedload sampler with a 6-inch by 6-inch square inlet (Helley and Smith, 1973; Druffel and others, 1976; Emmett, 1980). The samples collected with this instrument during the high 17,000-cubic-feet-per-second discharge of the storm contained large percentages of sand and finer material. The Puyallup River at Puyallup site is in an area of sand deposition. It is known that a sample collected by the Helley-Smith instrument is influenced by the placement of the instrument on the streambed. The sampling is sensitive to bedforms as well as to the cross-stream location of the sampling station. Perhaps gravels in transport were missed. However, the true cause of the discrepancy between modeled and measured sediment discharge is unknown.

Standard errors associated with discharges in the silt-, sand-, and gravel-size groups can be derived as follows. Table 9 lists computed and measured discharges. Sediment discharge measurements from the sampling stations Puyallup River at Orting, White River at Auburn, Carbon River at Crocker, and South Prairie Creek at Crocker were used in constructing the inflowing sediment-discharge rating tables. The data listed for these stations cannot be used for verification of the model without consideration of their influence on the inflowing loads. For sand- and silt-sizes, the standard error between modeled and measured discharge was computed by two methods. Standard error is the root-mean-square error, whose square is defined as the sum of the squares of the deviations of computed values from measured values, divided by the associated number of degrees of freedom in the sample. The number of degrees of freedom is the number of observations in the sample, minus the number of parameters estimated from the sample. That is, the number of degrees of freedom is the number of observations in excess of those needed to determine the parameters that are in turn used to determine the computed value. In the first, only the sampling stations Puyallup River at Puyallup and Puyallup River at Alderton were used, and the four stations that influenced the inflowing loads were excluded. There were 6 sand and silt

Table 9.--Computed and measured sediment discharge for selected sediment sampling stations, November 5, 1985, to February 25, 1986

[Q, water discharge in cubic feet per second; --, not measured]

	Sediment discharge, in tons per day		
Sampling station	Silt	Sand	Gravel and coarser[1]
Puyallup River at Orting, 1-19-86, 10:20 a.m., Q=3,020			
Computed:	3,100	9,100	18
Measured:	2,600	11,200	12
Computed/Measured:	1.19	1/1.23	1.50
Puyallup River at Orting, 2-24-86, 3:05 p.m., Q=4,600			
Computed:	10,200	27,600	140
Measured:	12,000	21,000	69
Computed/Measured:	1/1.18	1.31	2.0
Puyallup River at Alderton, 2-24-86, 4:20 p.m., Q=11,800			
Computed:	55,500	52,300	530
Measured:	30,300	46,400	270
Computed/Measured:	1.83	1.13	1.96
Puyallup River at Puyallup, 2-25-86, 8:40 a.m., Q=17,500			
Computed:	35,900	30,500	450
Measured:	31,100	45,400	3.0
Computed/Measured:	1.15	1/1.49	150
White River at Auburn, 2-24-86, 9:15 p.m., Q=12,000			
Computed:	34,200	66,400	850
Measured:	34,000	66,600	2,200
Computed/Measured:	1.01	1.00	1/2.6
Carbon River at Crocker, 1-19-86, 11:00 a.m., Q=1,700			
Computed:	660	1,700	15
Measured:	790	1,400	21
Computed/Measured:	1/1.20	1.21	1/1.40

[1] The first seven table entries list comparison data at times when there was near-simultaneity between the suspended and bedload measurements. Measured gravel discharges for these seven were adjusted slightly to the stream discharge of the sand and silt measurements. Succeeding table entries group measurements by station, repeating the first seven sand and silt entries, and showing the true nearly simultaneous gravel measurement.

Table 9.--Computed and measured sediment discharge for selected sediment sampling stations, November 5, 1985, to February 25, 1986 -- continued

	Sediment discharge, in tons per day		
Sampling station	Silt	Sand	Gravel and coarser
Carbon River at Crocker, 2-24-86, 12:15 p.m., Q=4,800			
Computed:	18,500	39,700	580
Measured:	15,600	46,600	650
Computed/Measured:	1.19	1/1.17	1/1.12
Puyallup River at Orting, 11-5-85, 1:50 p.m., Q=1,620			
Computed:	270	1,800	
Measured:	140	1,100	
Computed/Measured:	1.93	1.64	
Puyallup River at Orting, 1-18-86, 6:35 p.m., Q=2,600			
Computed:	1,000	2,400	
Measured:	2,800	8,600	
Computed/Measured:	1/2.8	1/3.6	
Puyallup River at Orting, 1-19-86, 10:20 a.m., Q=3,020			
Computed:	3,100	9,100	
Measured:	2,600	11,200	
Computed/Measured:	1.19	1/1.23	
Puyallup River at Orting, 1-19-86, 3:15 p.m., Q=2,600			
Computed:	--	--	13
Measured:	--	--	3.9
Computed/Measured:	--	--	3.3
Puyallup River at Orting, 1-19-86, 4:20 p.m., Q=2,400			
Computed:	1,600	6,000	
Measured:	1,100	5,400	
Computed/Measured:	1.45	1.11	
Puyallup River at Orting, 1-20-66, 8:10 a.m., Q=1,650			
Computed:	190	2,700	
Measured:	220	1,200	
Computed/Measured:	1/1.16	2.3	
Puyallup River at Orting, 2-24-86, 1:30 p.m., Q=4,800			
Computed:	--	--	96
Measured:	--	--	79
Computed/Measured:	--	--	1.22

Table 9.--Computed and measured sediment discharge for selected sediment sampling stations, November 5, 1985, to February 25, 1986 -- continued

Sampling station	Sediment discharge, in tons per day: Silt	Sand	Gravel and coarser
Puyallup River at Orting,			
2-24-86, 3:05 p.m., Q=4,600			
Computed:	10,200	27,600	
Measured:	12,000	21,000	
Computed/Measured:	1/1.18	1.31	
Puyallup River at Alderton,			
11-6-85, 1:30 p.m., Q=4,060			
Computed:	260	3,200	
Measured:	400	3,600	
Computed/Measured:	1/1.54	1/1.13	
Puyallup River at Alderton,			
1-18-86, 10:55 p.m., Q=7,000			
Computed:	1,800	7,200	
Measured:	9,000	21,600	
Computed/Measured:	1/5.0	1/3.0	
Puyallup River at Alderton,			
1-19-86, 9:50 a.m., Q=6,800			
Computed:	5,600	7,800	
Measured:	6,300	18,200	
Computed/Measured:	1/1.13	1/2.3	
Puyallup River at Alderton,			
1-19-86, 3:40 p.m., Q=5,400			
Computed:	2,500	5,300	
Measured:	2,800	5,300	
Computed/Measured:	1/1.12	1.00	
Puyallup River at Alderton,			
1-20-86, 8:17 a.m., Q=3,300			
Computed:	190	1,800	
Measured:	440	1,400	
Computed/Measured:	1/2.3	1.29	
Puyallup River at Alderton,			
2-24-86, 4:20 p.m., Q=11,800			
Computed:	55,500	52,300	
Measured:	30,300	46,400	
Computed/Measured:	1.83	1.13	
Puyallup River at Alderton,			
2-24-86, 5:30 p.m., Q=11,000			
Computed:	--	--	420
Measured:	--	--	240
Computed/Measured:	--	--	1.75

Table 9.--Computed and measured sediment discharge for selected sediment sampling stations, November 5, 1985, to February 25, 1986 -- continued

	Sediment discharge, in tons per day		
Sampling station	Silt	Sand	Gravel and coarser
Puyallup River at Puyallup, 1-19-86, 1:50 a.m., Q=10,700			
Computed:	2,700	14,000	
Measured:	16,400	30,300	
Computed/Measured:	1/6.1	1/2.2	
Puyallup River at Puyallup, 1-19-86, 11:25 a.m., Q=12,000			
Computed:	6,100	15,500	
Measured:	16,300	27,000	
Computed/Measured:	1/2.7	1/1.74	
Puyallup River at Puyallup, 1-20-86, 9:15 a.m., Q=7,380			
Computed:	2,000	6,100	
Measured:	2,400	6,300	
Computed/Measured:	1/1.20	1/1.03	
Puyallup River at Puyallup, 2-25-86, 8:40 a.m., Q=17,500			
Computed:	36,000	30,500	
Measured:	31,100	45,400	
Computed/Measured:	1.16	1/1.49	
Puyallup River at Puyallup, 2-25-86, 9:45 a.m., Q=17,000			
Computed:	--	--	410
Measured:	--	--	2.8
Computed/Measured:	--	--	150
White River at Auburn, 1-19-86, 2:45 p.m., Q=2,900			
Computed:	5,300	15,200	
Measured:	5,400	15,500	
Computed/Measured:	1/1.02	1/1.02	
White River at Auburn, 1-20-86, 10:30 a.m., Q=1,800			
Computed:	770	2,500	
Measured:	760	2,400	
Computed/Measured:	1.01	1.04	
White River at Auburn, 2-24-86, 9:15 p.m., Q=12,000			
Computed:	34,200	66,400	
Measured:	34,000	66,600	
Computed/Measured:	1.01	1.00	

Table 9.--Computed and measured sediment discharge for selected sediment sampling stations, November 5, 1985, to February 25, 1986 -- continued

Sampling station	Sediment discharge, in tons per day		
	Silt	Sand	Gravel and coarser
White River at Auburn,			
2-25-86, 12:15 a.m., Q=11,000			
Computed:	--	--	710
Measured:	--	--	1,800
Computed/Measured:	--	--	1/2.5
Carbon River at Crocker,			
11-5-85, 10:00 a.m., Q=1,460			
Computed:	100	300	
Measured:	170	560	
Computed/Measured:	1/1.70	1/1.87	
Carbon River at Crocker,			
1-18-86, 9:17 p.m., Q=1,930			
Computed:	330	480	
Measured:	890	3,900	
Computed/Measured:	1/2.7	1/8.1	
Carbon River at Crocker,			
1-19-86, 11:00 a.m., Q=1,700			
Computed:	660	1,700	
Measured:	790	1,400	
Computed/Measured:	1/1.20	1.21	
Carbon River at Crocker,			
1-19-86, 12:35 p.m., Q=1,600			
Computed:	--	--	15
Measured:	--	--	16
Computed/Measured:	--	--	1/1.07
Carbon River at Crocker,			
1-19-86, 5:15 p.m., Q=1,600			
Computed:	410	1,200	
Measured:	230	700	
Computed/Measured:	1.78	1.71	
Carbon River at Crocker,			
1-20-86, 11:10 a.m., Q=900			
Computed:	12	63	
Measured:	15	100	
Computed/Measured:	1/1.25	1/1.59	
Carbon River at Crocker,			
2-24-86, 12:15 p.m., Q=4,800			
Computed:	18,500	39,700	
Measured:	15,600	46,600	
Computed/Measured:	1.19	1/1.17	

Table 9.--Computed and measured sediment discharge for selected sediment sampling stations, November 5, 1985, to February 25, 1986 -- continued

	Sediment discharge, in tons per day		
Sampling station	Silt	Sand	Gravel and coarser
Carbon River at Crocker, 2-24-86, 1:55 p.m., Q=4,700			
Computed:	--	--	540
Measured:	--	--	620
Computed/Measured:	--	--	1/1.15
South Prairie Creek at Crocker, 1-19-86, 10:00 a.m., Q=730			
Computed:	53	180	
Measured:	45	120	
Computed/Measured:	1.18	1/1.50	
South Prairie Creek at Crocker, 1-20-86, 12:20 a.m., Q=680			
Computed:	49	130	
Measured:	150	230	
Computed/Measured:	1/3.1	1/1.77	
South Prairie Creek at Crocker, 1-20-86, 10:05 a.m., Q=560			
Computed:	23	66	
Measured:	11	23	
Computed/Measured:	2.1	2.9	

measurements at the Puyallup River at Alderton, and 4 at the Puyallup River at Puyallup (table 9), for a total of 10 degrees of freedom. The logarithmic standard errors ϵ were computed by

$$\epsilon^2 = \frac{1}{N} \sum [\log_{10}(Q_{ic}) - \log_{10}(Q_{im})]^2 \tag{19}$$

$$= \frac{1}{N} \sum [\log_{10}(Q_{ic}/Q_{im})]^2. \tag{20}$$

In these equations, Q_{ic} denotes the computed discharge in one of the size groups for sample i, Q_{im} denotes the corresponding measured discharge, Log_{10} denotes logarithm to the base 10, and N denotes the number of degrees of freedom. Define

$$\sigma = 10^{\epsilon}. \tag{21}$$

By the definition of ϵ, the range of one standard error is represented by

$$\log_{10}Q_c \quad \pm \quad \epsilon \quad = \quad \log_{10}Q_c \quad \pm \quad \log_{10}\sigma \tag{22}$$

$$= \begin{cases} \log_{10}(\sigma\ Q_c) \\ \log_{10}(Q_c/\sigma) \end{cases}. \tag{23}$$

Taking antilogs, the range of discharge values Q_c/σ to σQ_c corresponds to the logarithmic standard error ϵ. That is, Q_c is determined to within a factor of σ, denoted by the notation Q_c × or ÷ σ. The factors σ obtained by applying these equations to the sand and silt discharges for only the stations at Puyallup and Alderton on the Puyallup River were

$$\sigma_1 = \quad 2.5 \text{ for silt} \tag{24}$$

and

$$\sigma_1 = \quad 1.7 \text{ for sand} \tag{25}$$

where the number N of degrees of freedom in equation 20 was 10.

Errors for sand and silt discharges were also computed by a second method. The adjustment process used to arrive at inflowing loads on the Carbon and Puyallup Rivers only used multiplicative factors applied to the downstream rating tables. This provided an average adjustment over the entire range of discharges in the table, but did not yield a perfect match. To avoid misleading error estimates because of the exclusion of errors associated with the stations used in the adjustment procedure, the differences between computed and observed values for these stations were included by the following approximation procedure. The sand and silt loads at the White River at Auburn were again excluded; they did match well because the measurement location was at the upstream model boundary. For the Puyallup River at Orting, the Carbon River at Crocker, and South Prairie Creek at Crocker, it was assumed that the adjustment process accounted for a loss of one degree of freedom for each station, represented by the multiplicative factor used to adjust the silt- or sand-size classes. It was further assumed that another degree of freedom was lost at the Puyallup River at Orting and the Carbon River at Crocker in determining the average slope of the sediment transport curves. Thus five degrees of freedom were lost in total. There were six sand and silt measurements at the Puyallup River at Orting, six at the Carbon River at Crocker, and three at South Prairie Creek at Crocker (table 9). Combining these with the four measurements at the Puyallup River at Puyallup and the six at the Puyallup River at Alderton that were used in the first method of error analysis, a total of 25 measurements were used. The total number of degrees of freedom N for use in equation 20 was thus 25 minus 5, or 20. For this augmented number of measurements, equation 20 yielded

$$\sigma_2 = \quad 2.4 \text{ for silt} \tag{26}$$

and

$$\sigma_2 = \quad 2.2 \text{ for sand} \tag{27}$$

Taking the larger of σ_1 and σ_2 gave the following estimate of errors for silt and sand:

$$\sigma = 2.5 \text{ for silt} \tag{28}$$

and

$$\sigma = 2.2 \text{ for sand.} \tag{29}$$

For gravel transport, there was little correlation between discharges at the upstream model boundaries and the downstream measurement locations on the Puyallup and Carbon Rivers. This was evidence of the local nature of gravel transport. Indeed, it was determined that adjustment of the upstream discharge could not be determined by comparison with downstream discharge as in the case of sand and silt discharge. Further, table 9 shows that model gravel discharges did not equal measured discharges at the White River at Auburn, where the measurement station was at the upstream boundary. The reason is that the discharge is limited within the model to be no more than potential discharge computed by the sediment-transport equation. For these reasons, it was assumed that no degrees of freedom were lost in the adjustment procedure in the determination of gravel transport at the upstream locations. There was a total of seven gravel discharge measurements, one at the Puyallup River at Puyallup, one at the Puyallup River at Alderton, two at the Puyallup River at Orting, one at the White River at Auburn, and two at the Carbon River at Crocker. The error computation was also performed omitting the questionable measurement at the Puyallup River at Puyallup, that is, for N = 6 degrees of freedom in equation 20. These yielded the following error estimates for gravel discharge:

$$\sigma = \begin{cases} 1.9 & \text{for gravel (excluding Puyallup River at Puyallup)} \\ 7 & \text{for gravel (including Puyallup River at Puyallup)} \end{cases}. \tag{30}$$

Comparison of Computed and Measured Bed-Elevation Changes

Field surveys of channel geometry also provide a check of results from the computer model. U.S. Geological Survey personnel surveyed channel cross sections on the White River about July 27, 1984, and on the Carbon and Puyallup Rivers about August 16, 1984, and again on all three rivers about March 19, 1986. The average bed-elevation change during that period was determined from the surveys, and also predicted by the computer model. The slightly longer time interval for the White River was adhered to throughout the computer modeling to allow verification with these survey data. Measured changes in river profiles are shown by the uppermost graphs labeled "field surveys", in figures 11, 12, and 13. (Figures 11 to 31 showing model output are grouped together at the end of the report.) These measured cross-sectional changes include the effects of gravel-bar scalping operations (table 10) that took place during the modeling time interval. In figures 11, 12, and 13, the shading represents the average bed elevation as seen on March 19, 1986, referenced to the bed elevation (zero on the figures) of August 16, 1984, for the Puyallup or Carbon Rivers, or July 27, 1984, in the case of the White River. Scour during the period is thus depicted by white areas below the zero of the scale, and deposition by shaded areas above the zero.

Table 10.--Gravel-bar scalping volumes on the Puyallup, White, and Carbon Rivers from January 1, 1984, to November 24, 1986

[T_i, start of modeling period: July 27, 1984, for the White River, or August 16, 1984, for the Puyallup and Carbon Rivers; T_f, end of modeling period, March 19, 1986; --, no values]

River	Limits, in feet from river mouth		Scalping volumes, in cubic yards, for periods indicated[1]			
	Downstream	Upstream	1/1/84 to T_i	T_i to 12/31/84	1/1/85 to T_f	T_f to 11/24/86
Puyallup	91,200	94,500	--	--	--	38,000
Do.	110,300	118,400	19,600	20,900		
Do.	114,300	128,000	--	--	88,900	--
Do.	118,400	122,000	11,800	12,600	--	--
Do.	132,000	133,900	--	--	1,000	--
White	21,300	26,000	--	7,400	--	--
Do.	23,700	33,400	--	42,500	--	--
Do.	39,100	39,700	--	1,300	--	--
Do.	39,300	39,700	--	--	1,100	--
Carbon	2,000	3,000	--	--	--	13,300
Do.	28,200	33,100	--	--	--	36,900

[1] The volumes do not correspond exactly to totals in the report on channel capacities (Prych, 1987) because in some cases portions of the scalping documented there occurred upstream of the study limits of this report.

The model computations of average channel scour or fill, in the presence of gravel mining operations that were used to model gravel-bar scalping, are shown in the second graphs titled "computer model -- gravel mining alternative" in figures 11, 12, and 13. On the Carbon River, there was actually no modeled gravel-bar scalping during August 16, 1984, to March 19, 1986, but the case is included to avoid confusion by maintaining parallel graphs for all three rivers; therefore, the gravel mining and non-intervention alternatives are identical in figure 13. The gravel mining alternatives reflect conditions most closely approximating the actual conditions on the rivers during the period modeled. Thus, those bed-elevation change graphs are the most appropriate for comparison with the uppermost graphs of field-surveyed cross-sectional changes. Least-square errors that quantified the difference between modeled and surveyed bed-elevation change were computed according to

$$\sigma^2 = \frac{1}{N} \sum (\Delta y_c - \Delta y_m)^2, \tag{31}$$

where

Δy_c = model-computed average bed-elevation change,

Δy_m = field-measured average bed-elevation change, and

N = number of cross sections.

The number N of cross sections was 71 on the Puyallup River, 22 on the White River, and 20 on the Carbon River, or a total of 113 for all three rivers. Equation 31 yielded

$\sigma = 0.6$ for the Puyallup River, (32)
$\sigma = 0.3$ for the White River, (33)
$\sigma = 0.6$ for the Carbon River, and (34)
$\sigma = 0.5$ for all three rivers. (35)

Bed-Elevation Change for the Three Sediment Control Alternatives

The effects of the other two sediment control alternatives on bed-elevation change are also shown in figures 11, 12, and 13. The third graphs in each figure titled "computer model -- non-intervention alternative" show a baseline river system without incorporation of sediment control measures. The fourth graphs titled "computer model -- sediment trap alternative" show model computations of average bed-elevation changes resulting from sediment traps (table 8), installed on the rivers, to assess their usefulness. Sediment traps were dredged after each of the four major storms from July and August 1984 to March 19, 1986. Average annual volumes of sediment that were trapped during the modeling period are indicated in table 11.

Table 11.--Average annual volumes of sediment stopped by traps, July and August 1984 to March 19, 1986, from computer modeling[1]

River	Average annual sediment volume, in cubic yards per year				
	Silt	Sand	Gravel	Cobbles	Boulders
Puyallup	2,400	43,000	700	0	0
White	18,000	92,000	1,200	0	0
Carbon	2,800	22,000	2,000	0	0

[1] The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

Average Sediment Discharge for the Three Sediment Control Alternatives

Figures 14 through 19 show the modeled average annual sediment volumes in the indicated size groups that flowed through a particular location on the river during the modeling period. Accumulated weights of sediment were calculated by integrating the instantaneous sediment discharge (unit tons per day) at each cross section over the period from July and August 1984 to March 19, 1986. Total tons were converted to a volume by using a sediment bulk density of 93 pounds per cubic foot. This time-integrated volume was then divided by the 1.59 years for the Puyallup and Carbon Rivers, or 1.65 years for the White River, to obtain an average sediment discharge. Note in figures 14, 16, and 18 that average gravel discharge was much smaller than the corresponding average discharge for sand or silt. The gravel discharge curve has been included at an expanded scale in figures 15, 17, and 19 to show detail.

A constant average discharge over a reach indicates that the river transported that sediment volume through the reach without deposition or scour. Average sediment discharge that increases downstream (from right to left on the plots) indicates that more sediment was incorporated into the transported load; that is, that material of the indicated size was being picked up from the streambed. Special cases of such increased load occur due to tributary input into the Puyallup River from the Carbon and White Rivers (fig. 14), into the Carbon River from South Prairie Creek, and (almost imperceptibly on the plots) from Voight Creek (fig. 18). Conversely, average sediment discharge that decreases downstream indicates that material of the indicated size was being lost from sediment in transport and deposited along the river. As one would anticipate, silt is, for the most part, transported through the river system without any change between major input locations.

Rate of Deposition or Scour for the Three Sediment Control Alternatives

The graphs in figures 20 to 25 are the mathematical derivatives of graphs in figures 14 to 19 with respect to distance along the river, and show locations where the computer model indicated that material was subtracted from the load in transport by deposition on the river bed, or added to the load in transport by scour of the river bed. Tributary inputs within the model were treated as point source inflows at nodes, and do not appear in figures 20 to 25. Note that these graphs differ from the related plots of bed-elevation change, figures 11, 12, and 13. In figures 20 to 25, the deposition or scour is subdivided by size into sand and finer material, and gravel and coarser material. Stream width variations are not a factor; the amount of deposition or scour is given as a volume per foot of distance along the longitudinal river coordinate. Because the graphs represent changes in the sediment volumes in transport given in figures 14 to 19, gravel mining operations and dredging do not directly remove material, as they do in the bed elevation plots. However, the effect of sediment traps especially, and of gravel mining operations to a lesser extent, was reflected in the graphs by a secondary influence -- namely, that the change in channel geometry caused either more or less sediment to be added to the load in transport, or removed from the load in transport. It is this secondary effect that may be seen in the graphs in figures 20 to 25.

Particle-Size Distribution for the Three Sediment Control Alternatives

The particle-size distribution calculated by the computer model for the armor layer is shown in figures 26, 27, and 28 for the three sediment control alternatives. Where applicable, observed point measurements overlay the modeled distribution curves (see tables A3 and A4, Appendix A). The particle-size distribution calculated by the computer model for a surface layer approximately 30 feet thick that included the armor layer and inactive, near-subsurface layers is shown in figures 29, 30, and 31. Observed point measurements again overlay the appropriate modeled distribution curves (see table A6, Appendix A). The armor layer size distribution for December 31, 1984, is also shown in figures 29, 30, and 31 for comparison with observed data taken on that date. The measurements of particle size were obtained from observations of material on exposed gravel bars, using the Wolman method (Wolman, 1954) of counting randomly selected surface particles while classifying them according to size, as well as from sieve analysis of material dug from the bars. Figures 26, 27, and 28 indicate only minor changes in particle-size distribution, when comparing the presence of gravel mining or sediment traps to the absence of such measures, except within the sediment traps.

RESULTS OF SEDIMENT TRANSPORT MODELING

The computer modeling and supporting data provide a description of sediment transport on the lower Puyallup-White-Carbon River system that includes changes caused by gravel mining operations and sediment traps. By comparing modeled results of deposition, scour, sediment loads, and particle-size distributions, one can make the following observations.

Gravel Transport

This study indicates that gravel load represents only a small fraction of the total load and should not be overemphasized in planning. Those graphs in figures 15 to 25 that relate to gravel also indicate that gravel transport is a localized phenomenon, highly dependent on the local channel geometry. The figures show discharges and deposition rates that varied markedly from cross section to cross section. Alternating reaches of scour and deposition of gravel and coarser material were found throughout the river system. The computer model indicated highest average gravel discharges (see figs. 15, 17, and 19) just upstream of the gravel deposition reaches listed in table 12. Most of this load was deposited in the adjacent downstream reaches listed in table 12, as can be seen by the deposition peaks for gravel near these locations (see also figs. 5, 6, 21, 23, and 25).

A general-purpose location map for figures 6 through 10, which will be presented in this section "Results of Sediment Transport Modeling," is shown in figure 5. River coordinates, selected bridges, and the White River Power Plant, which will be referenced in the text and tables are shown in figure 5. The river coordinates shown in figure 5 are the distances in thousands of feet from the mouth of the Puyallup River at Commencement Bay; for the White and Carbon Rivers, the distances are in thousands of feet from their junctions with the Puyallup River. The same map base was used in constructing figures 5 through 10. In figures 6 through 10, areas of panels A through L of figure A2, Appendix A, are shown. The larger scale of the figure A2 panels allows detailed location of physical features and river coordinates. Panel references will be given in the text and tables to aid in locating a feature within a particular panel on these figures, and to indicate which panel of figure A2, Appendix A, to reference for more detail. The cross-reference location map, figure 5, may not be explicitly given in a text reference to figures 6 through 10, but its use will be implied for the purpose of locating river coordinates or features along the rivers.

Sand Transport

Sand transport, deposition, and scour needs to be considered in forming a complete description of the river system (fig. 6). Sand and silt transport rates were substantially larger than gravel transport rates (figs. 14 to 19). Because the volume of sand and finer material transported was so large, even small variations in average sediment discharge along the rivers meant corresponding large volumes of deposition or scour of sand and finer material.

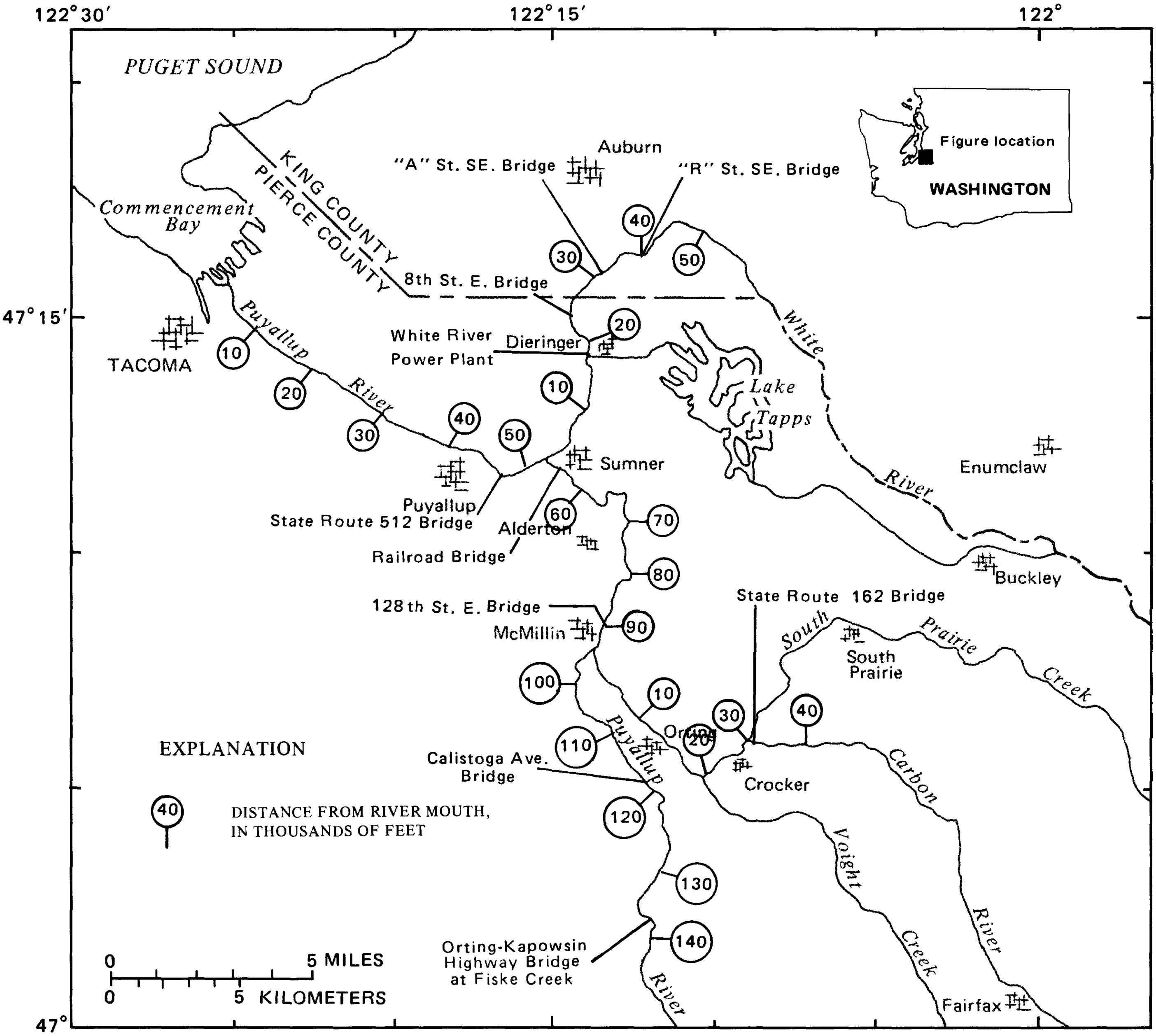

FIGURE 5.--Location of the lower Puyallup, White, and Carbon Rivers, river coordinates, selected bridges, and the White River Power Plant.

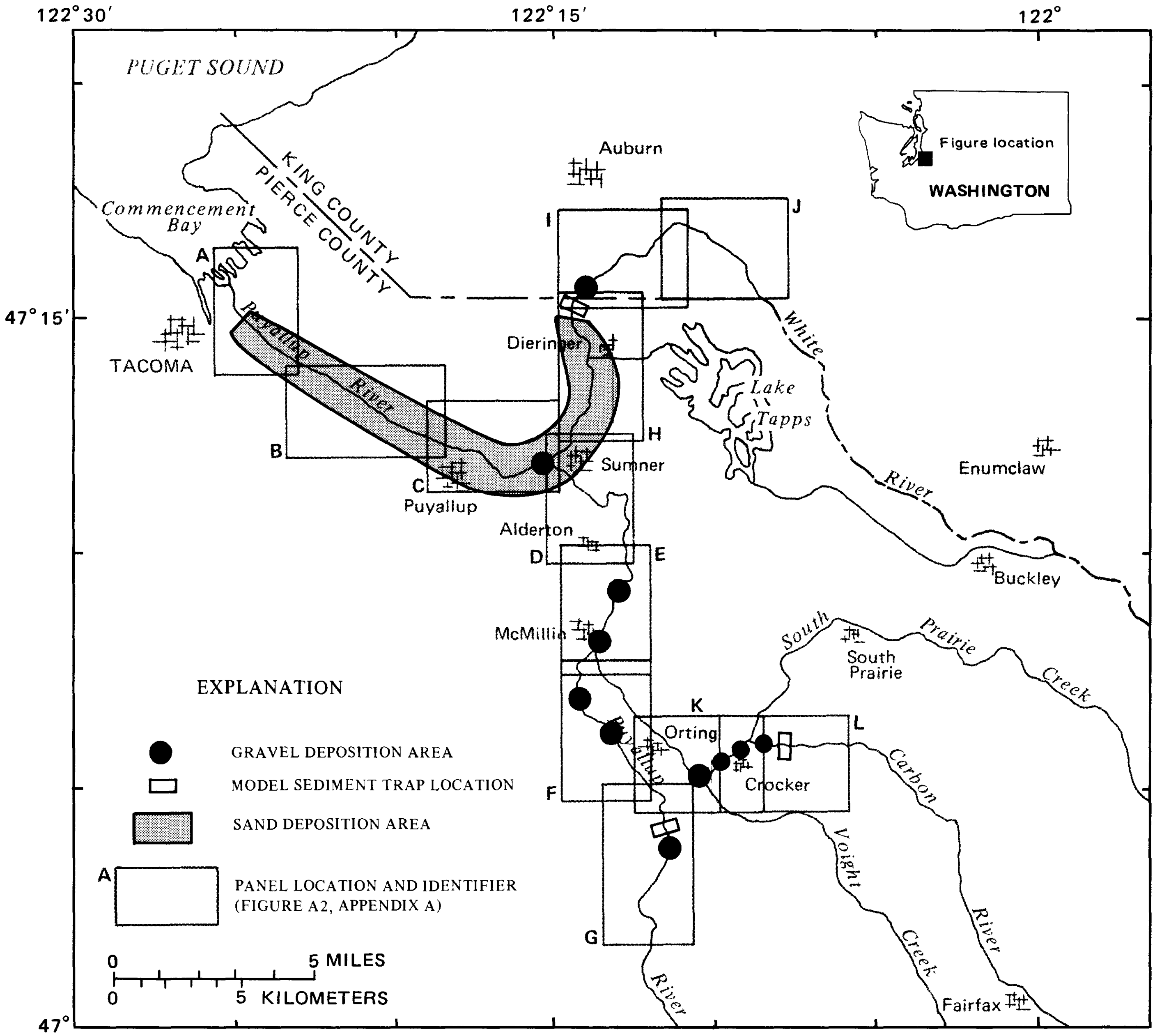

FIGURE 6.--Depositional areas for sand and finer material, and those for gravel and coarser material, from computer model.

Non-Intervention Alternative

The non-intervention alternative is based on the assumption that present gravel-bar scalping operations would cease and that sediment traps would not be installed. The general trend on the Carbon River and on the upper study reaches of the Puyallup and White Rivers was for the bed to scour rather than to deposit sediment (see the computer model results and field cross-section surveys in figs. 11, 12, and 13). Reaches of scour would be natural locations for the non-intervention approach. There were, however, areas of deposition that would not be ameliorated by the non-intervention approach.

Gravel Mining Alternative

Modeling indicated that gravel and coarser material were deposited in some river reaches (fig. 6). Gravel mining by the procedure of gravel-bar scalping provided a method of dealing with the gravel deposits (fig. 7). River reaches with high rates of gravel deposition, according to model results, are listed in table 12. These reaches would be the primary sites for a continued program of gravel-bar scalping. The rate of deposition for sand and finer material is included in table 12 to allow showing a rate of deposition for all size classes, because the total deposit is removed by the process of gravel-bar scalping. The total deposition rates provide guidelines from modeling for the amount of gravel removal that would have resulted in steady-state channel conditions during the modeling period. If the deposits in the reaches listed in table 12 were removed by scalping, the total volume of material removed during the modeling period would be 45,000 cubic yards on the Puyallup River, 7,000 cubic yards on the White River, and 20,000 cubic yards on the Carbon River. These totals were obtained by multiplying, for each reach, the total rate of deposition by reach length by number of years in the modeling period. There are 1.592 years from July 27, 1984, to March 19, 1986, and 1.647 years from August 16, 1984, to March 19, 1986. For example, for the first reach on the Puyallup River, which extends from 124,000 to 126,000 feet from the river's mouth, the reach length is 2,000 feet, the rate of deposition is 4.7 cubic yards per foot of river length per year, and the number of years in the modeling period is 1.592. Thus, the total deposition in this one reach is $2,000 \times 4.7 \times 1.592 = 14,965$ cubic yards (the answer has purposely been left unrounded to demonstrate the calculation). The total of the deposition in the seven reaches on the Puyallup River from table 12 is 45,000 cubic yards during the modeling period.

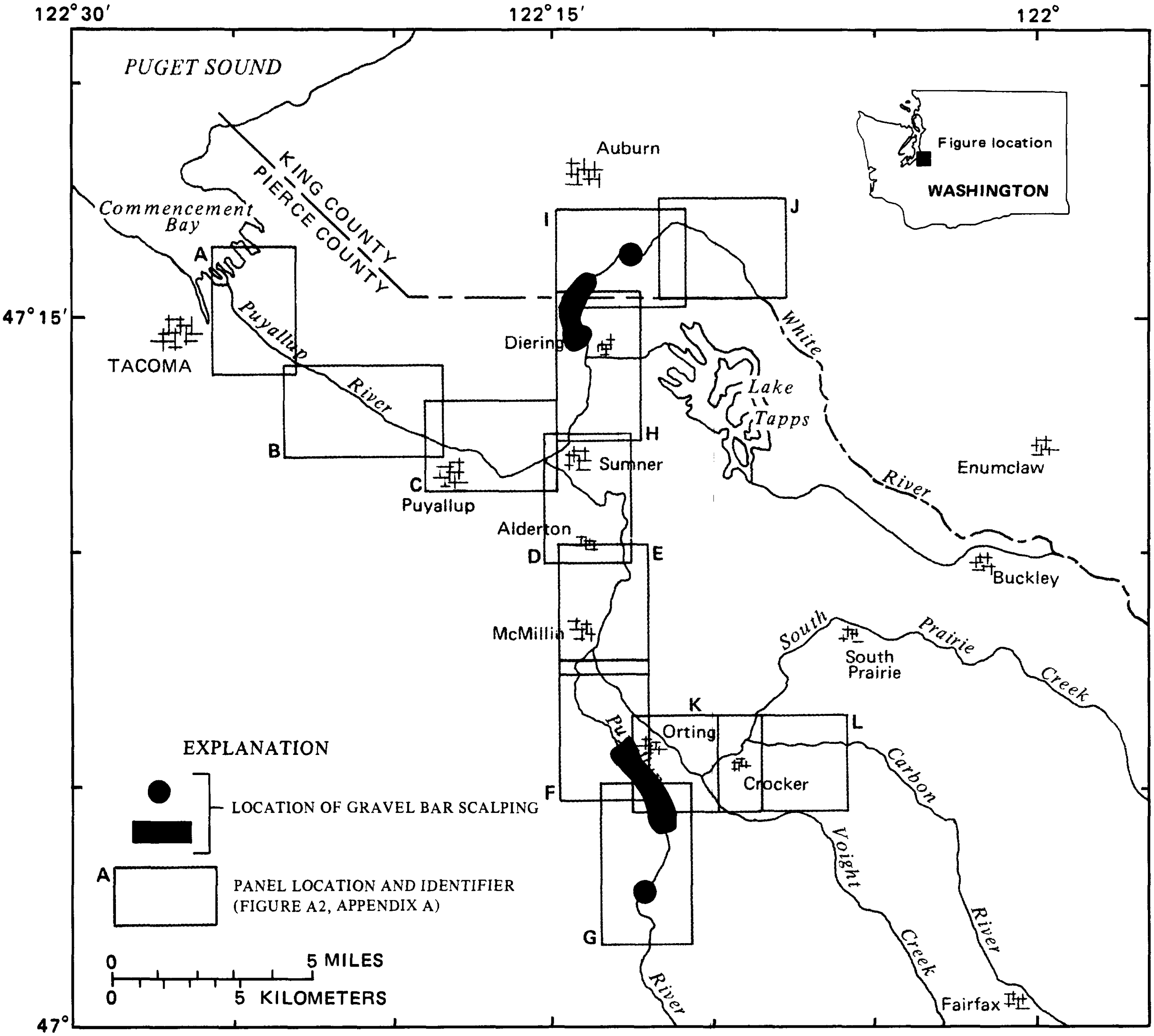

FIGURE 7. Locations of gravel bar scalping during the modeling period.

Table 12.--River reaches with substantial deposition of gravel and coarser material[1]

[g, deposition of gravel and coarser material; s, sand and finer material; t, all size classes]

River	Limit of reach, in feet from river mouth		Average rate of deposition (+) or scour (-), in cubic yards per foot of river length per year			Reach description[2]
	Downstream	Upstream	g	s	t	
Puyallup	124,000	126,000	4.3	0.4	4.7	In sediment control site /a/ near Orting, Washington (panel G)
Do.	123,200	124,000	1.1	-0.3	0.8	In sediment control site /a/ near Orting, Washington (panel G)
Do.	108,200	110,300	1.4	0.7	2.1	Between mouth of Carbon River and Orting, Washington (panel F)
Do.	100,200	102,200	1.7	0.5	2.2	Between mouth of Carbon River and Orting, Washington (panel F)
Do.	91,200	93,200	1.7	0.6	2.3	Near mouth of Carbon River (panel E)
Do.	83,700	86,100	1.2	0.0	1.2	Near McMillan, Washington (panel E)
Do.	53,500	54,400	3.4	-0.9	2.5	Near mouth of White River (panel C)
White	29,600	31,500	1.2	0.9	2.1	Near Auburn, Washington (panel I)
Carbon	32,400	33,300	2.5	0.0	2.5	Near Crocker, Washington (panel L)
Do.	28,200	30,000	2.4	-1.2	1.2	Near Crocker, Washington (panel K)
Do.	24,300	26,200	1.1	-0.5	0.6	Near Crocker, Washington (panel K)
Do.	18,600	21,900	2.2	0.0	2.2	Near Orting, Washington (panel K)

[1] Deposition rates were averaged during the time interval from July and August 1984 to March 19, 1986. The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

[2] The reference after each reach description is to a panel area shown in figure 6 (gravel deposition areas) or figure 8 (control sites); the same panel of figure A2, Appendix A, shows the area in more detail.

For comparison, during the modeling period, actual gravel-bar scalping operations removed 123,400 cubic yards from locations within the reach from 110,300 feet to 133,900 feet upstream of the mouth of the Puyallup River (table 10; fig. 7, panels F and G). The reaches with smaller gravel deposition rates that may require scalping intermittently are not listed in table 12; these reaches may account for some of the difference between the computed deposition of 45,000 cubic yards and the actual removal of 123,400 cubic yards. The actual gravel-bar scalping might also reflect the equivalent of overdredging, commonly done to provide some buffer time until the next dredging must be undertaken.

For further comparison, scalping operations removed 52,300 cubic yards from locations within the reach from 21,300 feet to 39,700 feet upstream of the mouth of the White River (table 10, fig. 7). The total of 7,000 cubic yards of material computed from table 12 accounts only for material deposited in reaches with high gravel deposition rates. The total volume could be larger if reaches with lower gravel deposition rates had been included in table 12. The 52,300 cubic yards of deposits actually removed probably also include sand deposited on the lower White River in reaches that don't appear in table 12. Thus, it is possible that the total actually removed, 52,300 cubic yards, may be somewhat larger than the amount obtained by totaling deposition only in reaches (table 12) with high gravel deposition rates. As in the case of the Puyallup River, designed overdredging may also account for some of the difference between computed deposition and actual removal.

Actual gravel-bar scalping locations did not correspond exactly to the model-selected reaches in table 12, although overlap existed, as can be seen by comparing figures 6 and 7. The effects of gravel-bar scalping appear in the plots of bed-elevation change, both as calculated by the computer model and as derived from surveys of the cross sections (figs. 11 and 12, gravel mining alternative and field surveys). Note the decrease of average bed elevation near 120,000 feet and 124,000 feet from the mouth of the Puyallup, upstream of the city of Orting limits (fig. 11), or near 27,000 feet from the mouth of the White River, upstream of the 8th Street East Bridge (fig. 12). Scalping removed more material at these locations than the river deposited during the modeling period, although it must be remembered that the figures refer to bed-elevation changes with respect to the bed at the start of the modeling period. If the starting elevation was already higher than desired, due to deposition that had occurred before the modeling started, it would be reasonable that scalping would lower the bed elevation below initial conditions. The scalping at these locations might also reflect intentional overdredging. Only a long-term time average balance between gravel deposition and gravel removal through scalping is realistic for the maintenance of channel cross-sectional areas. This goal can be achieved through continued monitoring and selection of scalping volumes and sites to provide a long-term balance with deposited volumes. The modeling results indicated that the scalping of gravel bars would be an effective method of maintaining channel capacity if restricted to reaches where deposition was occurring, provided that only the amount of aggradation is removed over the long term.

Sediment Trap Alternative: Effect on the Transport of Sand and Finer Material

In other river reaches, where sand and finer material was deposited, computer modeling indicated that sediment traps were effective in removing silt and sand from the sediment load carried further downstream. This reduction resulted secondarily in somewhat reduced silt and sand deposition further downstream. (The reduction is an indirect effect of the reduced transported load because changes in transported load, rather than the transported load itself, determine deposition; for example, a large sediment load can be carried completely through a river reach with no deposition.) Table 13 shows the effect of sediment traps on the deposition of sand and finer material. The modeling results indicated that the traps had markedly different effects on the transport and deposition of sand and finer material than on gravel and coarser material.

Table 13.--Effect of sediment traps on deposition of sand and finer material, showing average annual deposition in the indicated reaches from July and August 1984 to March 19, 1986[1]

River	Limits of sediment trap, in feet from river mouth: Downstream	Limits of sediment trap, in feet from river mouth: Upstream	Limits of deposition reach, in feet from river mouth: Downstream	Limits of deposition reach, in feet from river mouth: Upstream	Annual volume of sand and finer material, in cubic yards per year[2]: Deposition in reach without trap	Deposition in reach with trap	Reduction in deposition due to trap	Required maintenance removal from trap
Puyallup[3]	122,070	123,130	7,700	58,200	51,000	[4]8,000	[4]43,000	46,000
White[5]	27,510	28,560	500	27,500	52,000	19,000	33,000	110,000
White[3]	27,510	28,560	500	27,500	56,000	21,000	35,000	114,000
Carbon[3]	34,370	35,430	no significant deposition of sand and finer material					25,000

[1] The starting date was August 16, 1984, for the Carbon and Puyallup Rivers. The starting date for the White River was July 27, 1984, but the slightly shorter period starting August 16, 1984, is also given because of the influence of the White River trap on the Puyallup River.

[2] All four columns refer only to sand and finer material, and exclude annual volumes of gravel and coarser material.

[3] August 16, 1984, to March 19, 1986.

[4] Includes reduction of sand and finer load due to traps on the White and Carbon Rivers, as well as on the Puyallup River.

[5] July 27, 1984, to March 19, 1986.

On the White River, a model sediment trap was located from 27,510 to 28,560 feet upstream from the mouth (fig. 6, panel H). The trap location was within sediment transport control site /b/ (table 14; fig. 8, panels H and I), upstream of the 8th Street East Bridge located between Dieringer and Auburn (fig. 5). Sand and finer material were deposited on the reach from 500 to 27,500 feet upstream from the mouth (fig. 6, panels D and H). This deposition reach extends from the river's mouth to upstream of the 8th Street East Bridge and includes "hot spot" locations B1, B2, B3, and part of C1 (table 15; fig. 9, panels D and H). (The "hot spot" locations as defined herein include communities, developments, existing public utilities, structures, and flood-control works that require measures to reduce flood damages.) Deposition of sand and finer material in this reach was reduced from 52,000 to 19,000 cubic yards per year by the model sediment trap, a reduction of 33,000 cubic yards per year. However, this reduction was at the expense of maintenance removal of a much larger 110,000 cubic yards per year of sand and finer material from the model sediment trap. That is, the model indicated that most of the sand and finer material removed by the trap would have been transported into the lower Puyallup River and Commencement Bay, instead of being deposited in the White River below the trap.

Table 14.--Sediment transport control sites, by priority (Anderson, 1986)

Control site	River	Distance from mouth (feet)	Cross section	Location[1]
/a/	Puyallup	122,020-128,030	P135-P141	Orting area, upstream of city of Orting limits (panel G)
/b/	White	25,970- 29,620	W66- W70	Dieringer-Auburn area, upstream of 8th Street East Bridge (panels H, I)
/c/	Carbon	upstream of 31,450	upstream of C33	Crocker area, about 0.6 mile upstream of State Route 162 Bridge (panel L)
/d/	White	39,650- 43,240	RM7.51- RM8.19	Auburn area, upstream of the "R" Street Southeast Bridge (panel I)
/e/	White	32,790- 37,440	RM6.21- RM7.09	Auburn area, upstream of the "A" Street Southeast Bridge (panel I)
/f/	Puyallup	upstream of 137,050	upstream of P150.2	Orting area, upstream of Orting-Kapowsin Highway Bridge at Fiske Creek (panel G)

[1] The reference after each location is to a panel area shown in figure 8; the same panel of figures A2, Appendix A, shows the area in more detail. See figure 5 for locations of bridges.

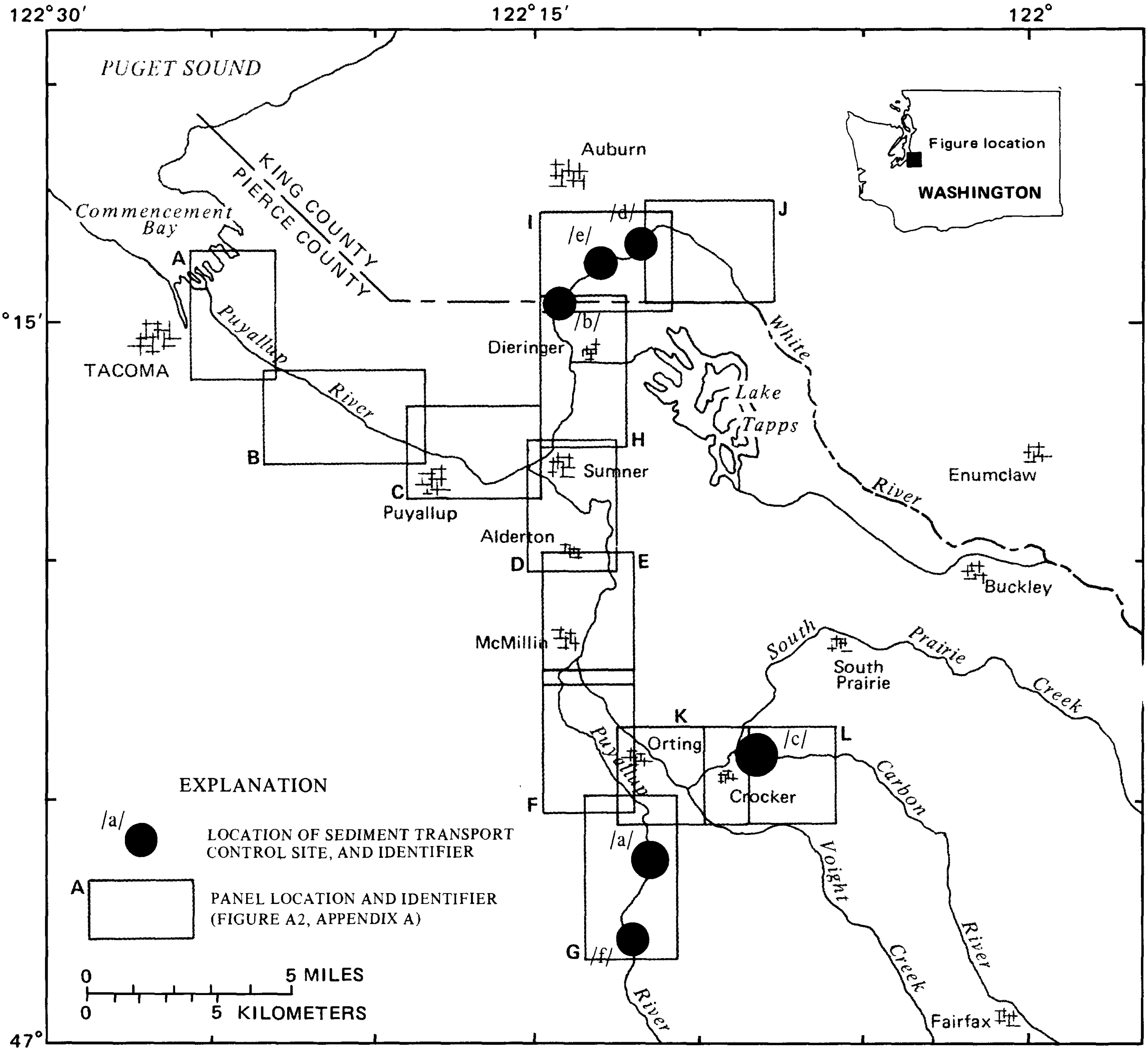

FIGURE 8.--Sediment transport control sites /a/ through /f/ (Anderson, 1986).

Table 15.--"Hot spot" locations, by priority (Anderson, 1986)

Hot Spot	River	Distance from mouth (feet)	Cross section	Location[1]
A1	Puyallup	110,300-115,200	P122-P127	Orting area, downstream of Calistoga Avenue Bridge (panel F)
A2	Puyallup	115,480-122,020	P128-P135	Orting area, upstream of Calistoga Avenue Bridge (panels F, G)
A3	Puyallup	122,020-125,980	P135-P139	Orting area, 1.3 to 2.0 miles upstream of Calistoga Avenue Bridge (panel G)
A4	Carbon	9,440- 19,760	C10- C20	Orting area (panels F, K)
B1	Lower White	5,970- 9,620	W46- W51	Sumner area (panels D, H)
B2	Lower White	9,620- 19,230	W51- W60	Dieringer area, downstream of White River Power Plant (panel H)
B3	Lower White	19,230- 25,970	W60- W66	Dieringer area, downstream of 8th Street East Bridge (panel H)
C1	Middle White	25,970- 29,620	W66- W70	Dieringer-Auburn area, upstream of 8th Street East Bridge (panels H, I)
C2	Middle White	29,620- 39,650	W70 -RM7.51	Auburn area, downstream of "R" Street Southeast Bridge (panel I)
D1	Puyallup	48,050- 49,550	P58- P60	Puyallup area, upstream of State Route 512 Bridge (panel C)
D2	Puyallup	53,510- 55,550	P64- P66	Puyallup area, at mouth of White River (panel C)
D3	Puyallup	56,560- 62,540	P68- P74	Puyallup area, upstream of railroad bridge (panel D)
D4	White	450- 1,480	W39- W40	Sumner area, at mouth of White River (panel D)
E1	Puyallup	84,990- 89,660	P97-P101	McMillan area, downstream of 128th Street East Bridge (panel E)
E2	Puyallup	89,660- 93,240	P101-P105	McMillan area, upstream of 128th Street East Bridge to mouth of Carbon River (panel E)
F1	Upper White	39,650- 55,860	RM7.51 -RM10.58	Auburn area, upstream of "R" Street Southeast Bridge (panels I, J)

[1] The reference after each location is to a panel area shown in figure 9; the same panel of figure A2, Appendix A, shows the area in more detail. See figure 5 for locations of bridges and the White River Power Plant.

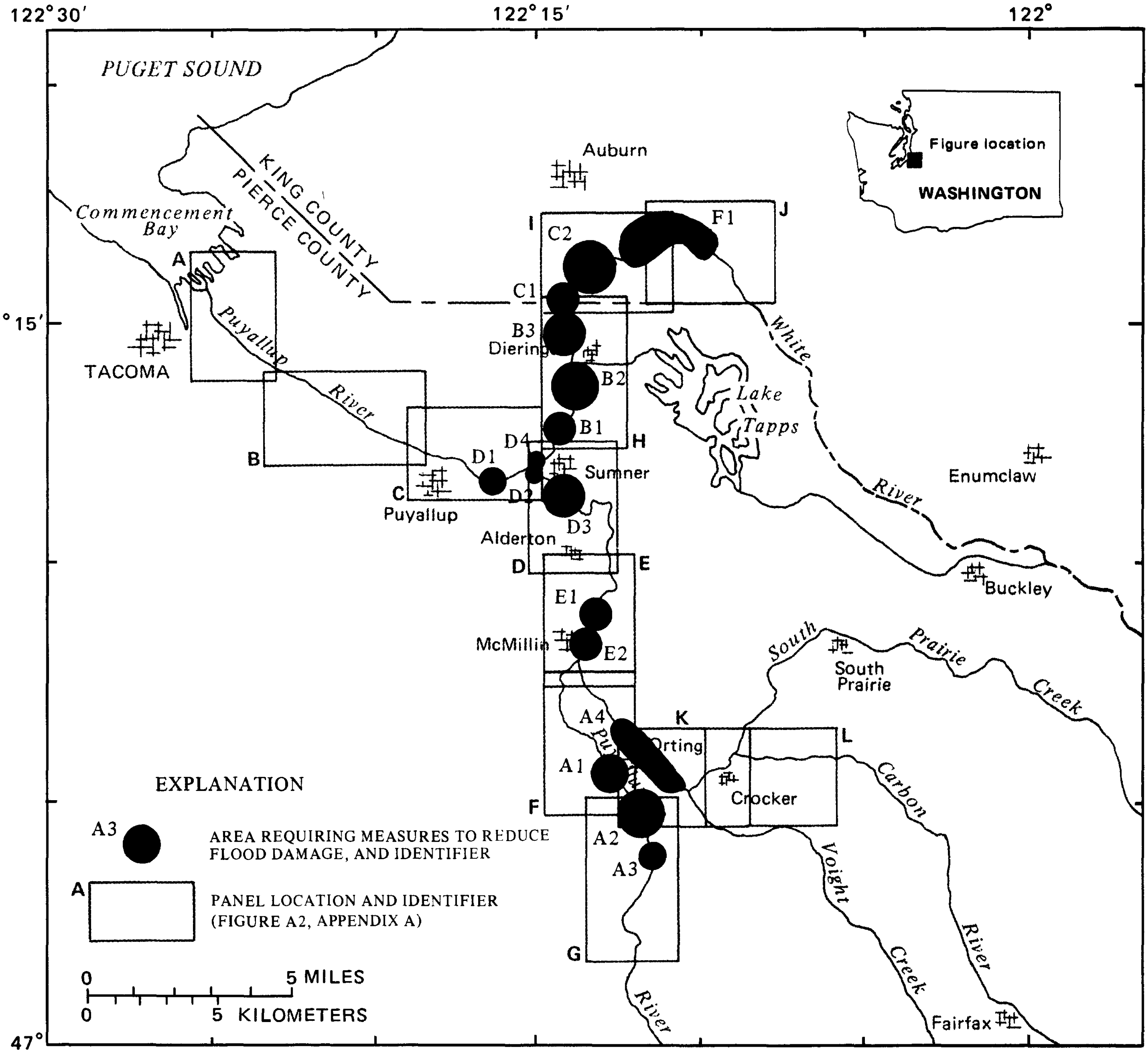

FIGURE 9.–Location of communites, developments, existing public utilities, structures, and flood control works that require measures to reduce flood damage.

A model trap on the Carbon River was located from 34,370 to 35,430 feet from the river's mouth (fig. 6, panel L), in sediment control site /c/ (table 14; fig. 8, panel L), upstream of the State Route 162 Bridge located about a half mile north of the city of Crocker (fig. 5). However, the Carbon River did not have any reaches where deposition of sand and finer material was larger than 0.7 cubic yards per foot of length along the river per year. Therefore, the model results indicate that traps for the purpose of sand removal probably are not needed on the Carbon River, unless the purpose is to remove sand that would be transported into the Puyallup River and Commencement Bay.

On the Puyallup River, deposition of sand and finer material occurred from 7,700 to 58,200 feet upstream from the mouth (fig. 6, panels A, B, C, and D). This deposition reach extends from the Port of Tacoma to upstream of the mouth of the White River, and includes "hot spots" D1, D2, and part of D3 (table 15; fig. 9, panels C and D). The model sediment trap on the Puyallup River was located between 122,070 and 123,130 feet from the mouth (fig. 6, panel G). This trap location is within sediment transport control site /a/ (table 14; fig. 8, panel G), upstream of the city of Orting limits. Sand deposition on the lower Puyallup River would be reduced by a sediment trap upstream. This can be seen by comparing the lower graph in figure 20, showing sand deposition with sediment traps, with the second graph showing sand deposition without the traps. Deposition of sand and finer material in the indicated reach of the lower Puyallup River was reduced from 51,000 to 8,000 cubic yards per year by the combined effect of sediment traps on the Puyallup, White, and Carbon Rivers, a reduction in annual deposition of 43,000 cubic yards.

It is perhaps more instructive to consider the combined deposition reaches for sand and finer material on both the lower White and Puyallup Rivers (fig. 6, panels A, B, C, D, and H). Comparison of the sediment trap alternative in figure 22 with the non-interaction alternative shows that sand deposition would be reduced below a trap on the White River. In addition to the reduction of 43,000 cubic yards per year on the Puyallup River, the model indicated a reduction of 35,000 cubic yards per year in deposition of sand and finer material on the White River from August 16, 1984, to March 19, 1986 (table 13), for a total reduction of 78,000 cubic yards per year. This modeled reduction was at the expense of the removal of 46,000 cubic yards per year from the trap on the Puyallup River, 114,000 cubic yards per year from the trap on the White River, and 25,000 cubic yards per year from the trap on the Carbon River, for a total annual removal in the three traps of 185,000 cubic yards.

It would probably be more efficient to deal with the deposits in the reaches where they occur, instead of upstream. Installing a sediment trap upstream had the effect of reducing the volume of sand and silt in transport, as can be seen by comparing the sediment trap and non-intervention alternatives for the Puyallup River (fig. 14), the White River (fig. 16), or the Carbon River (fig. 18). However, this only indirectly affected the volume deposited, which is represented by the changes in transport in the downstream direction. The transported load was still large. It was this large transported sediment load, most of which was carried through the river system into Commencement Bay, that was somewhat modified by the traps. Thus, modeling indicated that most of the sand and finer material removed by the traps would have been transported, in the absence of the traps, into Commencement Bay, rather than being deposited in the lower White and Puyallup Rivers.

Sediment Trap Alternative: Effect on the Transport of Gravel and Coarser Material

The computer model results indicated that the influences of sediment traps on gravel transport were much more restricted to the local reach downstream and upstream from the trap (fig. 10, panels G, H, I, and L), in contrast to the effects on sand and finer material. The effects just downstream of the traps are shown in table 16, and the effects just upstream of the traps in table 17.

On the White River, the sediment trap increased the scour of gravel and coarser material just downstream of the model sediment trap from 400 to 1,300 cubic yards per year, an increase of 900 cubic yards per year (table 16). The downstream reach extended from 26,000 to 27,500 feet upstream from the mouth of the White (fig. 10, panel H), and included part of "hot spot" C1 in the 8th Street East Bridge area between Dieringer and Auburn (table 15; fig. 9, panel H). Just upstream of the model trap, deposition was reduced from 500 cubic yards per year to 300 cubic yards per year, a reduction of 200 cubic yards per year (table 17). The upstream reach extended from 28,600 to 29,600 feet above the river's mouth (fig. 10, panel I), and included part of "hot spot" C1 upstream of the 8th Street East Bridge (table 15; fig. 9, panel I). Operation of the trap required the maintenance removal of 1,200 cubic yards per year of gravel from the trap. (Note that the last column is duplicated in tables 16 and 17, and already refers to the total removal of gravel and coarser material from the trap; the entries from the tables should not be added to arrive at total removal.) The addition of the trap caused increased deposition within the length of the trap, which was balanced by reduced deposition in the nearby upstream reach, and increased scour in the nearby downstream reach. In a local reach that extended from 26,000 to 29,600 feet from the river's mouth and included the trap, total deposition of gravel and coarser material was about the same as it had been without the trap, namely, 100 cubic yards per year. No significant change in the discharge, aggradation, or deposition of gravel and coarser material occurred upstream or downstream of the local reach. Note that the restriction of influence of the trap to a reach of 3,600 feet surrounding the trap was because of the local nature of gravel transport, and did not depend on trap size; a larger trap would not have increased the reach of influence.

On the Carbon River, the effect of a model sediment trap on deposition of gravel and coarser material was similar. Downstream of the model trap, in the reach near the town of Crocker extending from 28,100 to 34,400 feet from the river's mouth (fig. 10, panel L), scour was increased from 600 to 3,100 cubic yards per year, an increase of 2,500 cubic yards per year. In the upstream reach extending from 35,400 feet to 39,000 feet from the river's mouth (fig. 10, panel L), scour actually decreased just slightly, from 700 cubic yards per year to 300 cubic yards per year. The decrease in scour was the reverse of what was expected, and may be a result of the nearness of the upstream model boundary. The local reach of influence affected by the trap extended from 28,100 to 39,000 feet. Scour of gravel and coarser material in this reach remained about 1,500 cubic yards per year with or without the trap. The affected reach does not include any "hot spots" because the overall trend there is scour, rather than deposition. Operation of the sediment trap required the removal of 2,000 cubic yards per year of gravel and coarser material.

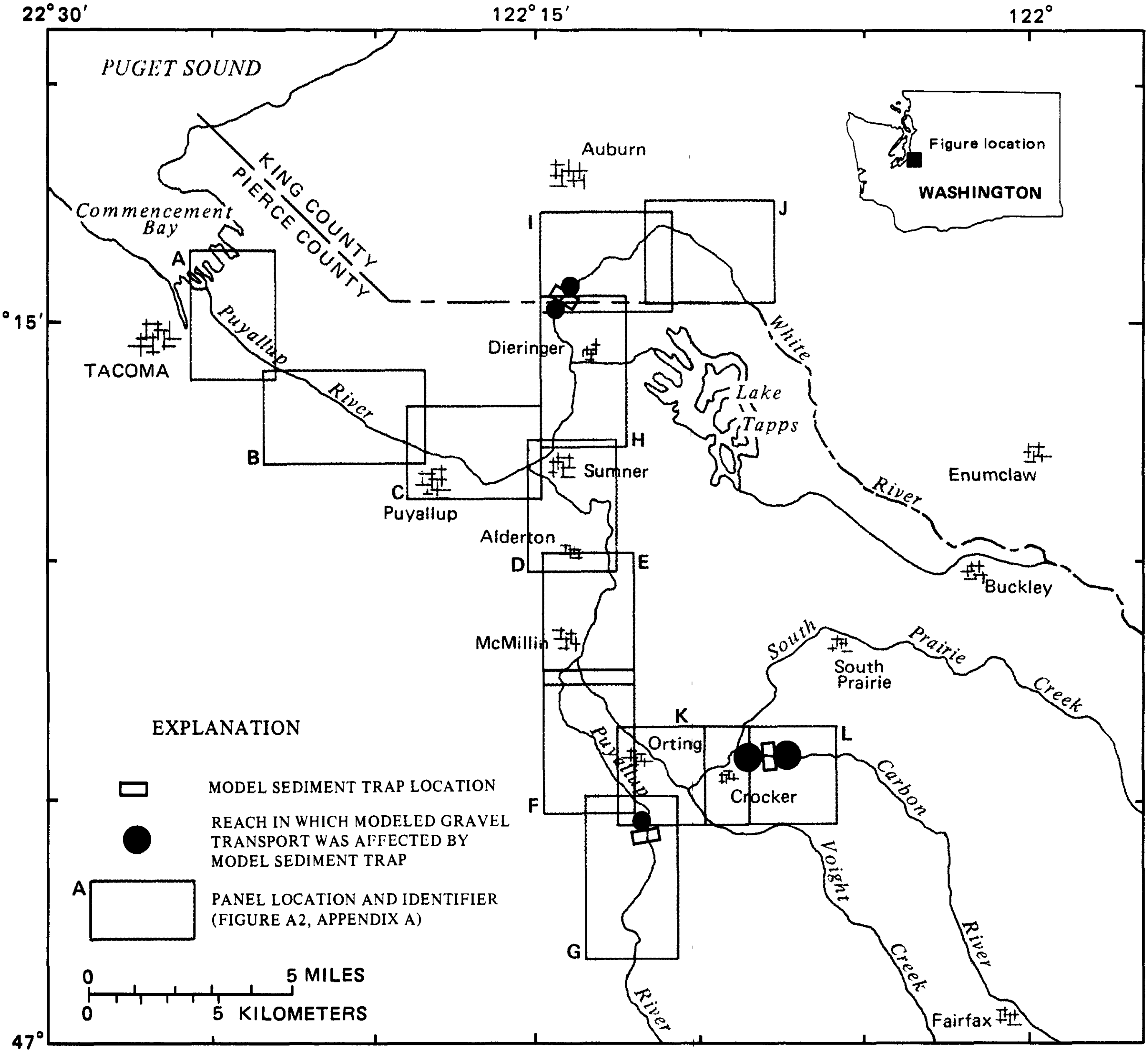

FIGURE 10.--Reaches in which modeled transport of gravel and coarser material was affected by sediment traps.

Table 16.--Downstream effect of sediment traps on deposition of gravel and coarser material, showing average annual deposition in the indicated reaches from July and August 1984 to March 19, 1986[1]

River	Limits of sediment trap, in feet from river mouth: Downstream	Limits of sediment trap, in feet from river mouth: Upstream	Limits of deposition reach, in feet from river mouth: Downstream	Limits of deposition reach, in feet from river mouth: Upstream	Annual volume of gravel and coarser material, in cubic yards per year[2]: Deposition (+) or scour (-) in reach without trap	Deposition (+) or scour (-) in reach with trap	Reduction in deposition and (or) increase in scour due to trap	Required maintenance removal from trap[3]
Puyallup	122,100	123,100	120,200	122,100	200	-200	400	700
White	27,500	28,600	26,000	27,500	-400	-1,300	900	1,200
Carbon	34,400	35,400	28,100	34,400	-600	-3,100	2,500	2,000

1 The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

2 All four columns refer only to gravel and coarser material, and exclude annual volumes of sand and finer material.

3 The column refers to the total required maintenance removal of gravel and coarser material from the trap; this quantity is duplicated in table 17, and the values from the two tables should not be added.

Table 17.--Upstream effect of sediment traps on deposition of gravel and coarser material, showing average annual deposition in the indicated reaches from July and August 1984 to March 19, 1986[1]

River	Limits of sediment trap, in feet from river mouth: Downstream	Limits of sediment trap, in feet from river mouth: Upstream	Limits of deposition reach, in feet from river mouth: Downstream	Limits of deposition reach, in feet from river mouth: Upstream	Annual volume of gravel and coarser material, in cubic yards per year[2]: Deposition (+) or scour (-) in reach without trap	Deposition (+) or scour (-) in reach with trap	Reduction in deposition and (or) increase in scour due to trap[3]	Required maintenance removal from trap[4]
Puyallup	122,100	123,100	123,100	123,100	0	0	0	700
White	27,500	28,600	28,600	29,600	500	300	200	1,200
Carbon	34,400	35,400	35,400	39,000	-700	-300	-400	2,000

1 The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

2 All four columns refer only to gravel and coarser material, and exclude annual volumes of sand and finer material.

3 The negative value for the Carbon River indicates a decrease in scour.

4 The column refers to the total required maintenance removal of gravel and coarser material from the trap; this quantity is duplicated in table 16, and the values from the two tables should not be added.

On the Puyallup River, the downstream reach affected by the model trap extended from 120,200 feet from the river's mouth to the downstream end of the trap at 122,100 feet (fig. 10, panel G). This reach includes part of "hot spot" A2 in the Orting area upstream of the Calistoga Avenue Bridge (table 15; fig. 9, panel G). Deposition of 200 cubic yards per year in this downstream reach was changed by the presence of the trap to scour of 200 cubic yards per year, an increase in scour of 400 cubic yards per year. Gravel transport was not affected upstream of the trap. Deposition remained at about 500 cubic yards per year in the surrounding local reach extending from 120,200 to 123,100 feet from the mouth, whether or not the trap was present. The effect of the trap was to cause increased deposition within its length, which was accounted for by reduced deposition and increased scour in the nearby downstream reach. Operation of the sediment trap required the removal of 700 cubic yards per year of gravel and coarser material.

Changes further downstream from the traps on each of the rivers might evolve slowly due to a gradually evolving streambed configuration. However, the time scale of this process would be decades to centuries. Moreover, there would be no guarantee that the desired effect of reduced deposition in localized areas would result. Instead, the entire streambed would gradually change, and increased scour from areas already experiencing scour could result, as was already evident in the downstream reaches near the sediment traps during the modeling period (see table 16).

Gravel Deposition and Scour

Local gravel transport causes localized areas of scour and deposition. Because gravel transport was not affected by sediment traps except near the traps, these localized deposits would probably most efficiently be reduced by periodic removal of material from the deposits. Examples are deposits in the Puyallup River that occurred near Orting and at the mouths of the Carbon and White Rivers, or in the White River near Auburn (fig. 6, table 12).

Sand Deposition and Scour

The computer model indicated considerable sand deposition in the White River (fig. 22) and lower Puyallup River (figs. 20 and 6). This deposition probably could most effectively be remedied by the periodic removal of material from the deposits, rather than with less efficient sediment traps upstream. Scour of sand-sized material also was an important contributor to bed degradation. For example, figure 20 indicates that scour of sand and finer material caused significant lowering of the bed elevation on the Puyallup River at locations of bed-elevation decrease shown in the profiles in figure 11.

Particle-Size Distribution

There appeared to be little difference in particle-size distribution in the armor layer that results from the three operational modes (non-intervention, gravel-bar scalping, or sediment traps) except at the locations of sediment traps, where the percentage of sand and finer material was large within the traps, and small in the small-boulder buffer sections at the upstream and downstream ends (figs. 26, 27, and 28).

Possible Future Work

A continued program of field observation and model runs may be desirable. The model would continue to provide insights into approaches or processes on which to focus attention, and would guide the allocation of data collection activities. Feedback of these data would in turn provide more specific information for modeling of selected aspects of sediment transport within the river system.

SUMMARY AND CONCLUSIONS

The study that is the subject of this report was done by the U.S. Geological Survey, in cooperation with the Pierce County Public Works Department and the State of Washington Department of Ecology, to obtain information about sediment deposition, scour, and movement in the lower Puyallup, White, and Carbon Rivers of western Washington. The information would allow determining locations and characteristics of sediment deposits that might affect channel flood-carrying capacity, and would allow estimating the effects of measures for controlling the deposition.

The study obtained a comprehensive description of sediment transport within the lower Puyallup River basin under the assumptions of specified alternative sediment-control measures. The three alternatives were to retain the existing practice of gravel mining by gravel-bar scalping; to install sediment traps on the Puyallup, White, and Carbon Rivers; or to not intervene with sediment-control measures on the river system. Measured cross sections, hydrographs, and sediment data collected from July and August 1984 to March 19, 1986, provided data for input and verification of sediment transport computer model HEC-6. The following conclusions about the sediment-transport processes and the sediment-management practices can be drawn from the data and results of computer modeling.

1. Gravel discharge is only a small part of the total sediment discharge. Gravel transport is a localized process, sensitive to local channel geometry.

2. Sand and silt transport rates account for most of the total sediment discharge. Because of the large volumes in transport, substantial deposition or scour can result from even small variations of the transport rates along the rivers. Transport of sand and finer material needs to be taken into consideration to understand the sediment transport process, and to design sediment control measures.

3. Both cross-section surveys and computer model results indicated that in much of the modeled system, scour rather than deposition took place. The non-intervention alternative would, therefore, suffice as a sediment-control measure on these reaches.

4. Scalping of gravel bars could be the most appropriate alternative to be applied to locations of substantial gravel deposition. Actual scalping volumes of sediment could vary from deposited volumes during a particular time interval, such as the modeling period, if only longer-term average balance between deposits and removal is sought.

5. On the basis of model results, sediment traps were effective in modifying the sand and silt transport downstream, but they were almost totally ineffective in changing gravel transport except near the traps themselves. This difference resulted because sand and silt were transported at greater rates and more consistently along the channel than gravel, which was transported at a lesser rate and more locally in nature. During the modeling period, changes in gravel transport downstream of the traps to accommodate continual gravel removal by the traps were restricted to local reaches of influence near the traps. The reduction of sand and silt loads in transport reduced sand deposition in downstream reaches.

6. Gravel-bar scalping provides a means of reducing widely dispersed and localized gravel deposits.

7. Sand deposits occurred in long reaches in the lower sections of the Puyallup and White Rivers. Modeled conditions along these reaches in the presence of sediment traps indicated reduced sand deposition, but the modeled traps required the maintenance removal of sediment that otherwise would have been transported into Commencement Bay. A more efficient control method might be to remove the material from the deposits themselves.

8. Particle-size distribution remained virtually the same under the control alternatives, except at the sediment traps, where the percentage of sand and finer material was large within the traps, and small in the small-boulder buffer sections at the upstream and downstream ends.

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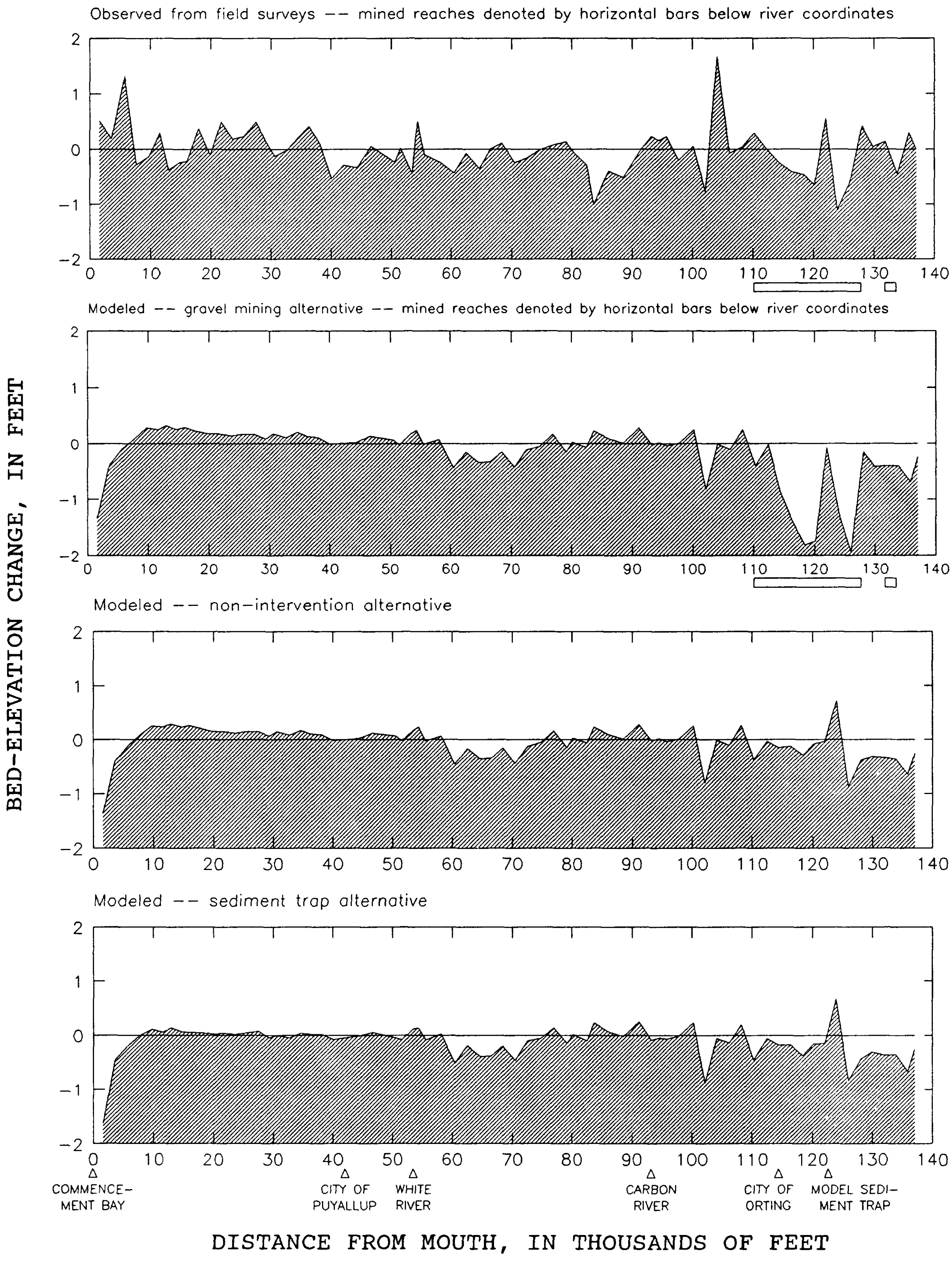


FIGURE 11.--Observed and modeled bed-elevation change on the Puyallup River from August 16, 1984, to March 19, 1986.

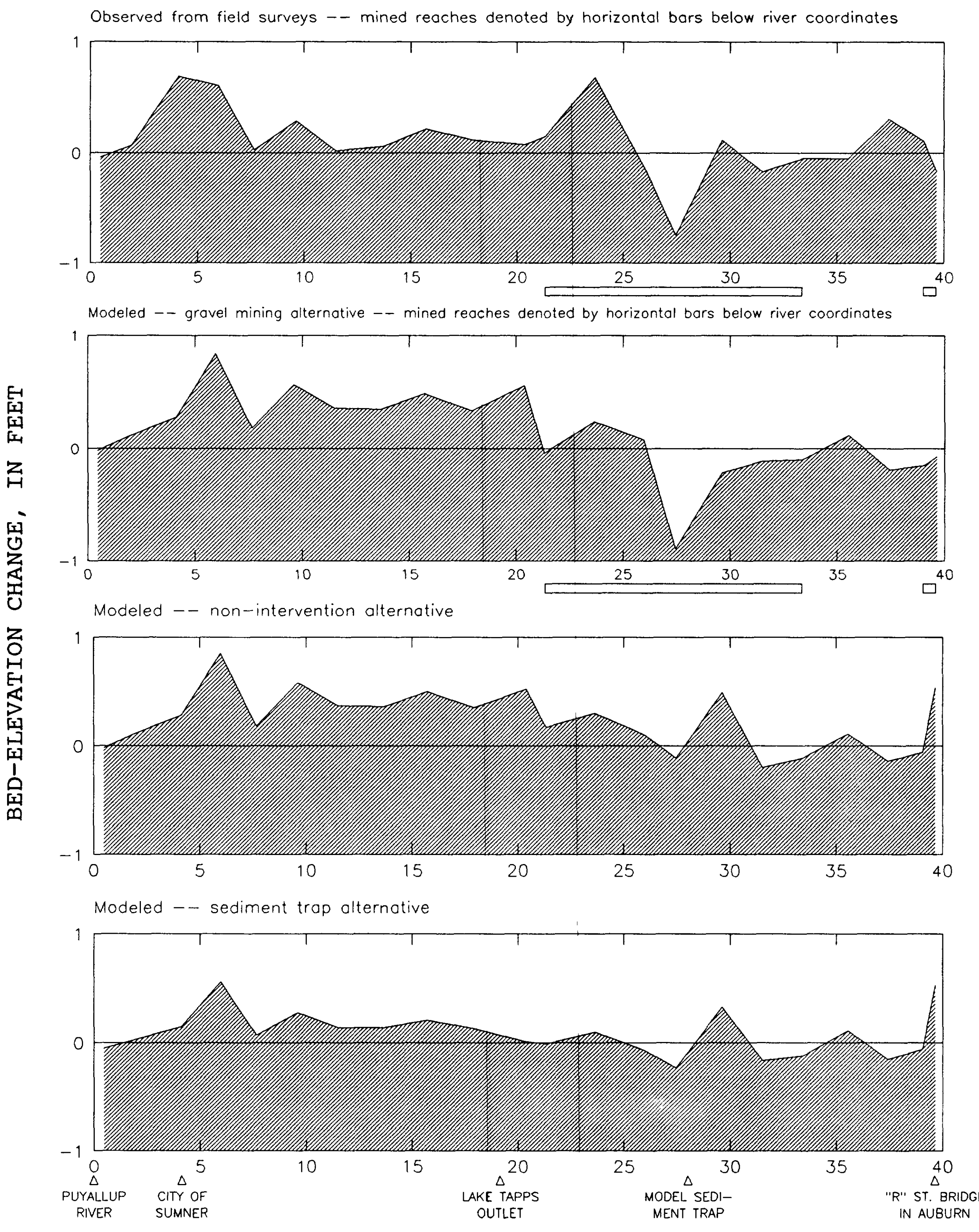


FIGURE 12.--Observed and modeled bed-elevation change on the White River from July 27, 1984, to March 19, 1986.

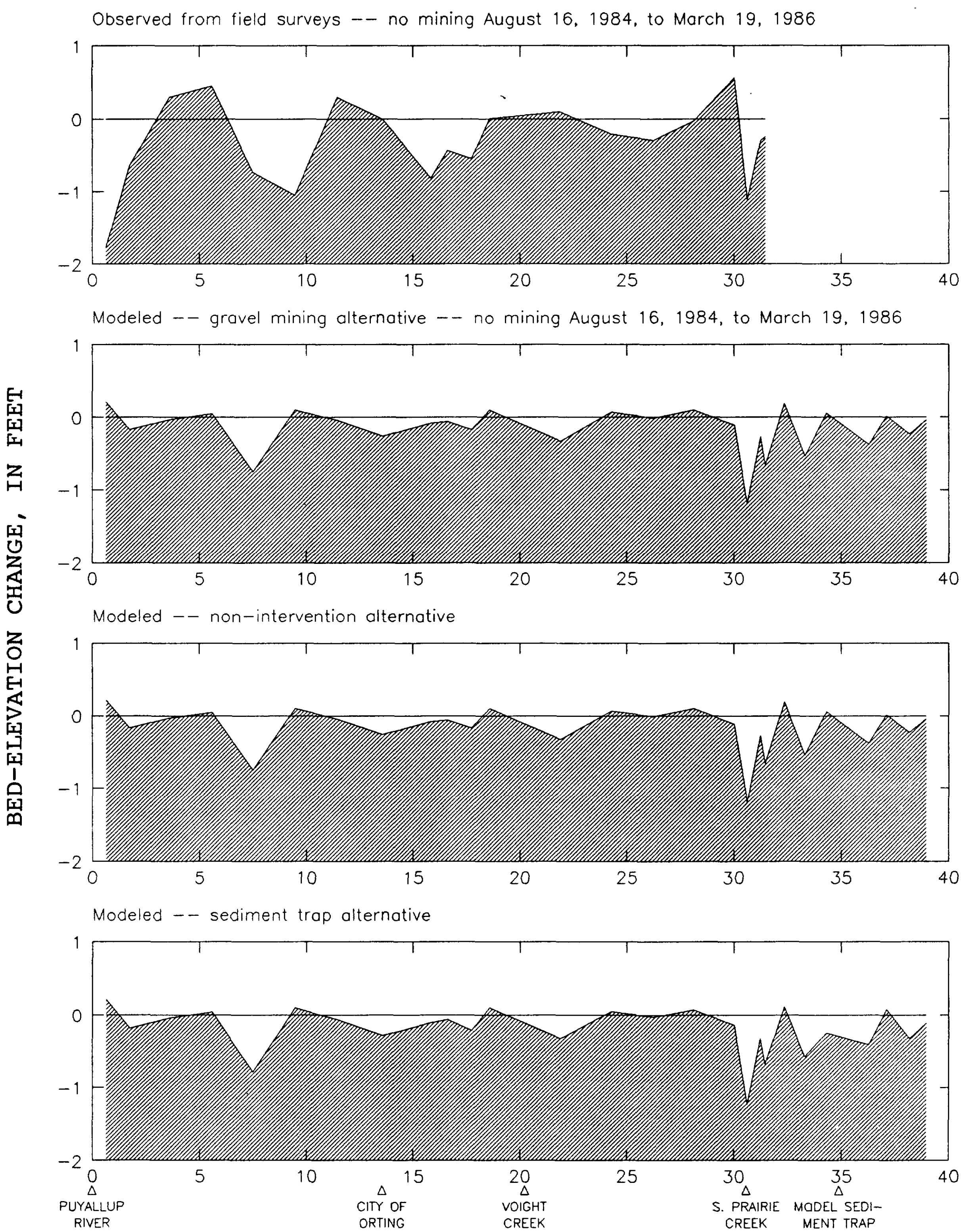


FIGURE 13.--Observed and modeled bed-elevation change on the Carbon River from August 16, 1984, to March 19, 1986.

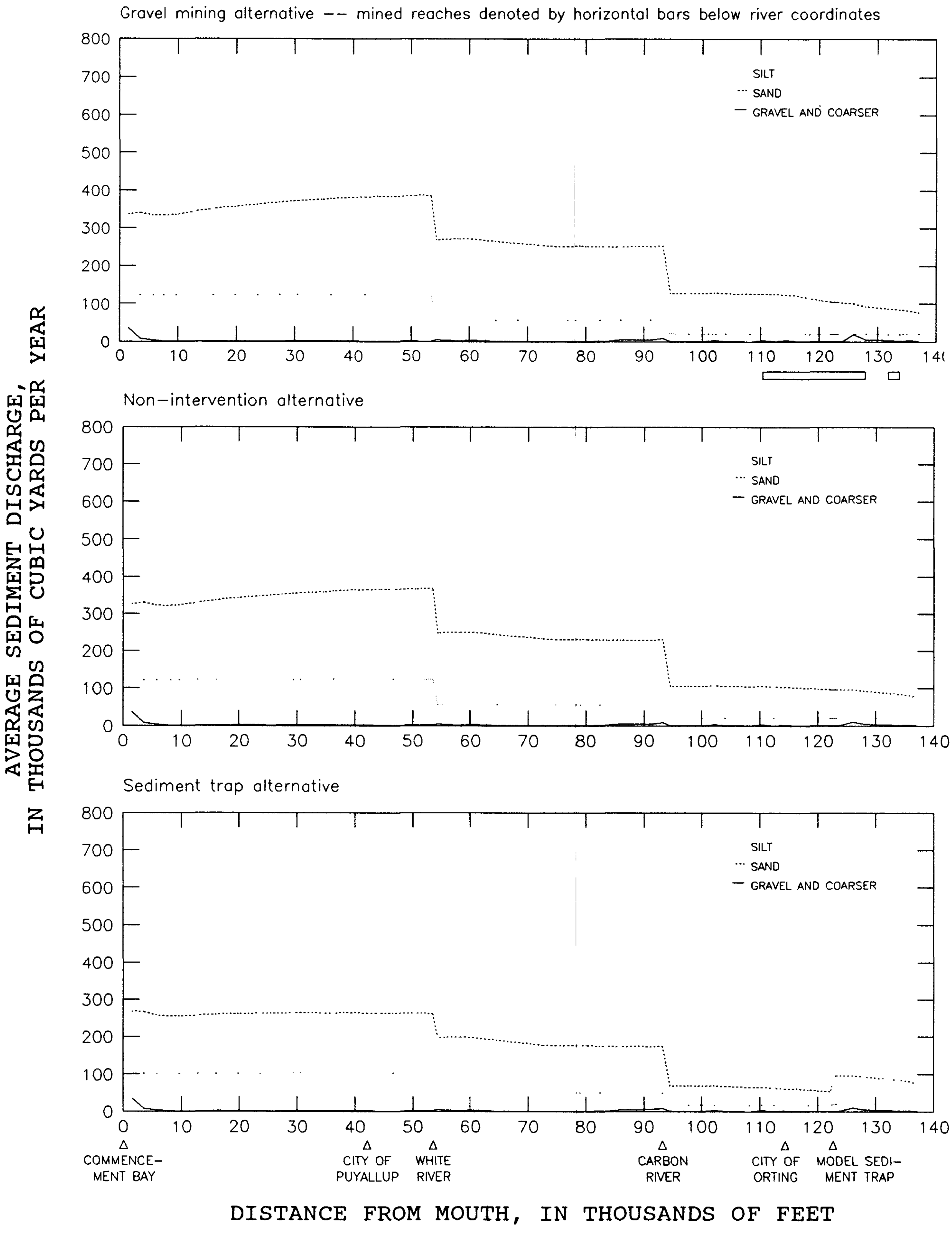


FIGURE 14.–Modeled average sediment discharge on the Puyallup River during August 16, 1984, to March 19, 1986.

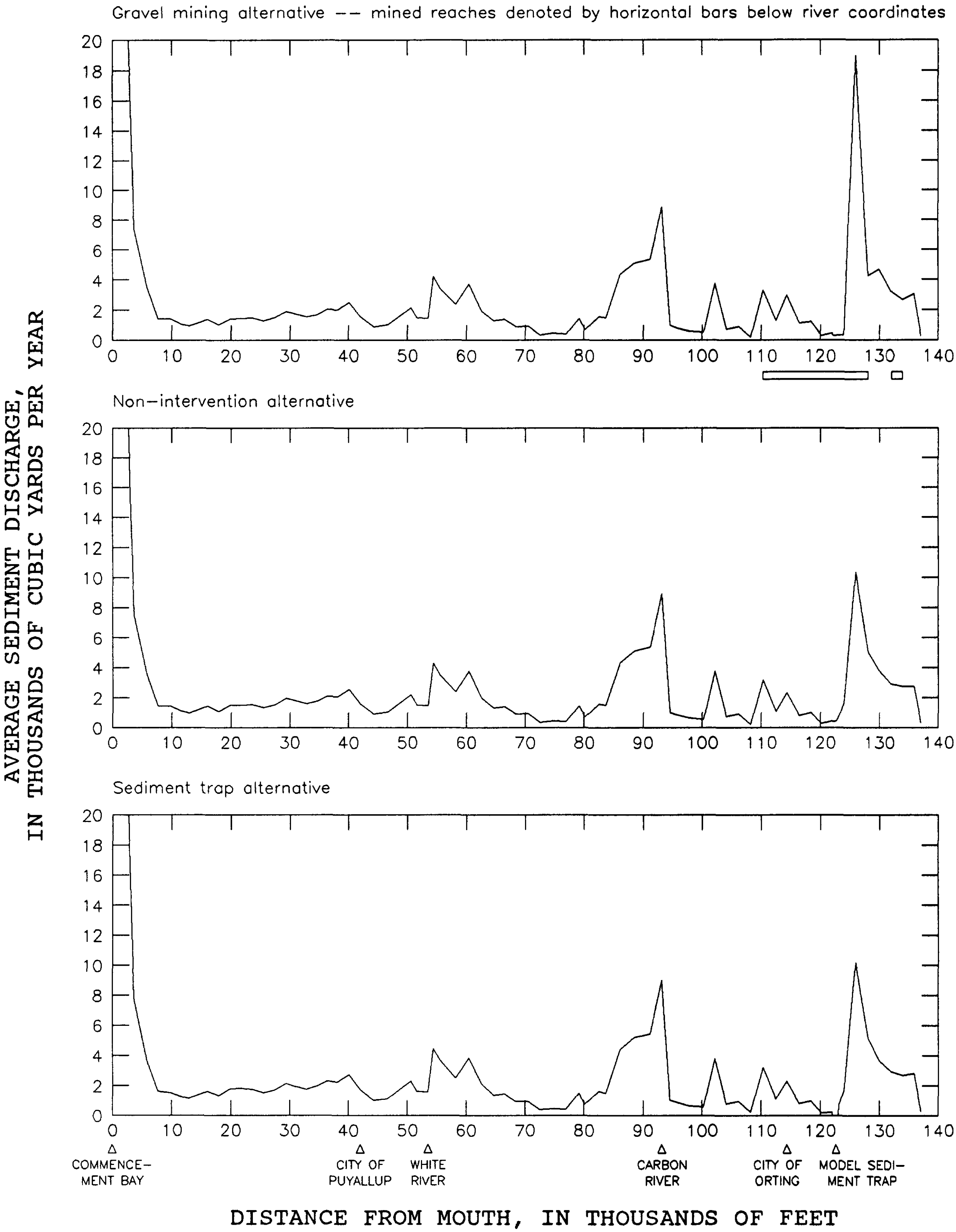


FIGURE 15.–Modeled average discharge of gravel and coarser material on the Puyallup River during August 16, 1984, to March 19, 1986.

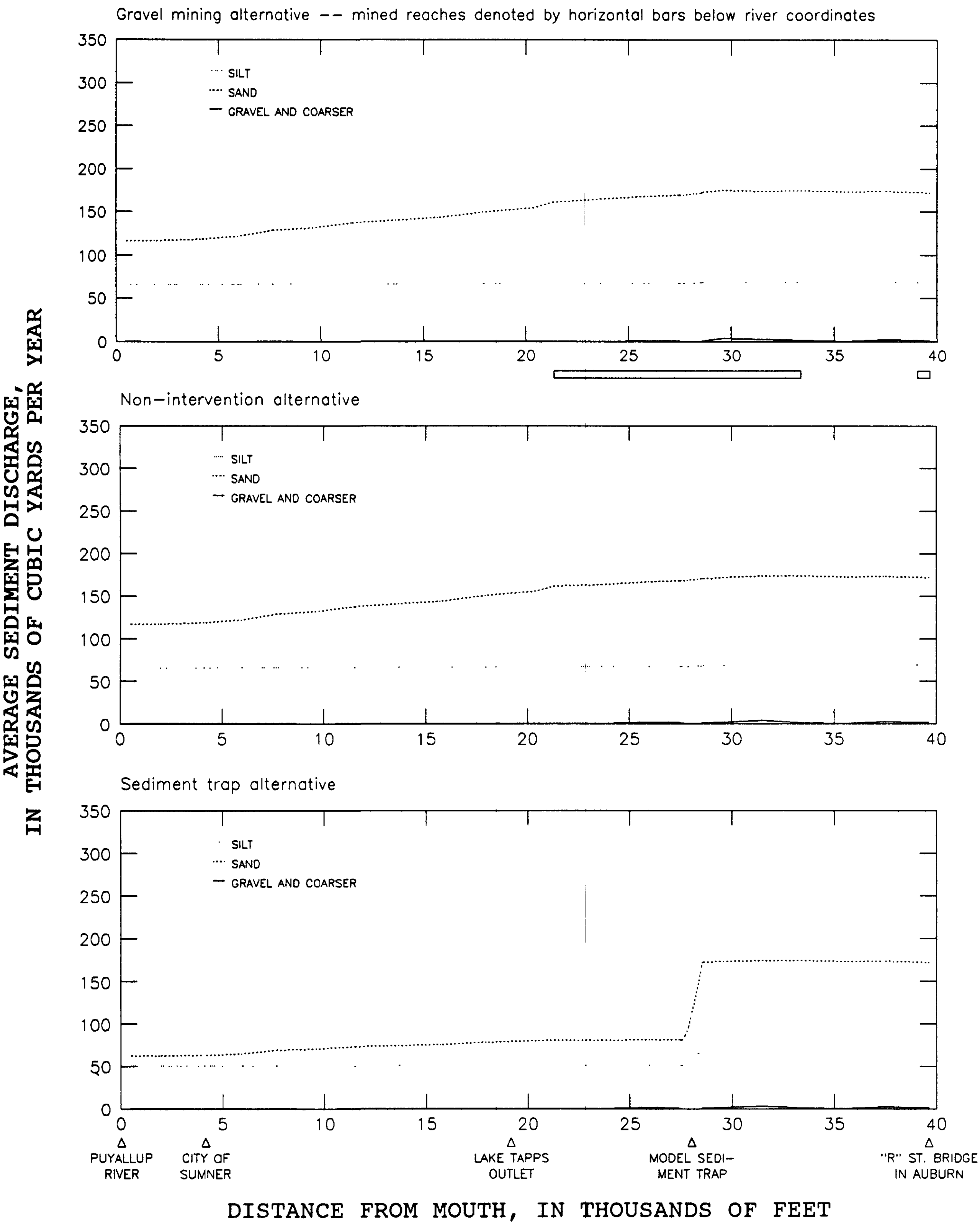


FIGURE 16.–Modeled average sediment discharge on the White River during July 27, 1984, to March 19, 1986.

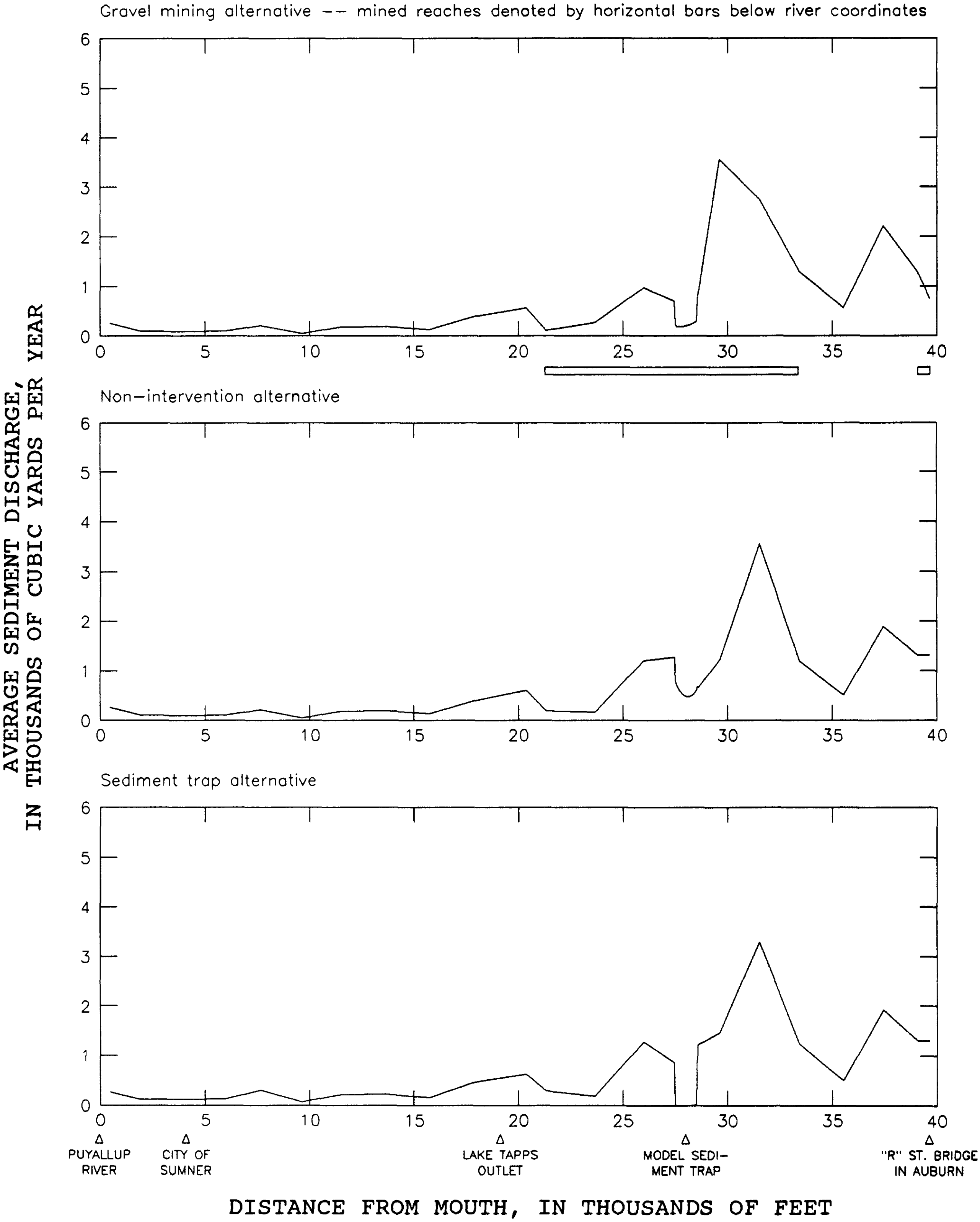


FIGURE 17.–Modeled average discharge of gravel and coarser material on the White River during July 27, 1984, to March 19, 1986.

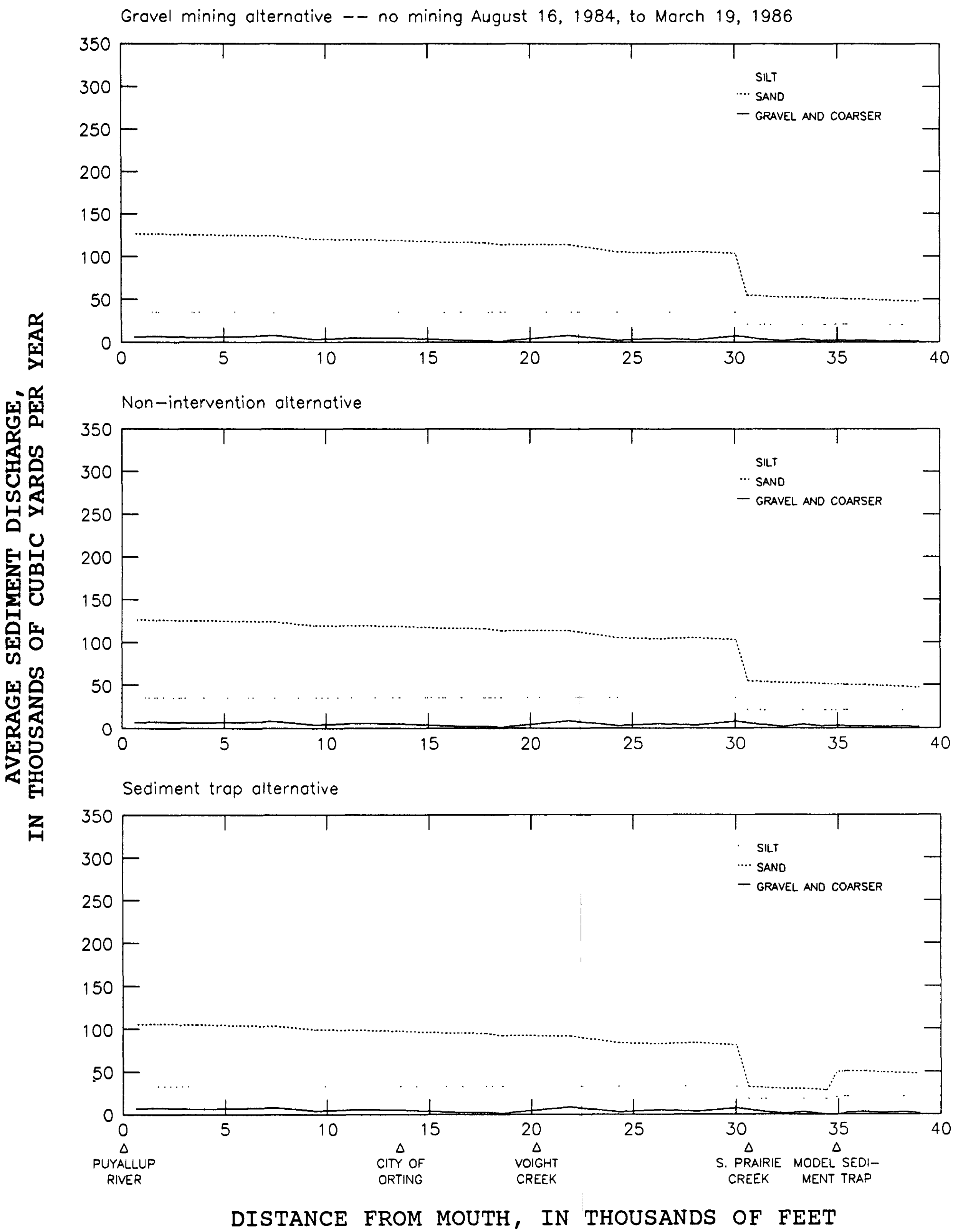


FIGURE 18.–Modeled average sediment discharge on the Carbon River during August 16, 1984, to March 19, 1986.

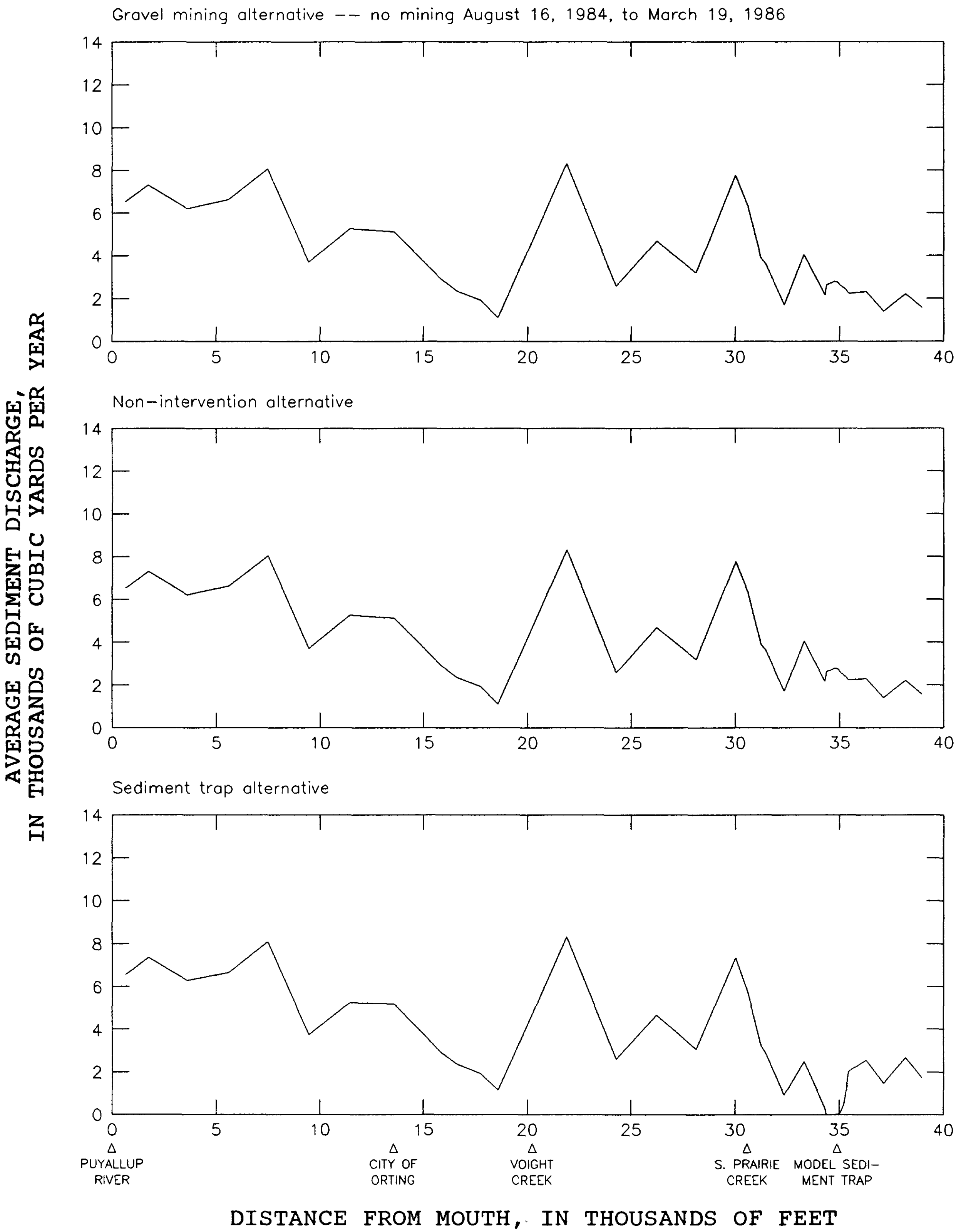


FIGURE 19.--Modeled average discharge of gravel and coarser material on the Carbon River during August 16, 1984, to March 19, 1986.

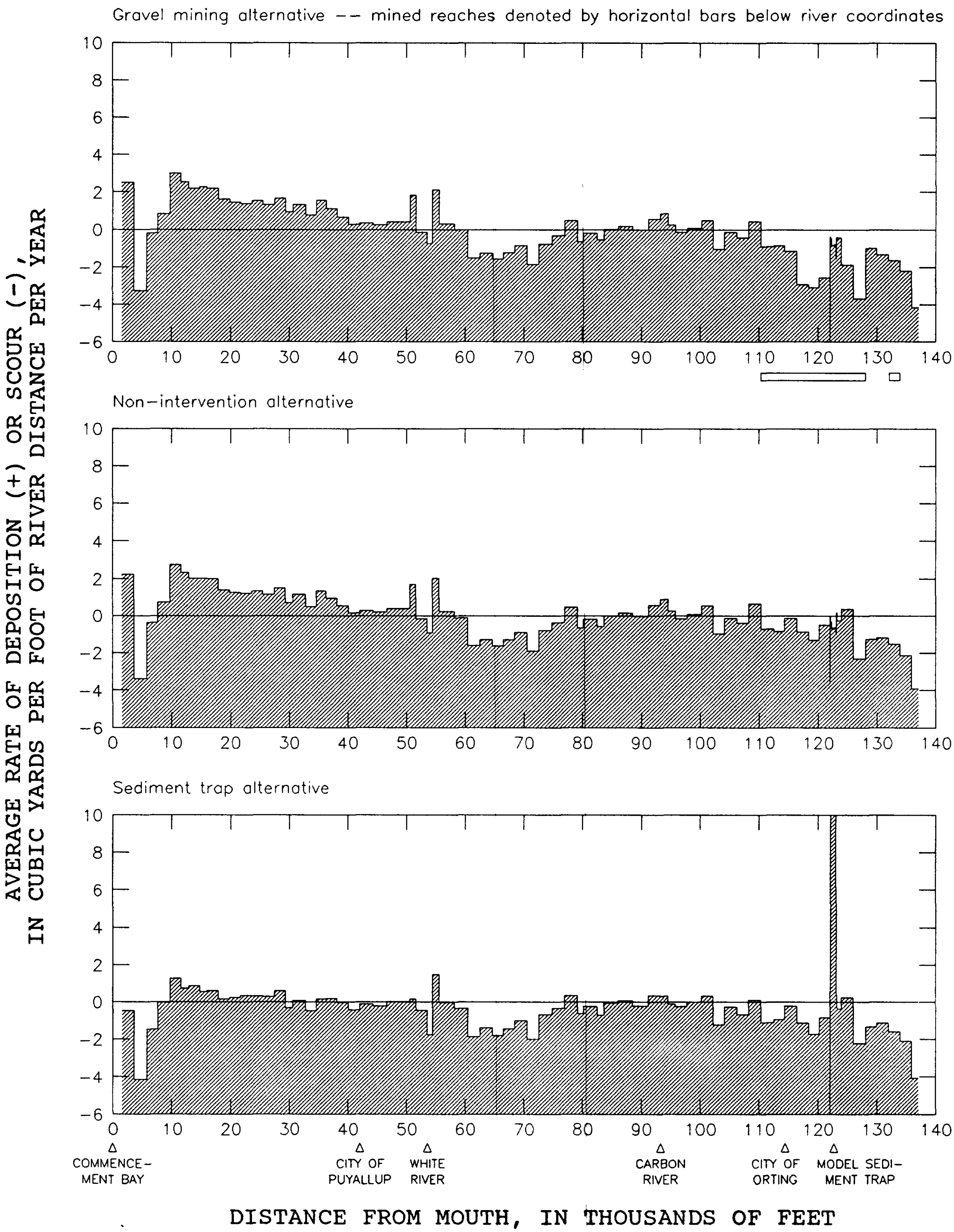


FIGURE 20.–Modeled deposition or scour of sand and finer material on the Puyallup River during August 16, 1984, to March 19, 1986.

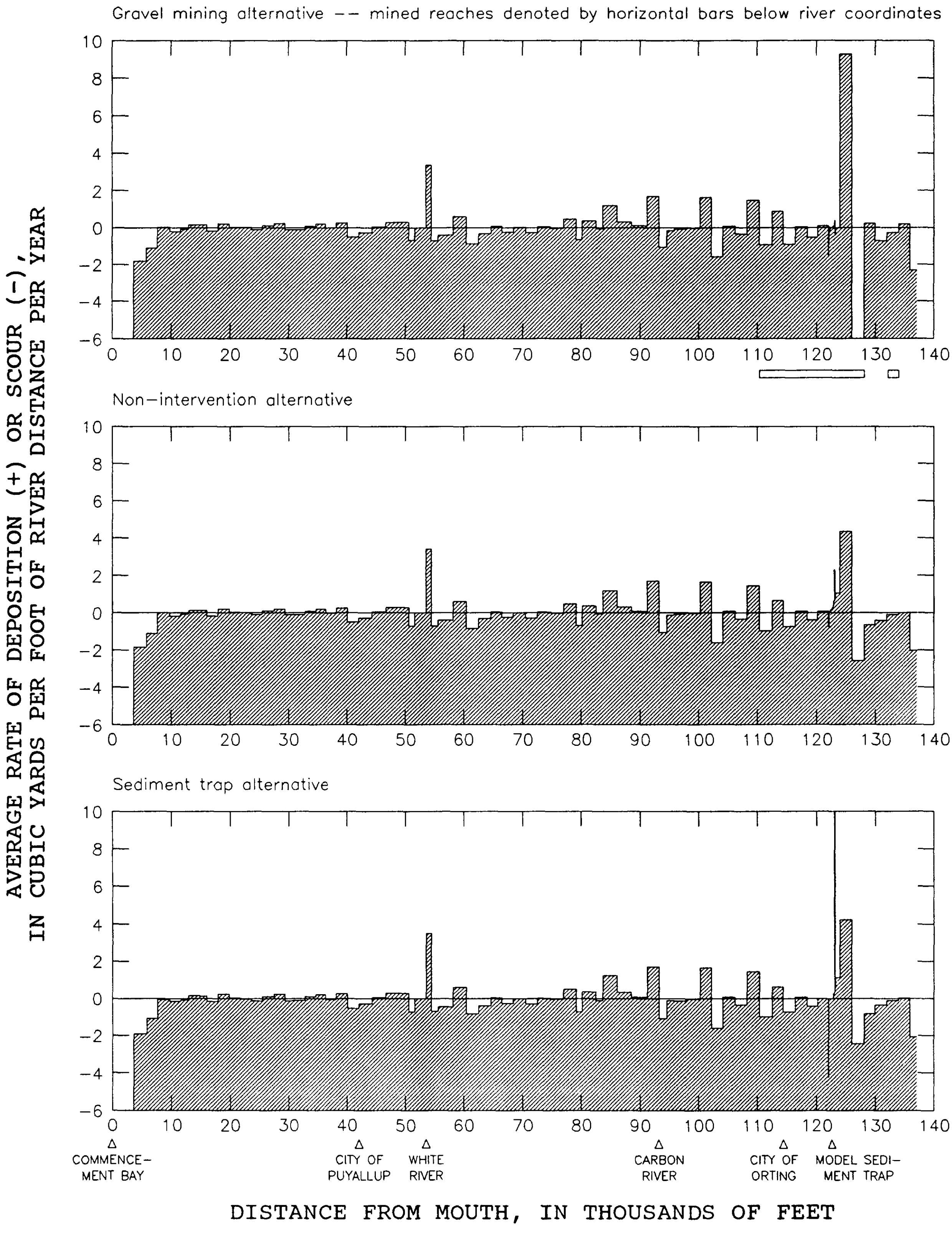


FIGURE 21.--Modeled deposition or scour of gravel and coarser material on the Puyallup River during August 16, 1984, to March 19, 1986.

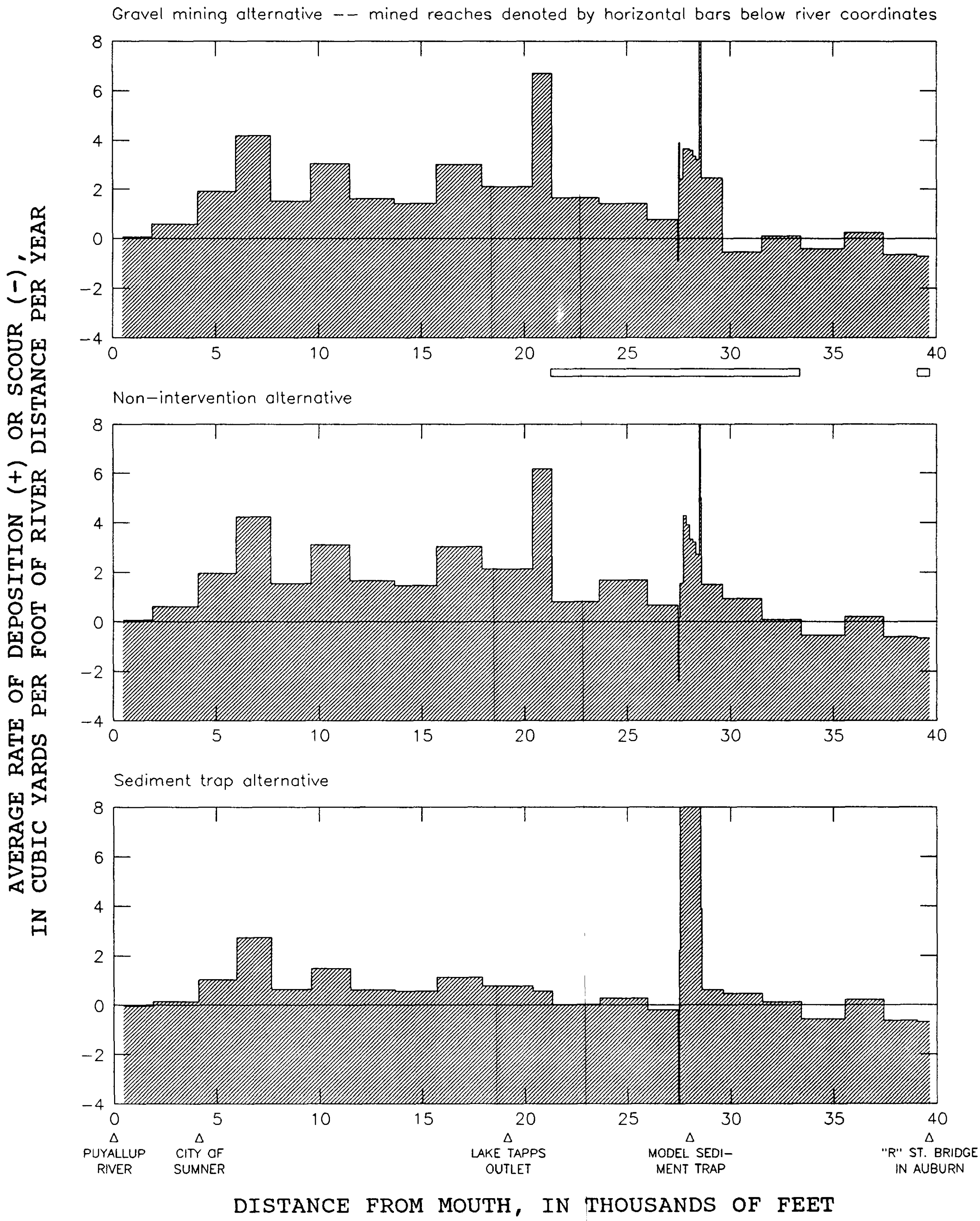


FIGURE 22.–Modeled deposition or scour of sand and finer material on the White River during July 27, 1984, to March 19, 1986.

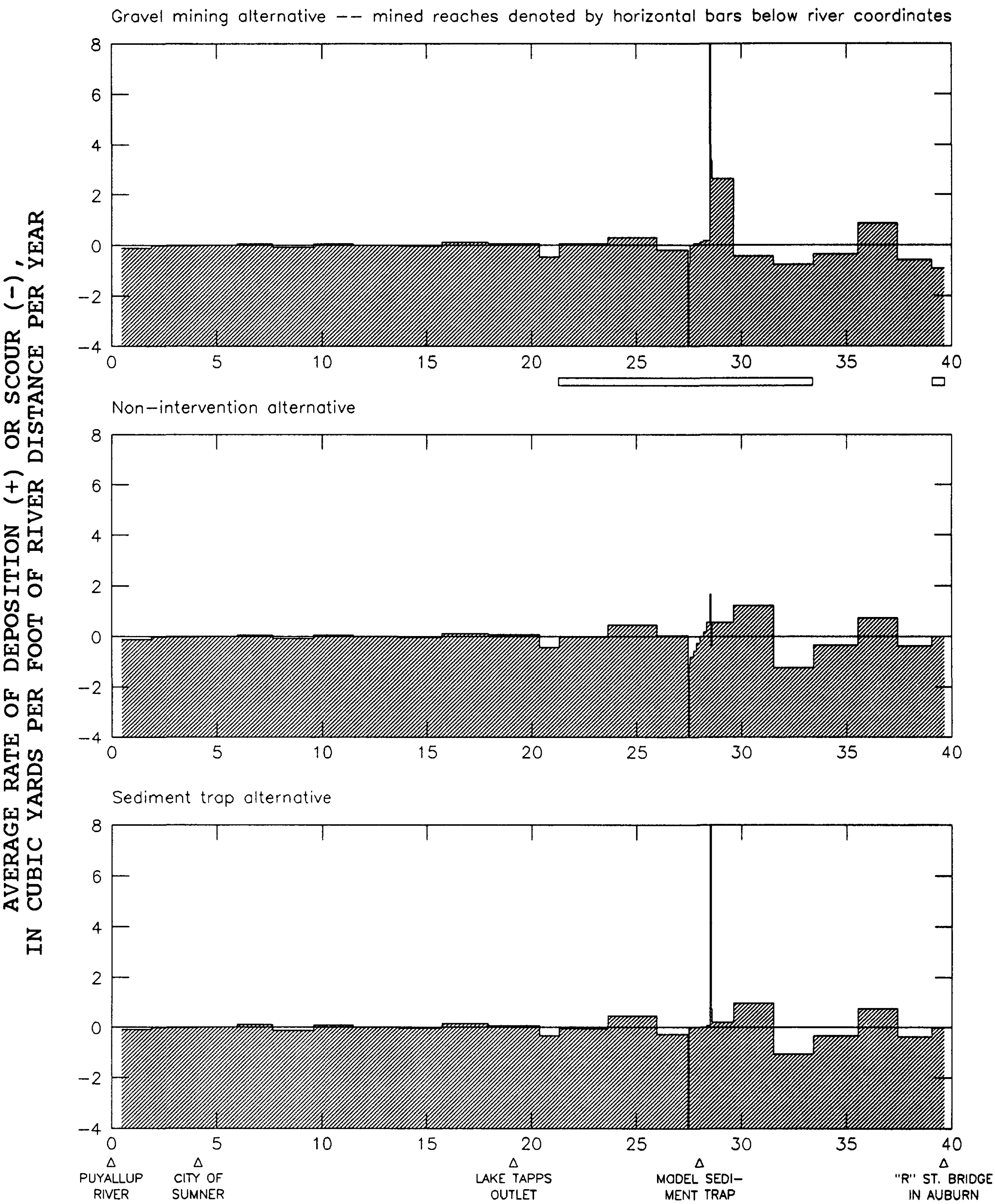


FIGURE 23.--Modeled deposition or scour of gravel and coarser material on the White River during July 27, 1984, to March 19, 1986.

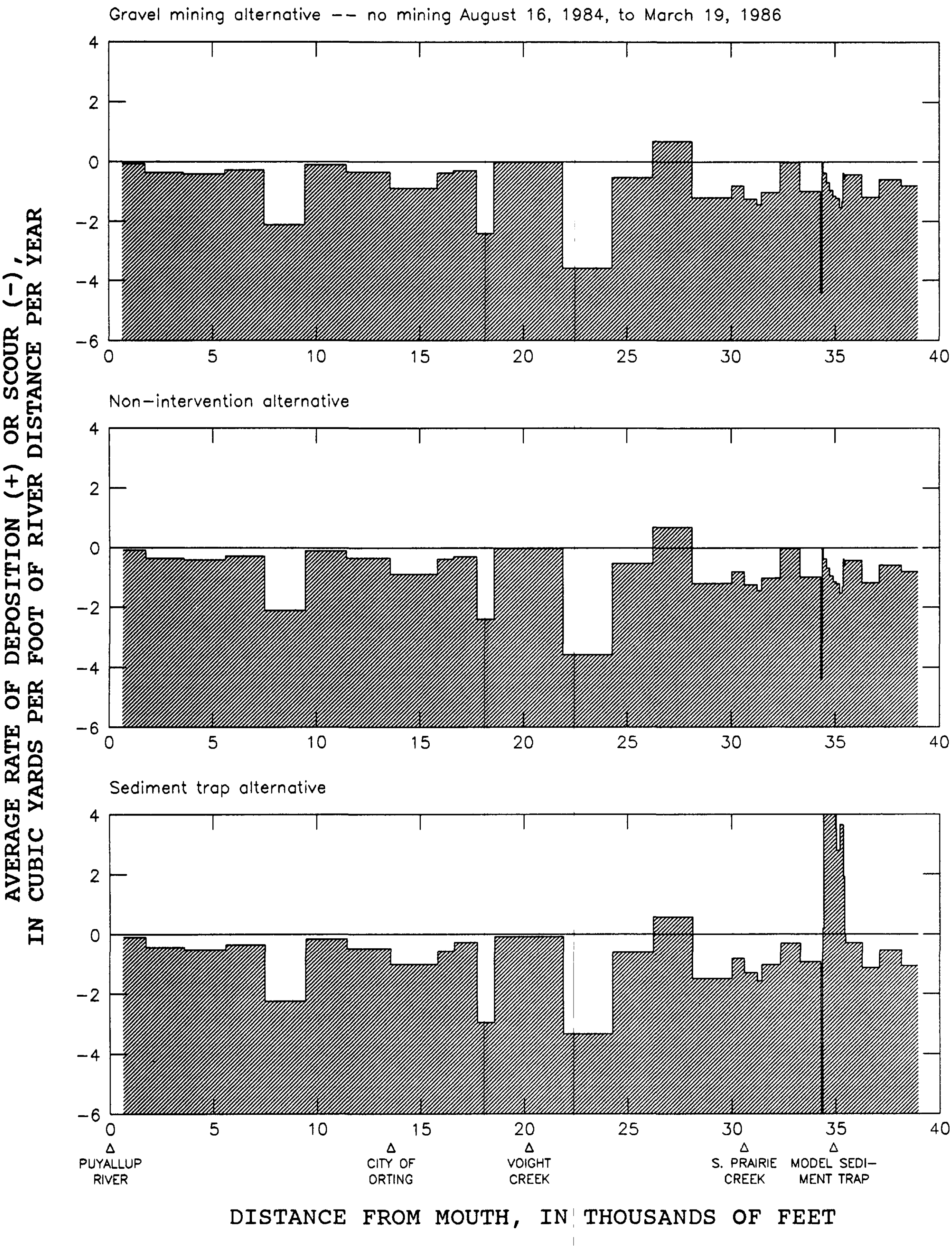


FIGURE 24.-- Modeled deposition or scour of sand and finer material on the Carbon River during August 16, 1984, to March 19, 1986.

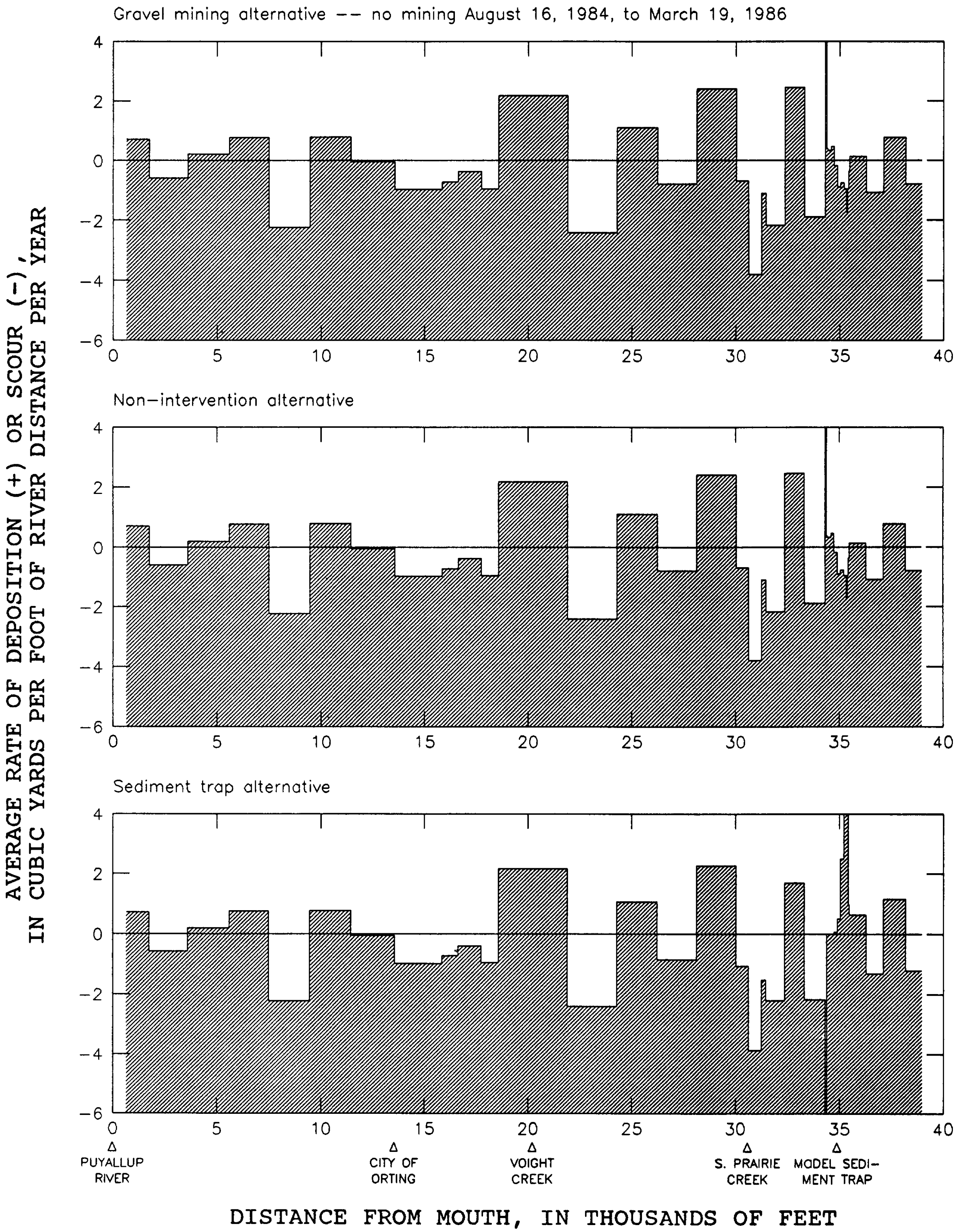


FIGURE 25.--Modeled deposition or scour of gravel and coarser material on the Carbon River during August 16, 1984, to March 19, 1986.

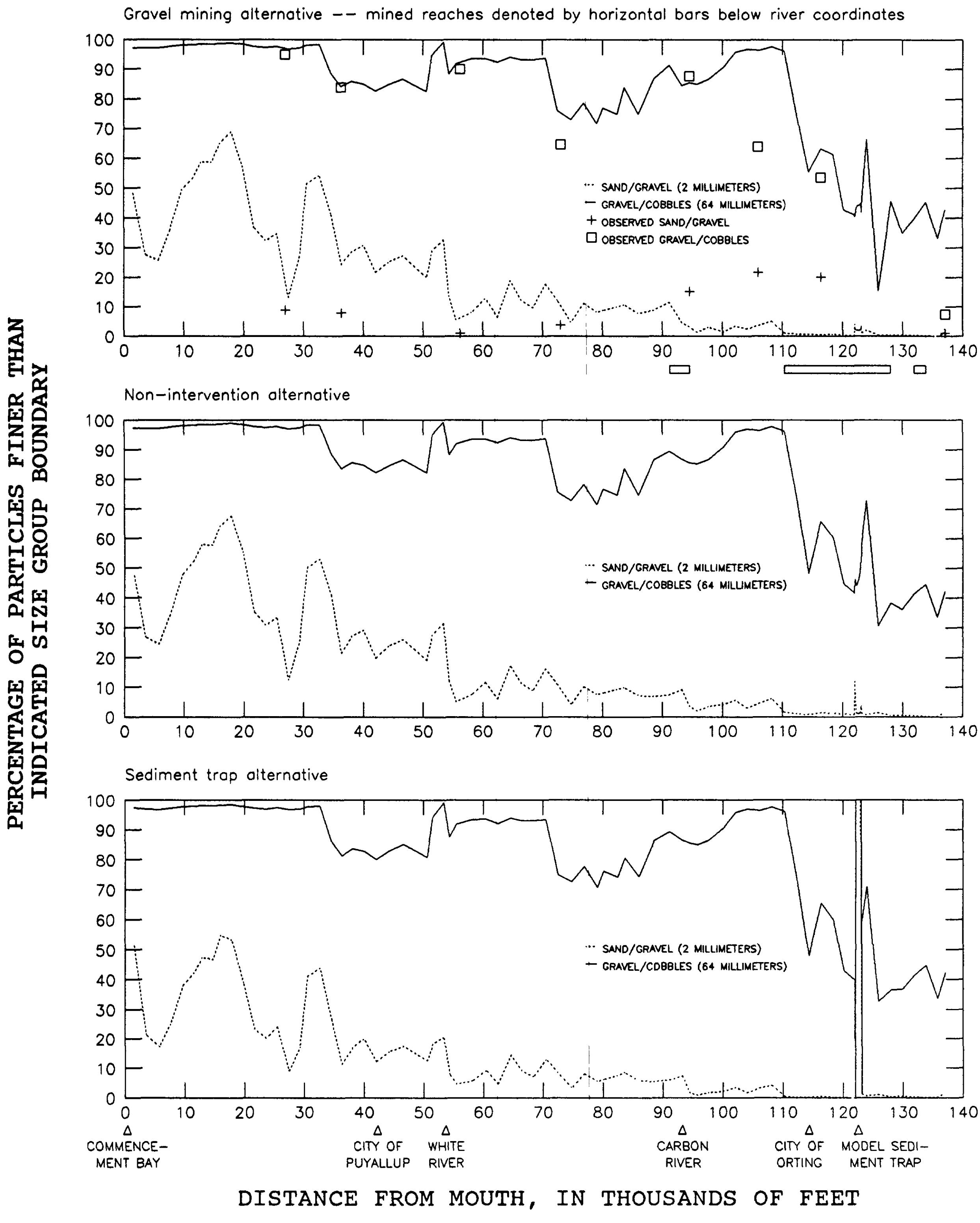


FIGURE 26.–Modeled particle-size distribution in the armor layer of the Puyallup River on September 30, 1986. Observed point values overlay the computed curves

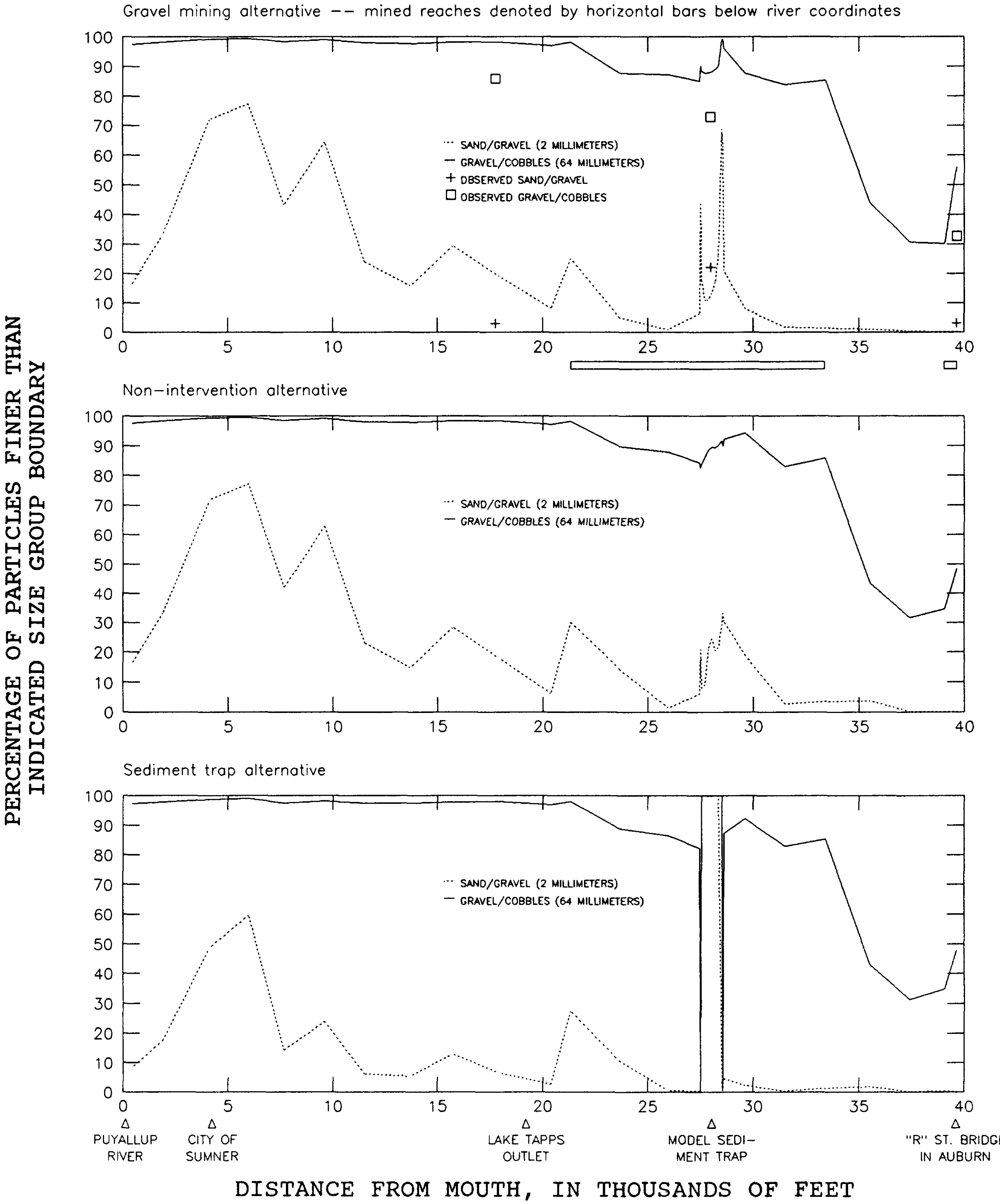


FIGURE 27.--Modeled particle-size distribution in the armor layer of the White River on September 30, 1986. Observed point values overlay the computed curves.

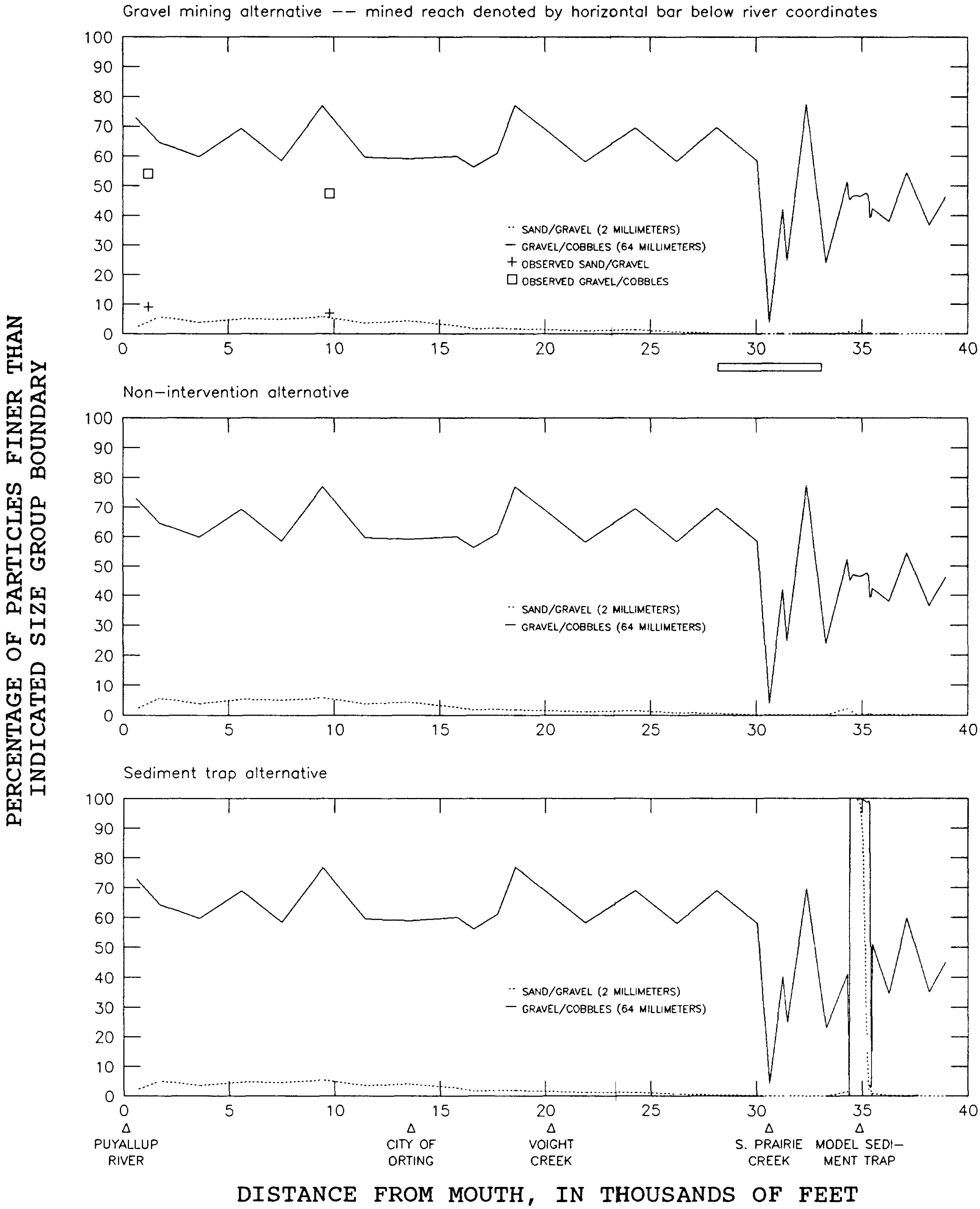


FIGURE 28.--Modeled particle-size distribution in the armor layer of the Carbon River on September 30, 1986. Observed point values overlay the computed curves.

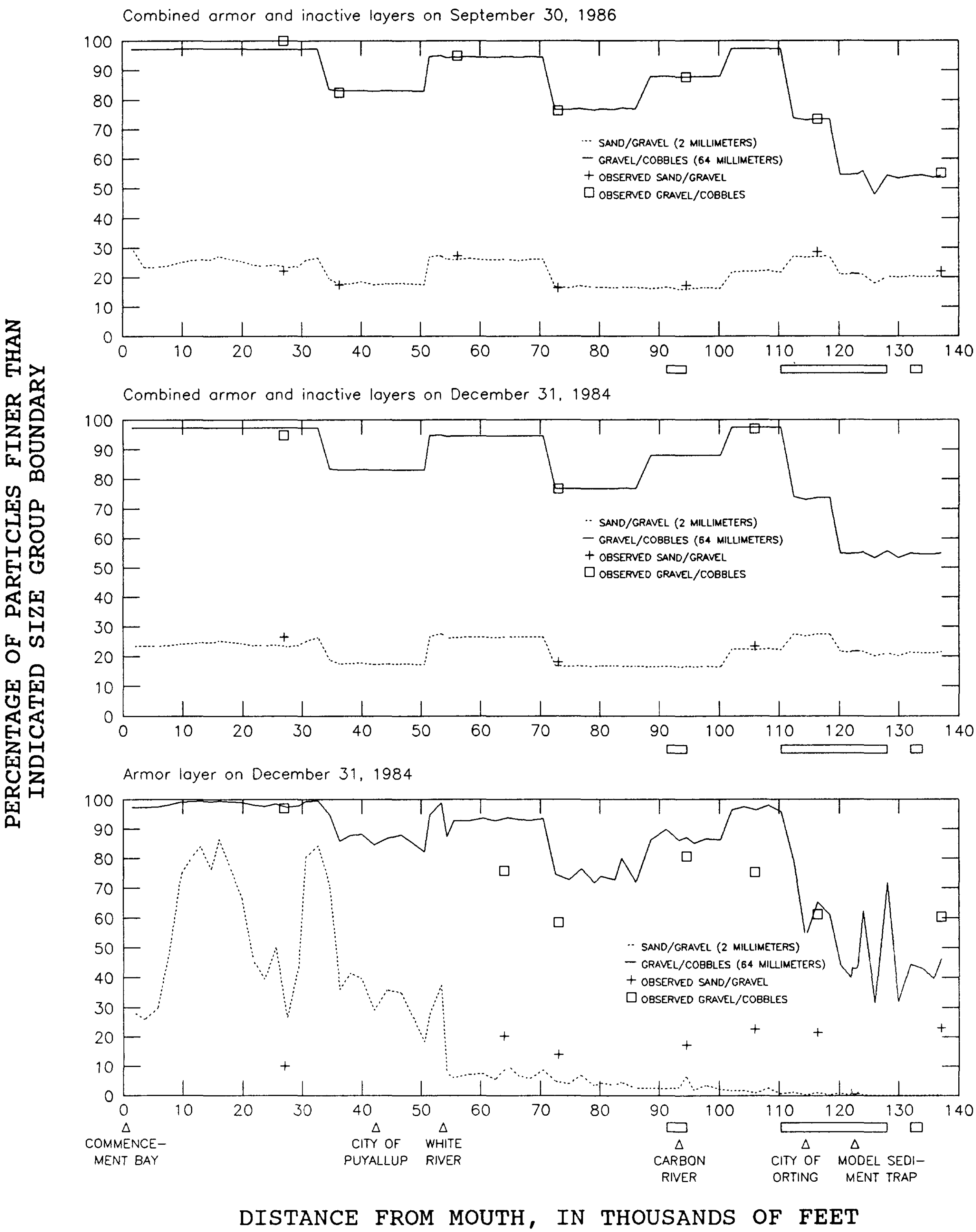


FIGURE 29.--Modeled particle-size distributions on the Puyallup River -- gravel mining alternative. Mined reaches are denoted by horizontal bars below river coordinates. Observed point values overlay the computed curves.

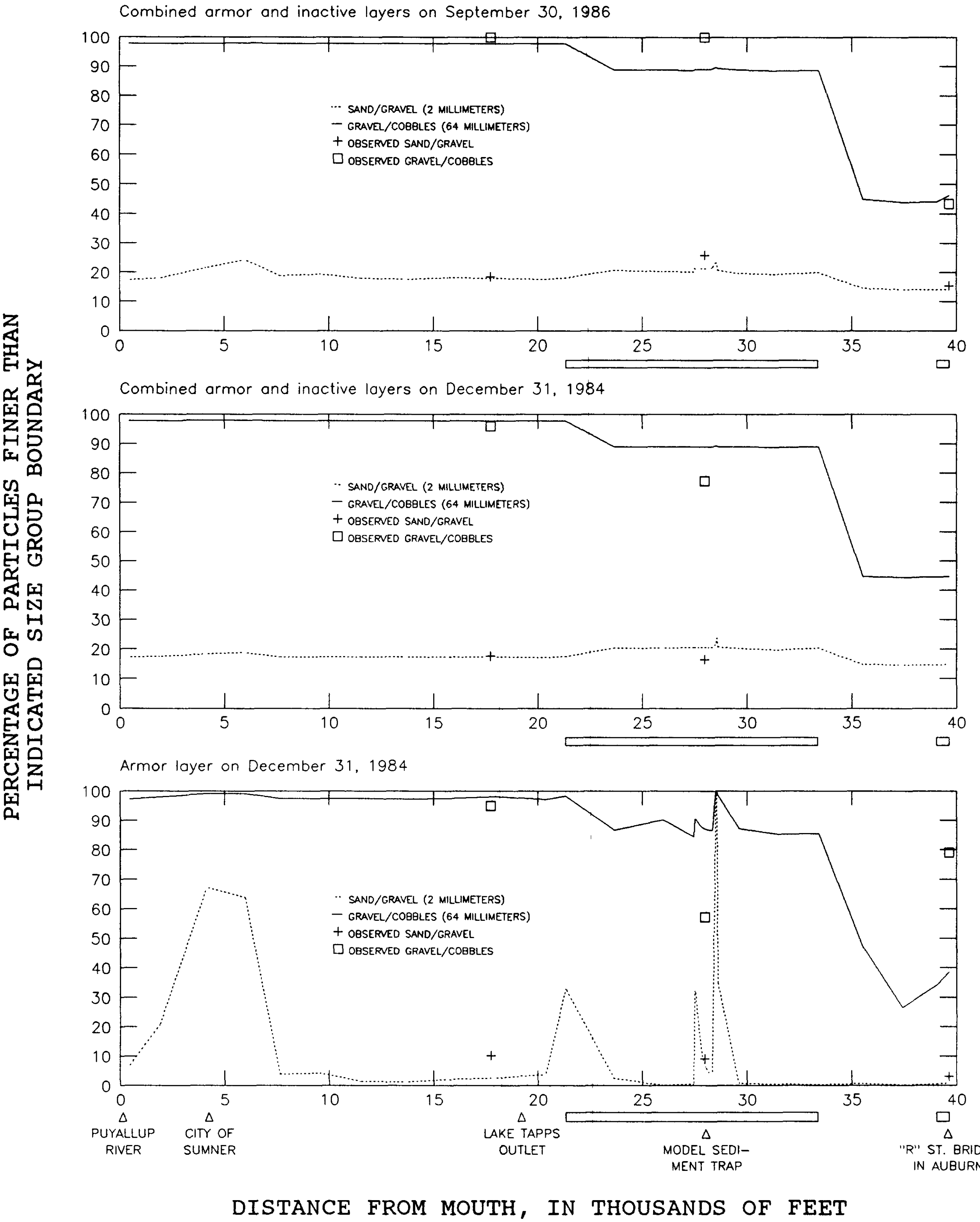


FIGURE 30.--Modeled pariticle-size distributions on the White River -- gravel mining alternative. Mined reaches are denoted by horizontal bars below river coordinates. Observed point values overlay the computed curves.

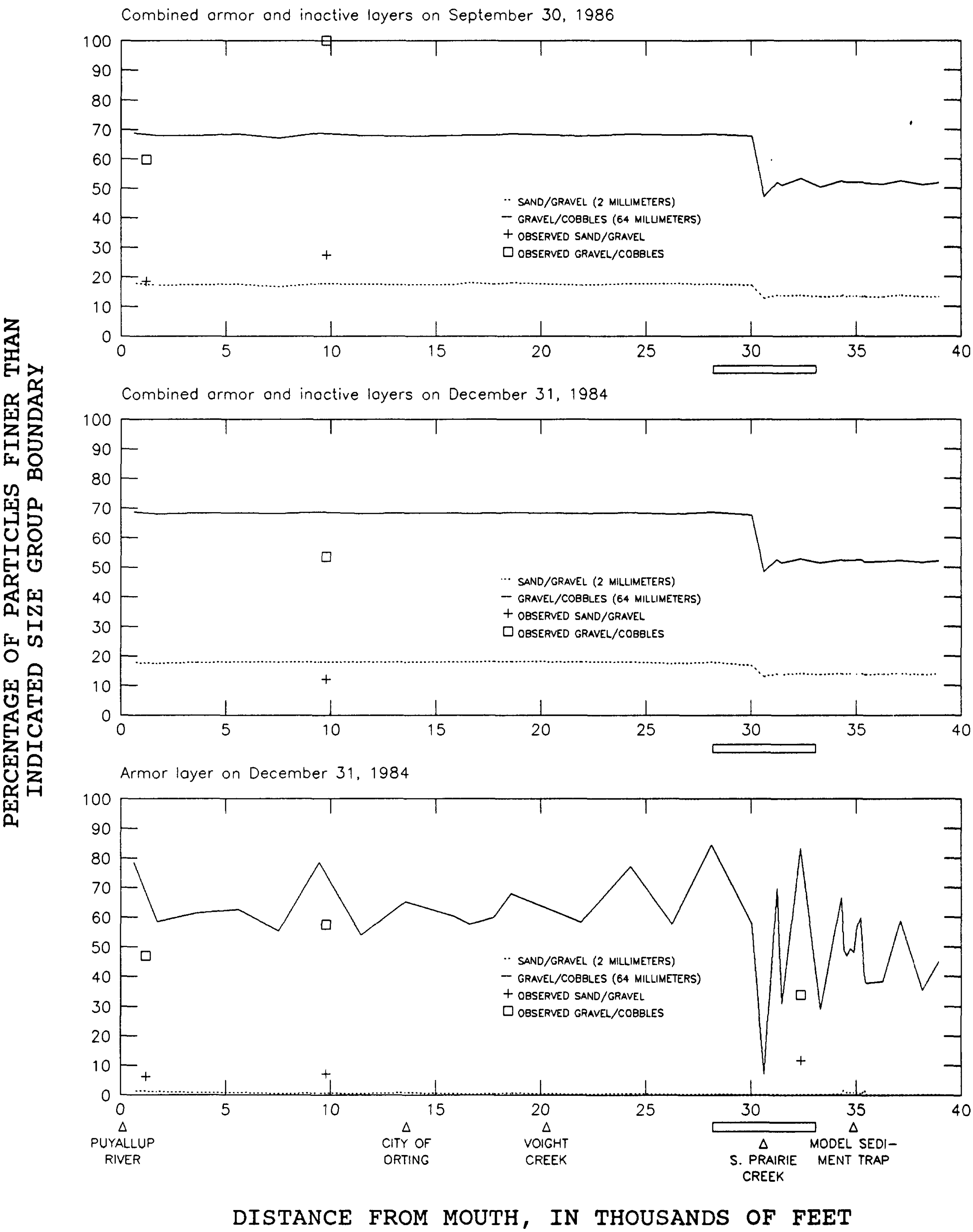


FIGURE 31.--Modeled particle-size distributions on the Carbon River -- gravel mining alternative. Mined reaches are denoted by horizontal bars below river coordinates. Observed point values overlay the computed curves.

APPENDIX A: SEDIMENT DATA

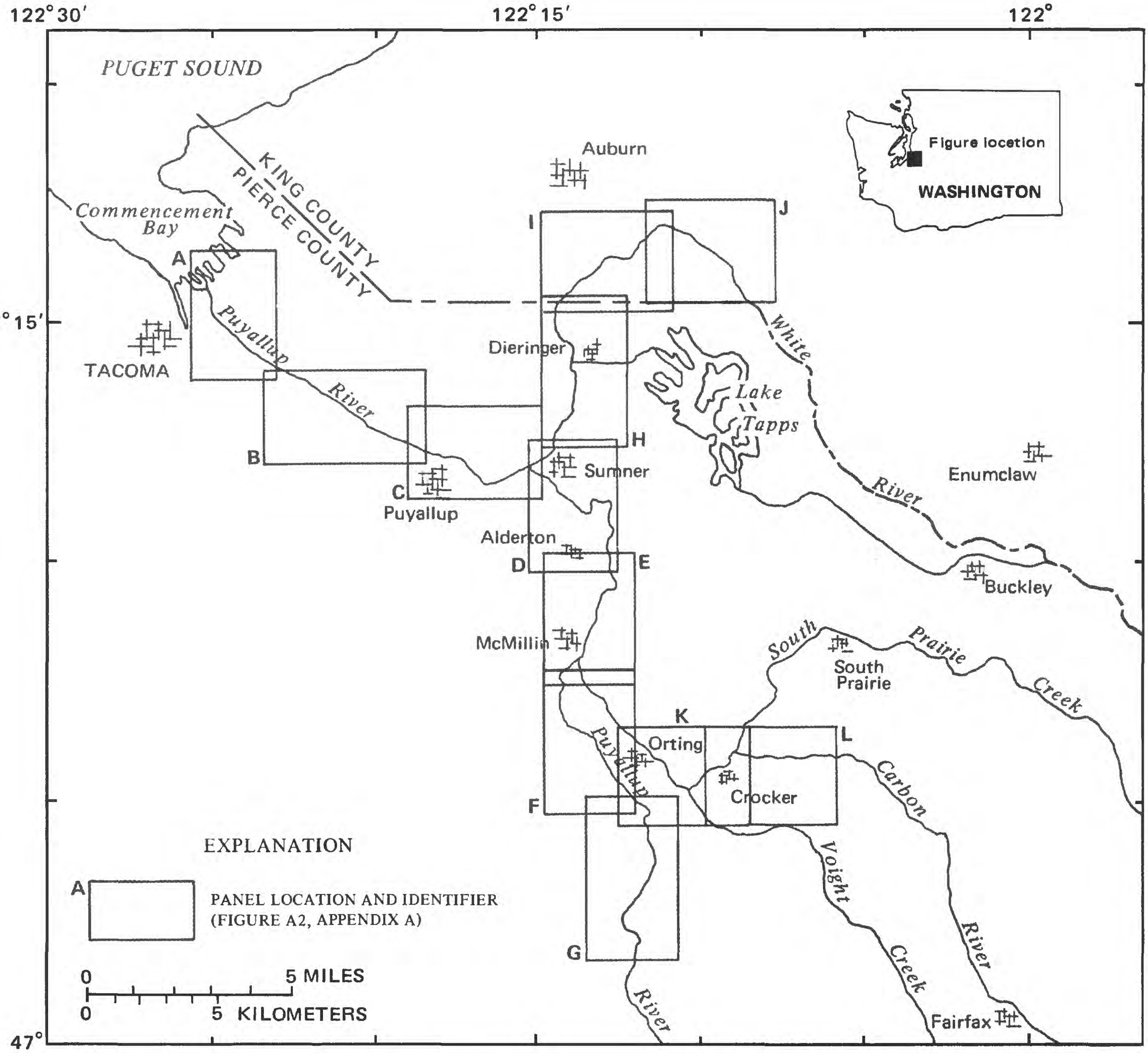
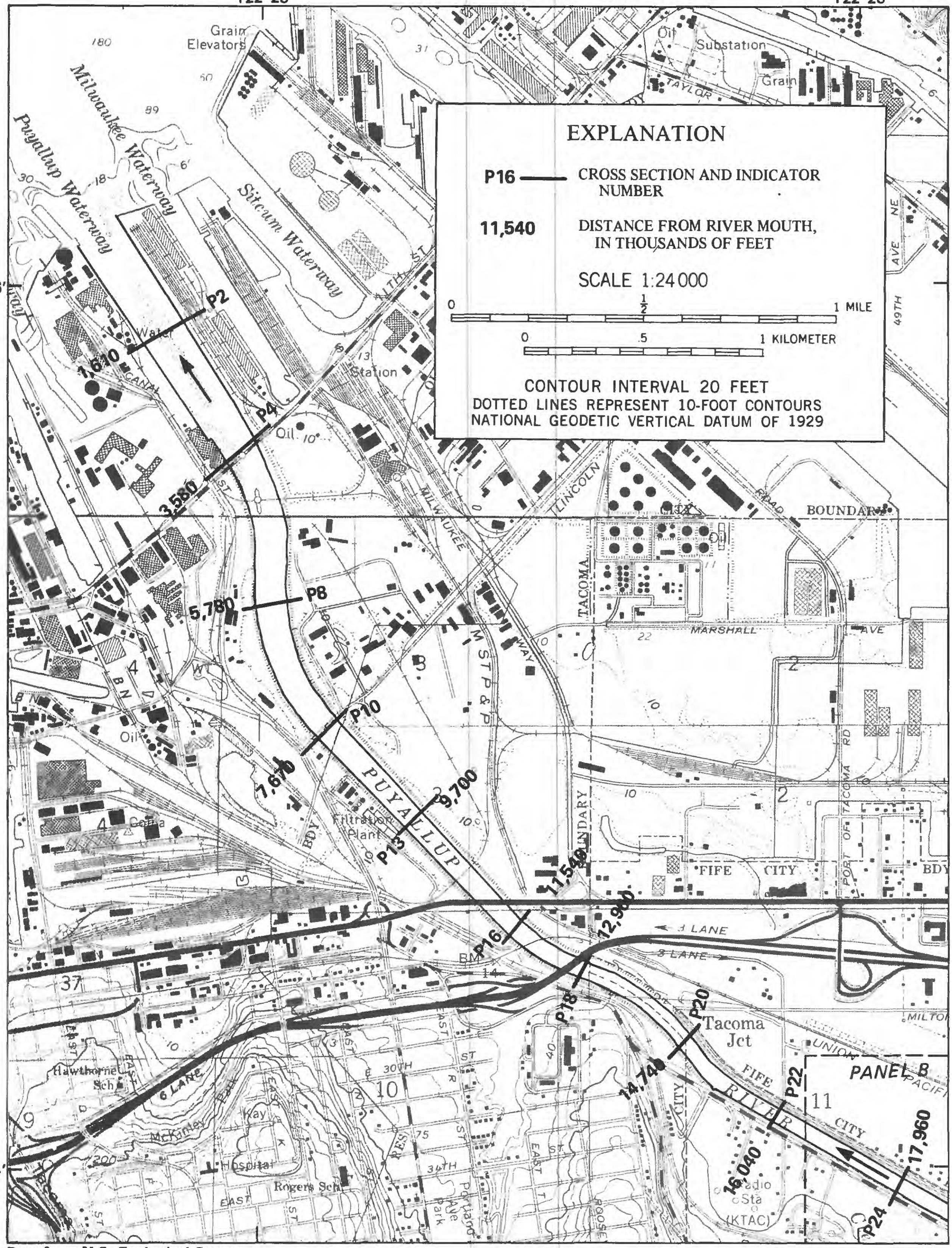


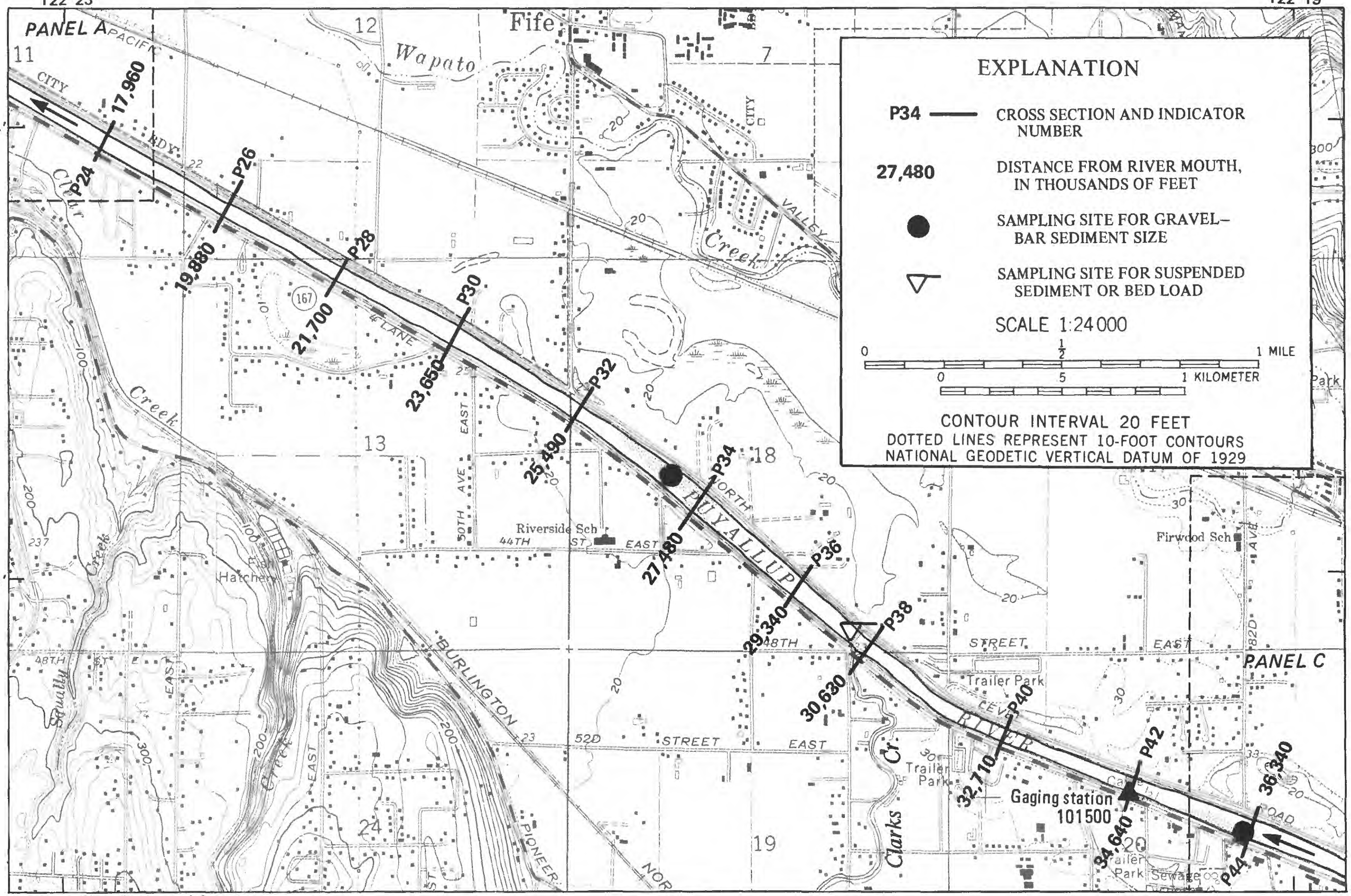
FIGURE A1.--Puyallup River drainage basin showing areas included in panels of figure A2.

PANEL A



Base from U.S. Geological Survey
Tacoma North, 1961, photorevised 1981 and
Tacoma South, 1961, photorevised 1981

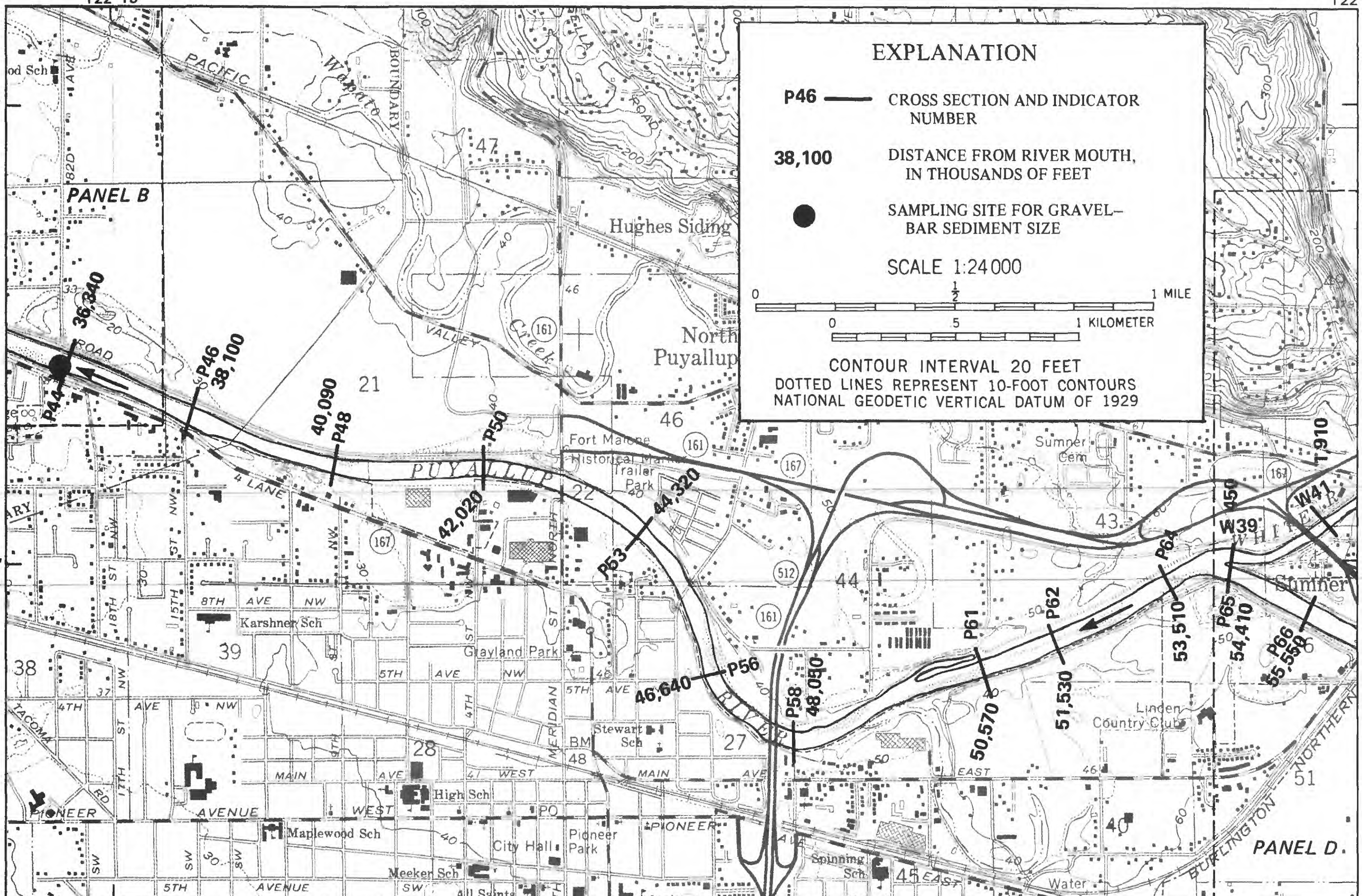
FIGURE A2.--River reach showing locations of surveyed cross sections, on panel A. Areas included on each panel are shown on figure A1.



Base from U.S. Geological Survey
Tacoma South, 1961, photorevised 1981 and
Puyallup, 1961, photorevised 1981

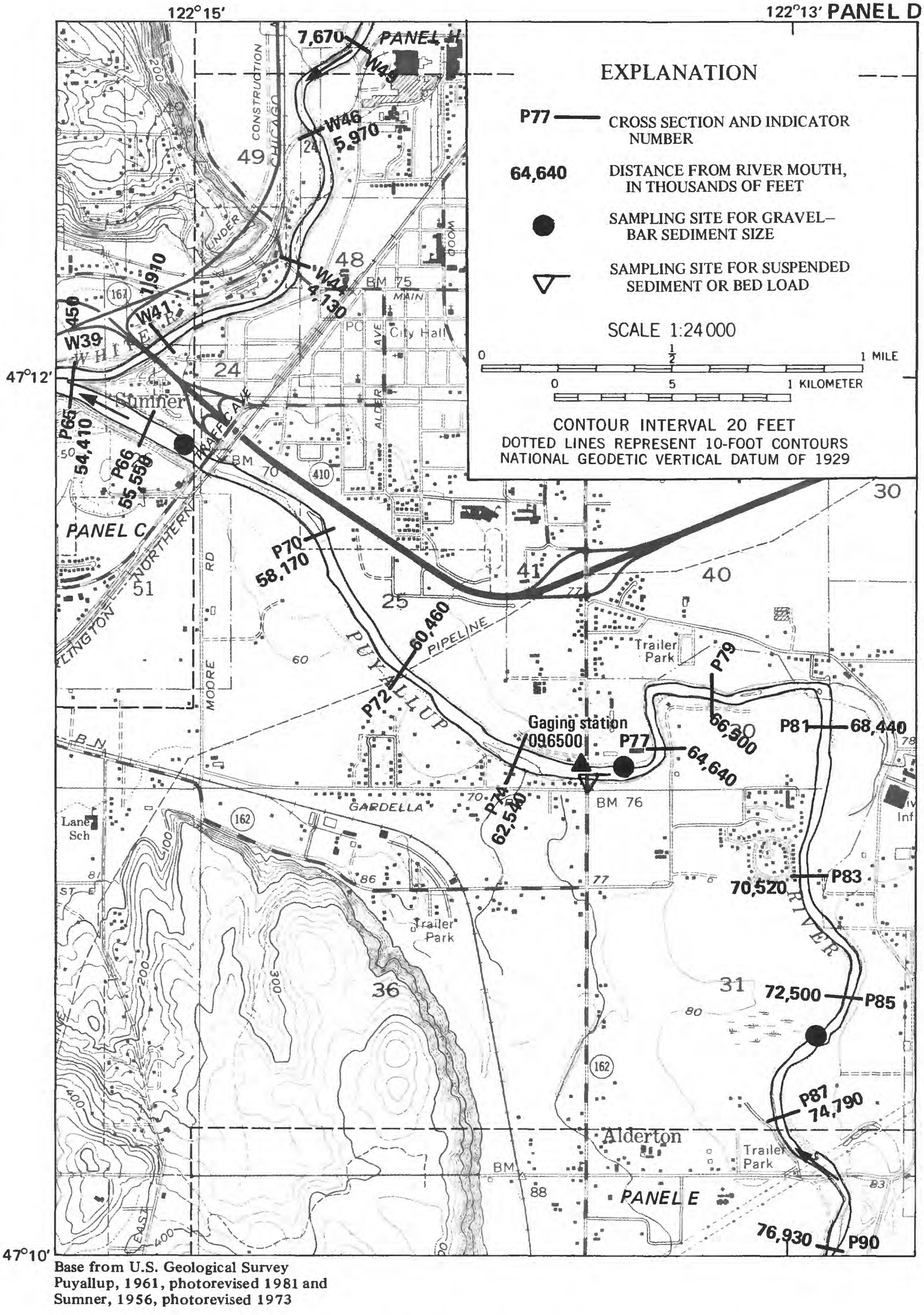
FIGURE A2.–River reach showing locations of surveyed cross sections, on panel B. Areas included on each panel are shown on figure A1.

PANEL C



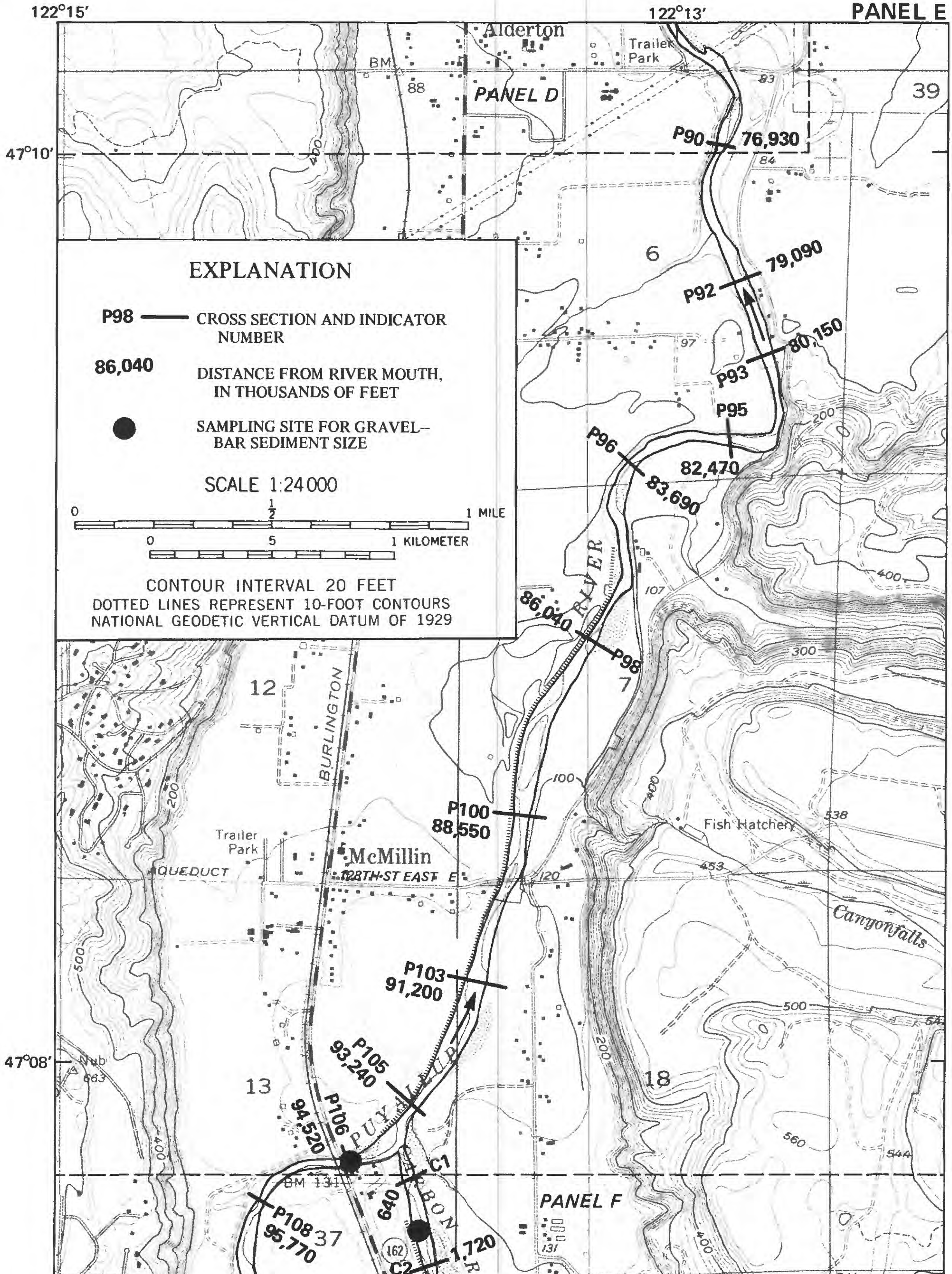
Base from U.S. Geological Survey
Puyallup, 1961, photorevised 1981

FIGURE A2.–River reach showing locations of surveyed cross sections, on panel C. Areas included on each panel are shown on figure A1.



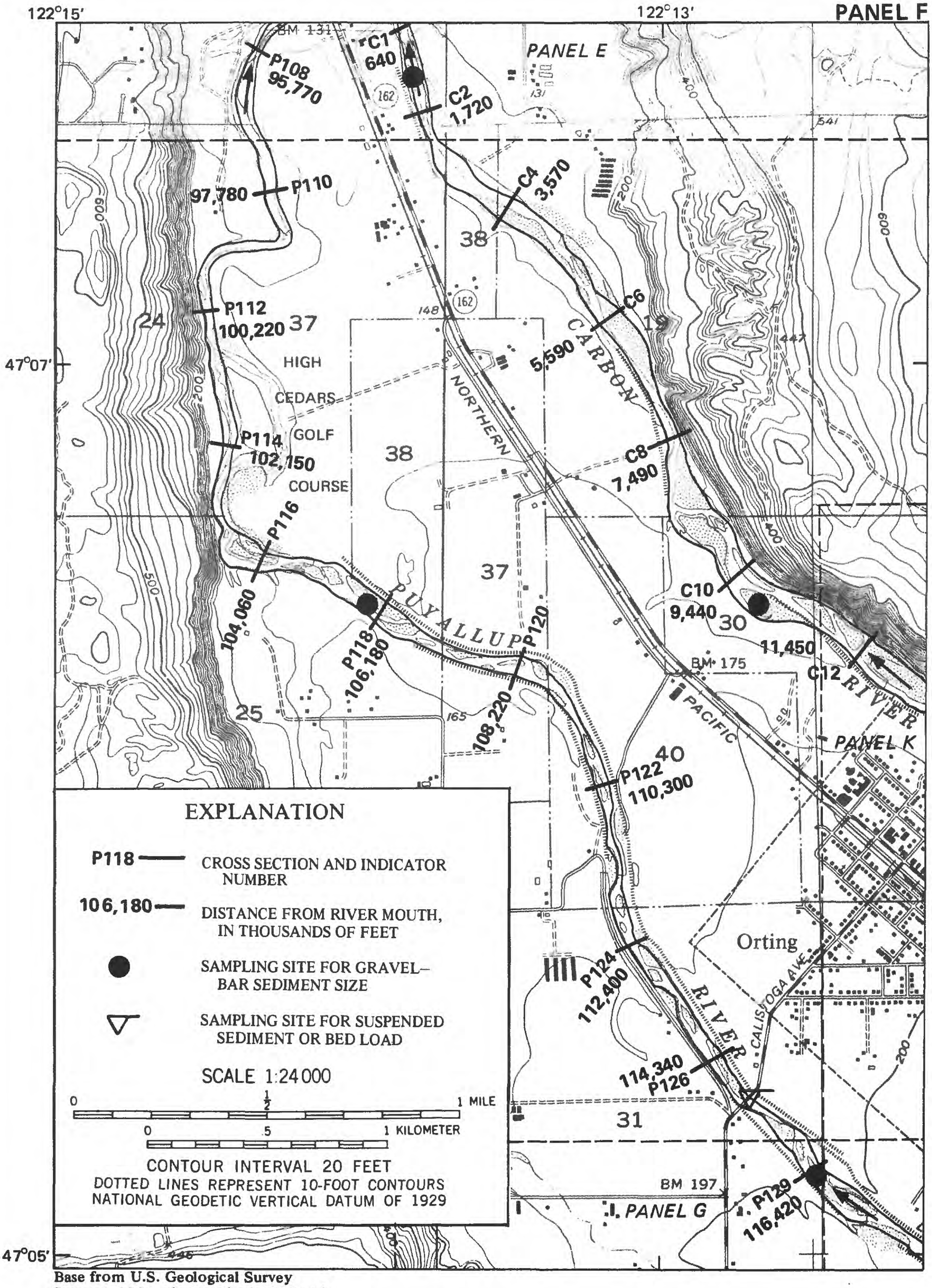
Base from U.S. Geological Survey
Puyallup, 1961, photorevised 1981 and
Sumner, 1956, photorevised 1973

FIGURE A2.--River reach showing locations of surveyed cross sections, on panel D. Areas included on each panel are shown on figure A1.



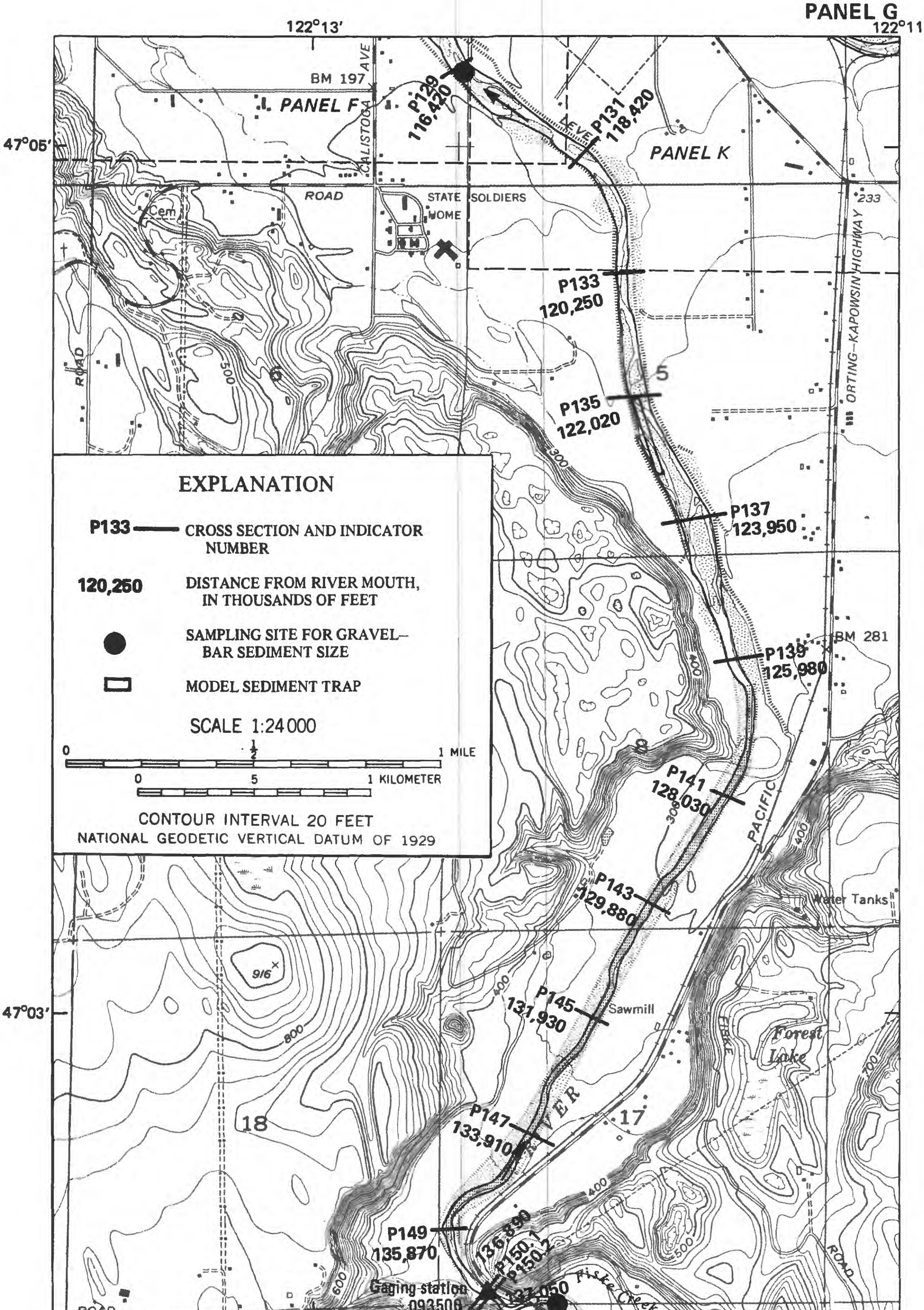
Base from U.S. Geological Survey
Sumner, 1956, photorevised 1973

FIGURE A2.–River reach showing locations of surveyed cross sections, on panel E. Areas included on each panel are shown on figure A1.



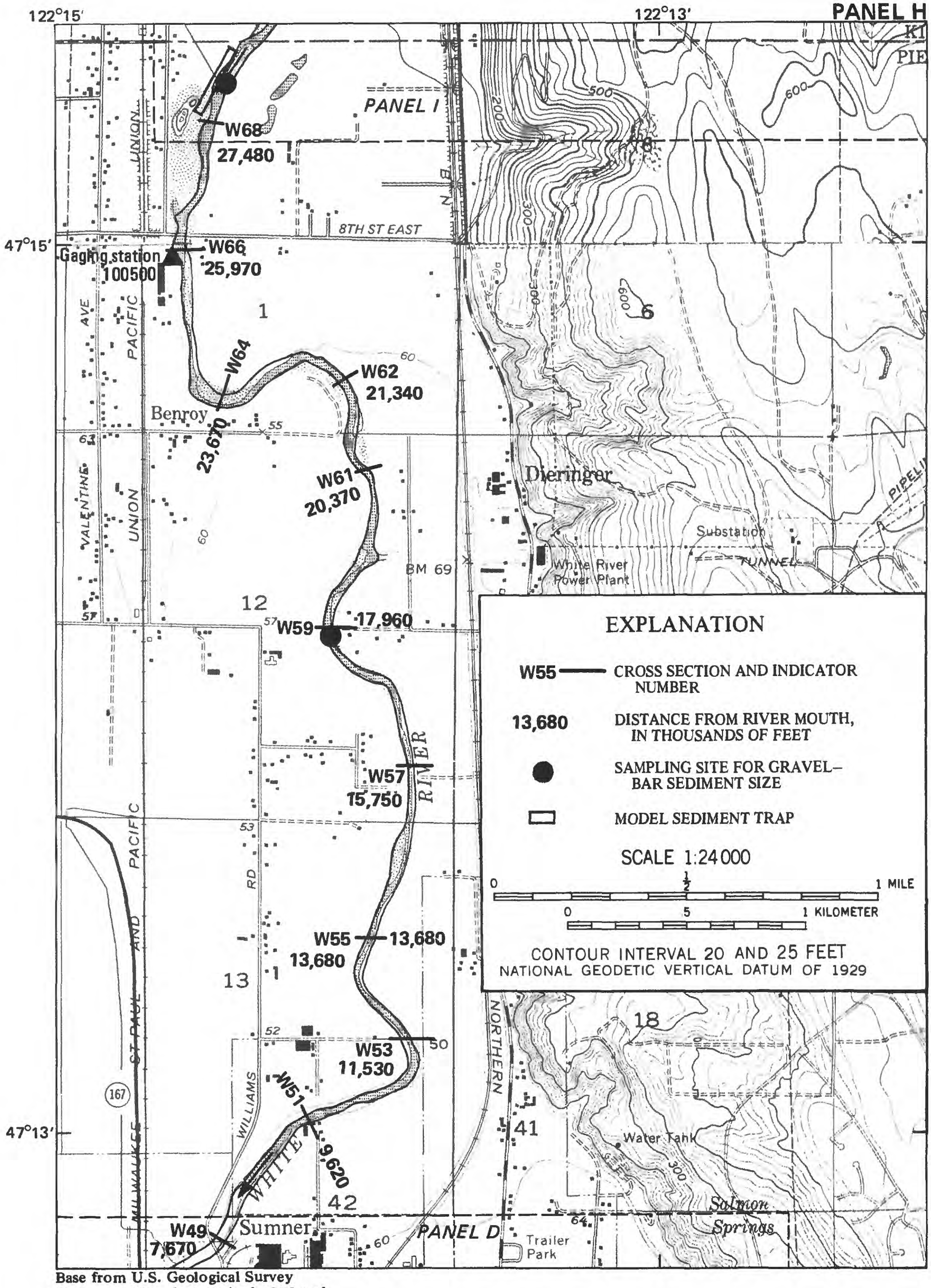
Base from U.S. Geological Survey
Sumner, 1956, photorevised 1973 and
Orting 1956, photorevised 1968

FIGURE A2.--River reach showing locations of surveyed cross sections, on panel F. Areas included on each panel are shown on figure A1.



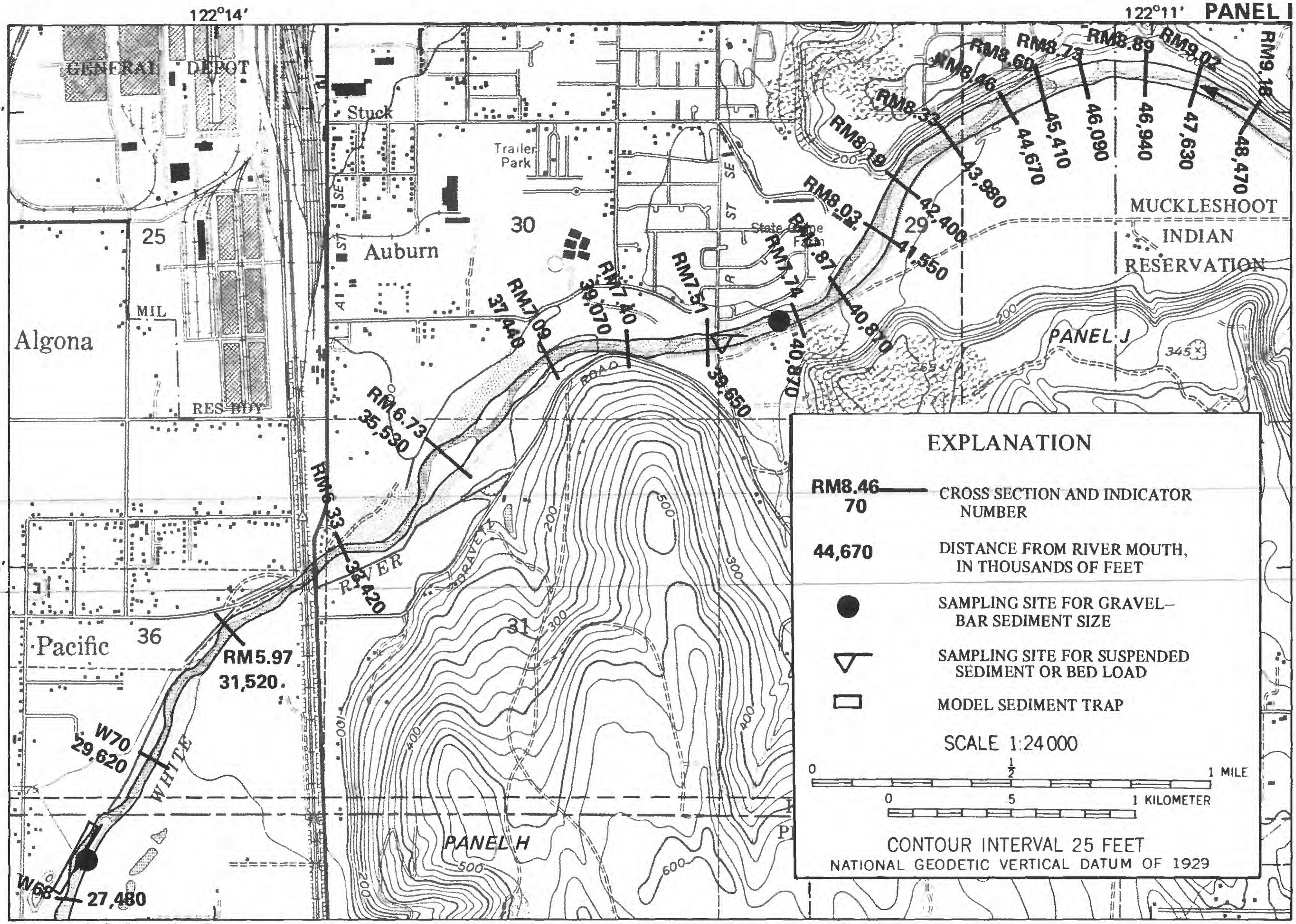
Base from U.S. Geological Survey
Orting, 1956, photorevised 1968

FIGURE A2.–River reach showing locations of surveyed cross sections, on panel G. Areas included on each panel are shown on figure A1.



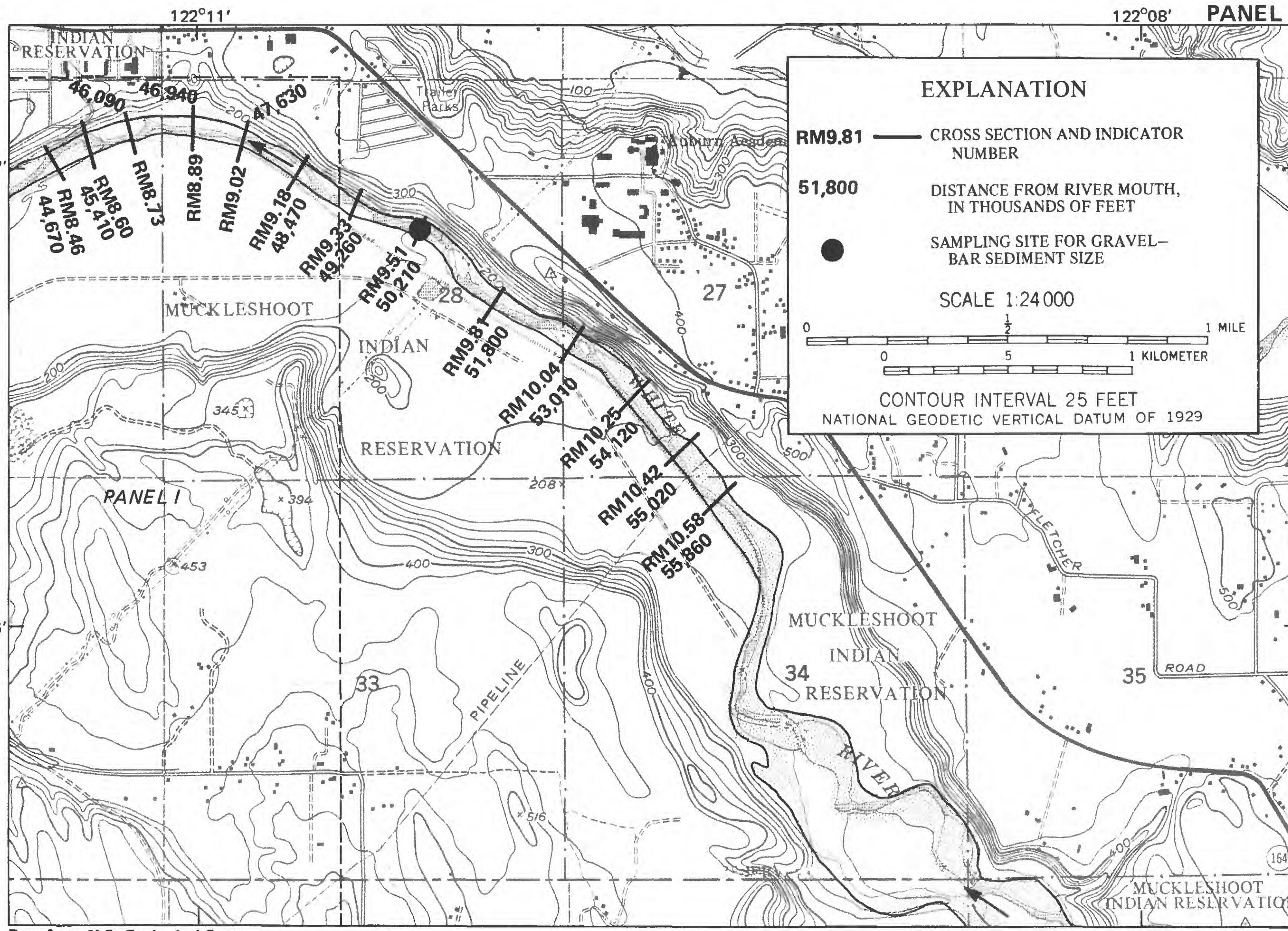
Base from U.S. Geological Survey
Sumner, 1956 photorevised 1973 and
Auburn, 1949, photorevised 1973

FIGURE A2.–River reach showing locations of surveyed cross sections, on panel H. Areas included on each panel are shown on figure A1.



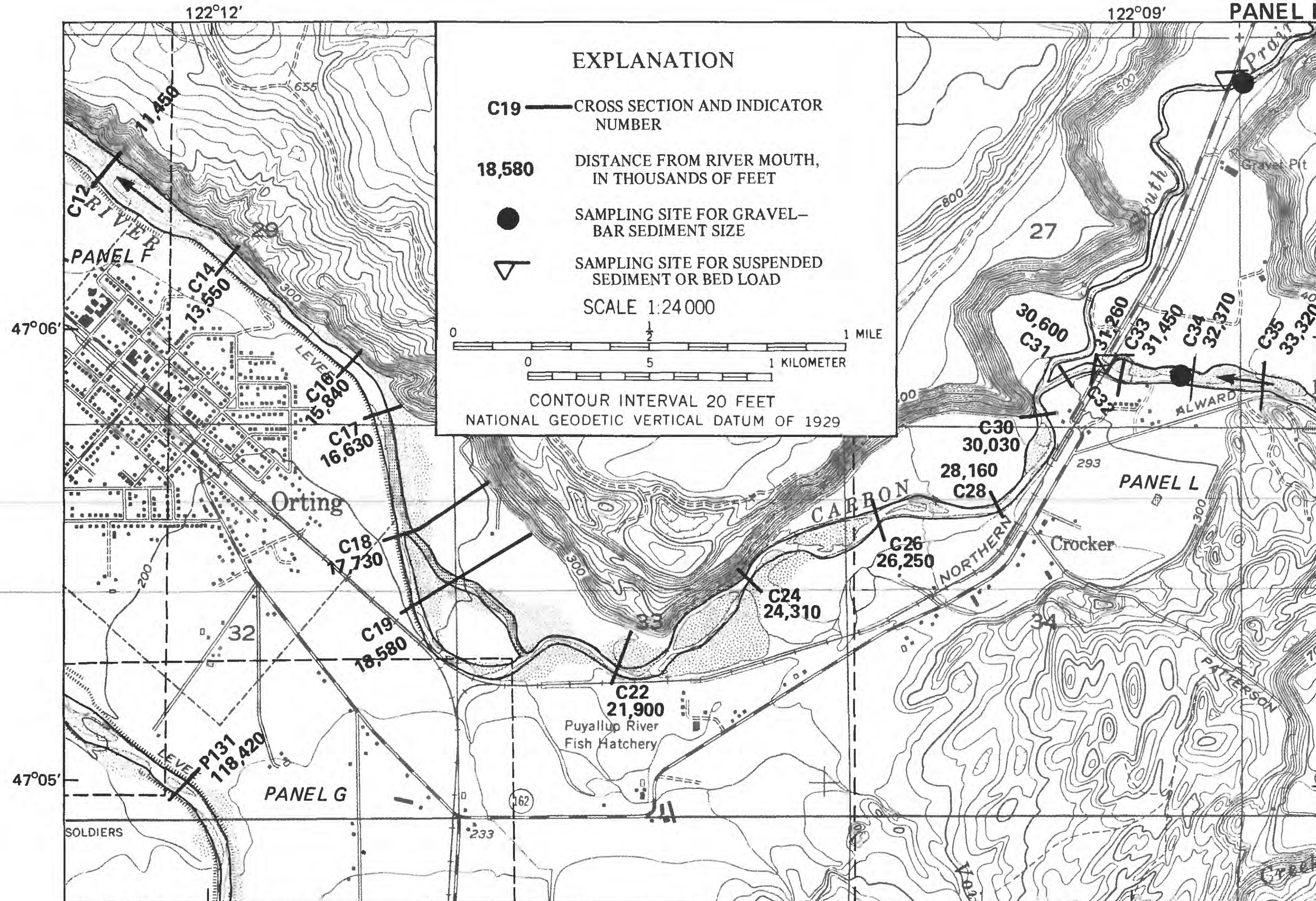
Base from U.S. Geological Survey
Auburn, 1949, photorevised 1973

FIGURE A2.--River reach showing locations of surveyed cross sections, on panel I. Areas included on each panel are shown on figure A1.



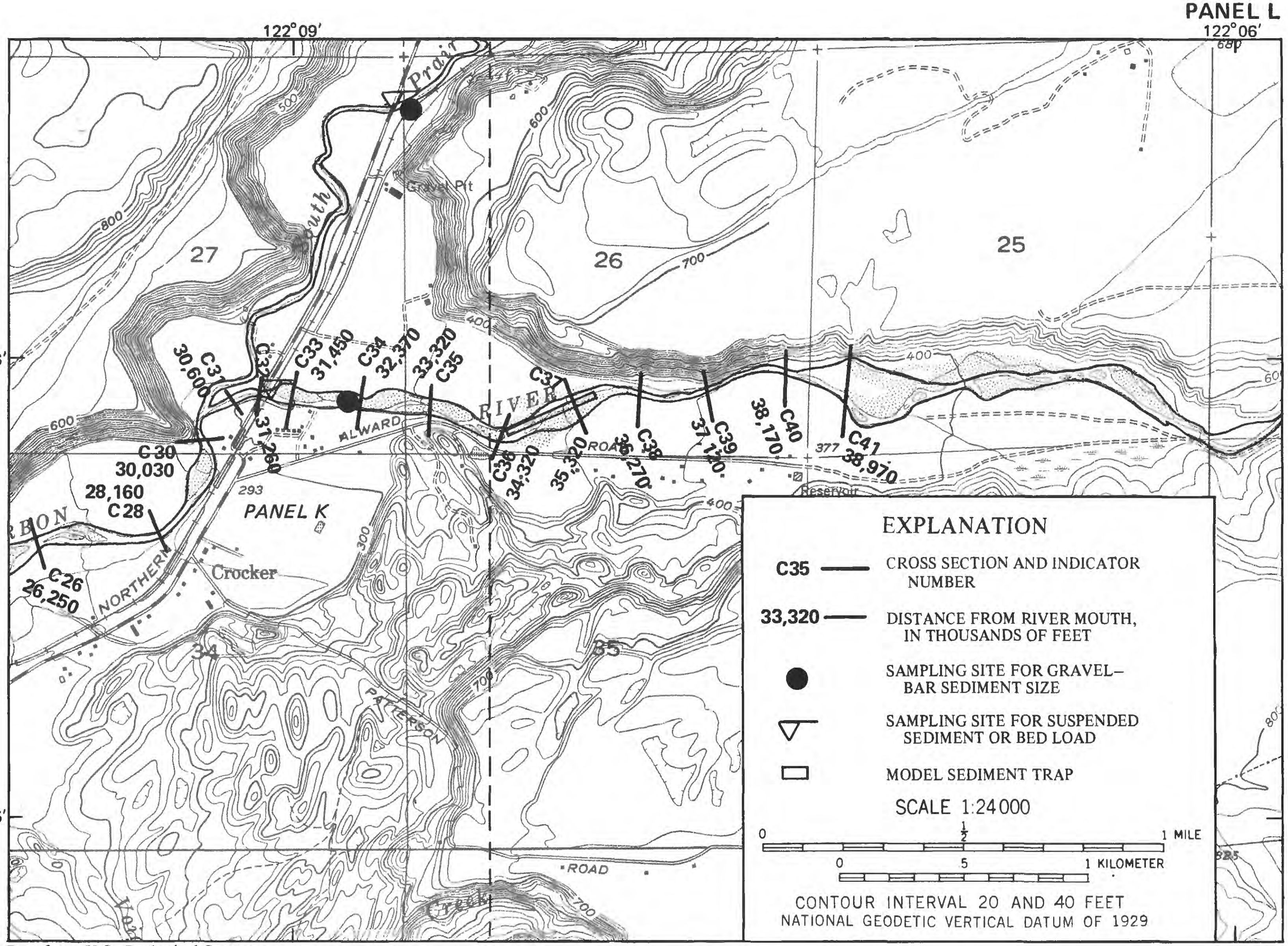
Base from U.S. Geological Survey
Auburn, 1949, photorevised 1973

FIGURE A2.--River reach showing locations of surveyed cross sections, on panel J. Areas included on each panel are shown on figure A1.



Base from U.S. Geological Survey
Orting, 1956, photorevised 1968

FIGURE A2.–River reach showing locations of surveyed cross sections, on panel K. Areas included on each panel are shown on figure A1.



Base from U.S. Geological Survey
Orting, 1956, photorevised 1968 and
Wilkeson, 1956, photorevised 1968

FIGURE A2.--River reach showing locations of surveyed cross sections, on panel L. Areas included on each panel are shown on figure A1.

Table A1.--Cross sections used in the modeling (see figure A2 for locations)

Cross section number	Distance from river mouth (feet)	River mile	Cross section number	Distance from river mouth (feet)	River mile	Cross section number	Distance from river mouth (feet)	River mile
Puyallup River								
P2	1,610	0.30	P56	46,640	8.83	P106	94,520	17.90
P4	3,580	0.68	P61	50,570	9.58	P108	95,770	18.14
P8	5,780	1.09	P62	51,530	9.76	P110	97,780	18.52
P10	7,670	1.45	P64	53,510	10.13	P112	100,220	18.98
P13	9,700	1.84	P65	54,410	10.30	P114	102,150	19.35
P16	11,540	2.19	P66	55,550	10.52	P116	104,060	19.71
P18	12,960	2.45	P70	58,170	11.02	P118	106,180	20.11
P20	14,740	2.79	P72	60,460	11.45	P120	108,220	20.50
P22	16,040	3.04	P74	62,540	11.84	P122	110,300	20.89
P24	17,960	3.40	P77	64,640	12.24	P124	112,400	21.29
P26	19,880	3.77	P79	66,500	12.59	P126	114,340	21.66
P28	21,700	4.11	P81	68,440	12.96	P129	116,420	22.05
P30	23,650	4.48	P83	70,520	13.36	P131	118,420	22.43
P32	25,490	4.83	P85	72,500	13.73	P133	120,250	22.77
P34	27,480	5.20	P87	74,790	14.16	P135	122,020	23.11
P36	29,340	5.56	P90	76,930	14.57	P137	123,950	23.48
P38	30,630	5.80	P92	79,090	14.98	P139	125,980	23.86
P40	32,710	6.20	P93	80,150	15.18	P141	128,030	24.25
P42	34,640	6.56	P95	82,470	15.62	P143	129,880	24.60
P44	36,340	6.88	P96	83,690	15.85	P145	131,930	24.99
P46	38,100	7.22	P98	86,040	16.30	P147	133,910	25.36
P48	40,090	7.59	P100	88,550	16.77	P149	135,870	25.73
P50	42,020	7.96	P103	91,200	17.27	P150.2	137,050	25.96
P53	44,320	8.39	P105	93,240	17.66			
White River								
W39	450	0.09	W57	15,750	2.98	W70	29,620	5.61
W41	1,910	0.36	W59	17,960	3.40	RM5.97	31,520	5.97
W44	4,130	0.78	W61	20,370	3.86	RM6.33	33,420	6.33
W46	5,970	1.13	W62	21,340	4.04	RM6.73	35,530	6.73
W49	7,670	1.45	W64	23,670	4.48	RM7.09	37,440	7.09
W51	9,620	1.82	W66	25,970	4.92	RM7.40	39,070	7.40
W53	11,530	2.18	W68	27,480	5.20	RM7.51	39,650	7.51
W55	13,680	2.59						
Carbon River								
C1	640	0.12	C18	17,730	3.36	C33	31,450	5.96
C2	1,720	0.33	C19	18,580	3.52	C34	32,370	6.13
C4	3,570	0.68	C22	21,900	4.15	C35	33,320	6.31
C6	5,590	1.06	C24	24,310	4.60	C36	34,320	6.50
C8	7,490	1.42	C26	26,250	4.97	C37	35,320	6.69
C10	9,440	1.79	C28	28,160	5.33	C38	36,270	6.87
C12	11,450	2.17	C30	30,030	5.69	C39	37,120	7.03
C14	13,550	2.57	C31	30,600	5.80	C40	38,170	7.23
C16	15,840	3.00	C32	31,260	5.92	C41	38,970	7.38
C17	16,630	3.15						

Table A2.--Location of field observation sites. The sites refer to those in tables A3 to A13. Bed material sites for tables A3 to A6 are indicated in figure A2 by solid dots. Sediment load sites for tables A7 to A13 are indicated in figure A2 by open, inverted triangles that have their horizontal top lines extended to the right

[-- indicates no values]

Sampling site[1]		Panel[2]	Site type	Down-stream cross section	Up-stream cross section	Distance from mouth (feet)
Puyallup River	below Clarks Creek near Puyallup	B	bed material	P32	P34	27,000
Do.	at Puyallup	B	sediment load	P36	P38	30,400
Do.	at Puyallup sewage treatment plant	B	bed material	P44	P44	36,300
Do.	at Sumner below Traffic Avenue Bridge	D	bed material	P66	P70	56,200
Do.	at Alderton	D	sediment load	P74	P77	63,600
Do.	above Alderton gage	D	bed material	P74	P77	63,900
Do.	at fish-study cross section at Alderton[3]	D	bed material	P85	P87	73,100
Do.	under State Route 162 Bridge near McMillin	E	bed material	P106	P106	94,500
Do.	at High Cedars Golf Course near Orting	F	bed material	P116	P118	106,000
Do.	at Orting	F	sediment load	P126	P129	115,100
Do.	above Calistoga Avenue Bridge in Orting	F	bed material	P129	P129	116,400
Do.	above gage near Orting	G	bed material	>P150.2	--	138,200
White River	below Dieringer	H	bed material	W57	W59	17,700
Do.	below Pacific	I	bed material	W68	W70	28,000
Do.	at Auburn	I	sediment load	RM7.51	RM7.74	39,800
Do.	above "R" Street Southeast Bridge at Auburn	I	bed material	RM7.51	RM7.74	40,600
Do.	below power lines above Auburn	J	bed material	RM9.51	RM9.51	50,200
Carbon River	near mouth	E	bed material	C1	C2	1,200
Do.	at Orting	F	bed material	C10	C12	9,800
Do.	at Crocker	L	sediment load	C32	C33	31,300
Do.	above State Route 162 Bridge near Crocker	L	bed material	C34	C34	32,400
South Prairie Creek	at Crocker	L	sediment load	--	--	6,000
Do.	above State Route 162 Bridge near Crocker	L	bed material	--	--	6,200

[1] All locations are in Washington State.

[2] The column lists the panel of figure A2, Appendix A, that shows the site.

[3] The cross section P85 and nearby reach was the location of a fish habitat study that was part of the overall lower Puyallup River basin flood protection study (S. S. Embry, U.S. Geological Survey, written commun., 1989).

Table A3.--Field observations of particle-size distribution for bed materials on the surfaces of gravel bars. Samples were collected by the Wolman particle count method

Sample Number	Date	Percent by number of particles with intermediate axis smaller than the indicated size (Column headings are particle sizes, in millimeters) <4.0	5.6	8.0	11.0	16.0	22.0	32.0	45.0	64.0	91.0	128.0	181.0	256.0	>256.0
Puyallup River below Clarks Creek near Puyallup, Washington															
1	12/06/84	26	26	26	30	39	57	85	97	99	100	100	100	100	100
2	12/06/84	5	8	14	20	28	50	67	85	92	99	100	100	100	100
1	08/05/86	18	18	18	20	29	46	63	75	92	98	100	100	100	100
2	08/05/86	1	1	2	10	33	54	78	93	98	100	100	100	100	100
Puyallup River at Puyallup, Washington, sewage treatment plant															
1	10/06/86	9	9	9	9	12	28	42	61	84	100	100	100	100	100
Puyallup River at Sumner, Washington, below Traffic Avenue Bridge															
1	10/06/86	1	3	5	9	20	34	53	76	90	98	100	100	100	100
Puyallup River above Alderton gage, Washington															
1	02/22/85	21	21	21	22	30	38	47	62	76	92	99	100	100	100
Puyallup River at fish-study cross section at Alderton, Washington															
1	12/05/84	22	22	22	23	23	27	30	41	63	90	98	100	100	100
2	12/05/84	17	17	17	17	17	17	21	36	58	86	99	100	100	100
1	08/05/86	6	6	6	6	8	10	18	43	65	95	99	100	100	100
2	08/05/86	4	4	5	6	10	14	28	45	64	88	100	100	100	100
Puyallup River under State Route 162 Bridge near McMillin, Washington															
1	02/25/85	25	25	26	28	30	38	49	65	79	93	100	100	100	100
2	02/25/85	9	9	13	17	24	34	48	64	84	95	100	100	100	100
3	02/22/85	24	25	25	27	28	32	44	58	79	96	100	100	100	100
2	08/07/86	17	17	17	18	22	31	48	66	88	99	100	100	100	100
Puyallup River at High Cedars Golf Course near Orting, Washington															
1	12/05/84	40	40	40	41	41	44	52	69	79	88	95	99	100	100
2	12/05/84	21	21	21	25	26	32	41	56	72	86	97	100	100	100
1	08/07/86	27	27	27	27	28	28	33	44	63	87	99	100	100	100
2	08/07/86	21	21	21	21	21	28	36	46	67	78	95	100	100	100
Puyallup River above Calistoga Avenue Bridge in Orting, Washington															
1	02/22/85	10	10	10	10	10	13	26	34	43	63	77	94	99	100
2	02/20/85	35	35	35	35	35	40	50	68	80	90	100	100	100	100
1	08/07/86	14	14	14	14	16	19	27	34	52	75	90	96	99	100
2	08/07/86	28	28	28	28	30	31	39	45	55	67	82	92	100	100
Puyallup River above gage near Orting, Washington															
1	12/05/84	22	22	22	24	26	26	31	39	47	60	70	81	93	100
2	12/05/84	22	22	23	25	28	30	39	56	69	84	90	96	99	100
1	08/07/86	1	1	1	1	1	1	1	2	6	14	37	72	94	100
2	08/07/86	2	2	2	2	2	2	3	6	10	21	54	75	95	100

Table A3.--Field observations of particle-size distribution for bed materials on the surfaces of gravel bars. Samples were collected by the Wolman particle count method -- continued

Sample Number	Date	Percent by number of particles with intermediate axis smaller than the indicated size (Column headings are particle sizes, in millimeters) <4.0	5.6	8.0	11.0	16.0	22.0	32.0	45.0	64.0	91.0	128.0	181.0	256.0	>256.0
White River below Dieringer, Washington															
1	12/04/84	21	22	26	34	47	58	85	91	99	100	100	100	100	100
2	12/04/84	2	2	6	7	14	21	47	64	86	100	100	100	100	100
1	10/06/86	3	3	4	7	20	29	51	67	86	99	100	100	100	100
2	10/06/86	4	5	7	8	16	28	48	67	85	97	100	100	100	100
White River below Pacific, Washington															
1	12/05/84	5	5	5	5	9	14	19	40	56	74	90	99	100	100
2	12/05/84	16	16	16	16	17	18	29	41	59	74	83	95	100	100
1	08/05/86	36	36	36	36	37	38	47	53	66	82	98	100	100	100
2	08/05/86	9	9	9	9	9	15	40	64	79	96	100	100	100	100
White River above "R" Street Southeast Bridge at Auburn, Washington															
1	02/25/85	2	4	9	15	29	47	65	75	89	95	97	100	100	100
2	02/25/85	3	3	6	9	13	18	28	51	67	83	94	100	100	100
3	02/25/85	5	5	7	8	14	26	42	60	82	94	100	100	100	100
1	10/06/86	2	2	2	3	6	7	14	23	36	57	72	93	98	100
2	10/06/86	5	5	5	5	7	8	13	18	28	55	69	85	93	100
White River below power lines above Auburn, Washington															
1	12/04/84	9	9	10	12	13	20	28	37	46	88	83	95	100	100
2	12/04/84	27	27	29	31	31	33	41	50	62	75	84	95	99	100
3	12/04/84	18	18	18	18	18	21	21	25	33	56	71	88	97	100
1	08/05/86	5	5	5	5	13	20	30	44	58	71	81	94	100	100
2	08/05/86	20	21	21	21	21	22	28	44	56	70	91	98	100	100
3	08/05/86	25	25	26	26	26	27	30	33	43	50	68	88	94	100
Carbon River near mouth															
1	12/06/84	6	6	6	6	6	8	15	29	44	71	88	98	100	100
2	12/06/84	9	9	9	9	9	12	16	27	52	74	89	100	100	100
1	10/06/86	15	16	16	16	17	22	29	41	59	71	87	99	100	100
2	10/06/86	6	6	7	8	12	13	22	36	51	71	85	98	100	100
Carbon River at Orting, Washington															
1	02/22/85	7	8	11	15	21	24	37	55	70	86	96	99	100	100
2	02/22/85	9	11	12	14	19	23	26	39	45	58	75	96	100	100
1	08/07/86	5	5	5	5	9	11	23	34	50	72	95	100	100	100
2	08/07/86	11	11	11	11	14	15	24	28	46	57	82	97	100	100
Carbon River above State Route 162 Bridge near Crocker, Washington															
1	12/06/84	16	16	16	18	18	18	26	30	39	50	71	81	97	100
2	12/06/84	7	7	7	8	8	9	13	18	26	38	55	74	92	100
South Prairie Creek above State Route 162 Bridge near Crocker, Washington															
1	02/22/85	4	7	14	20	31	43	52	65	78	93	98	100	100	100
2	02/22/85	5	7	7	10	18	29	45	64	75	88	97	100	100	100

Table A4.--Field observations of particle-size distribution for bed material on the surfaces of gravel bars. Samples of approximately 1/3 cubic foot in volume were collected by shovel, and subsequently analyzed by laboratory sieve analysis

	Percent by weight of particles finer than the indicated size (Column headings are particle sizes, in millimeters)												
Date	0.0625	0.125	0.25	0.50	1.	2.	4.	8.	16.	32.	64.	128.	256.
Puyallup River below Clarks Creek, near Puyallup, Washington													
12/06/64	0.1	0.2	1.2	2.5	2.8	3.1	4.0	7.3	20.9	59.2	100.0	100.0	100.0
Puyallup River at fish-study cross section at Alderton, Washington													
12/05/64	0.3	1.1	3.5	5.0	5.1	5.3	5.6	6.3	9.1	17.7	57.2	100.0	100.0
Puyallup River at High Cedars Golf Course near Orting, Washington													
12/05/84	0.5	1.5	5.0	8.8	10.8	12.2	13.9	15.9	21.0	38.9	77.8	100.0	100.0
White River below Dieringer, Washington													
12/04/84	0.3	1.3	4.8	9.2	10.0	10.7	12.1	17.6	32.3	61.2	100.0	100.0	100.0

Table A5.--Field observations of particle-size distribution for sand deposits on the surfaces of gravel bars. Samples of approximately 1/3 cubic foot in volume were collected by shovel, and subsequently analyzed by laboratory sieve analysis

	Percent by weight of particles finer than the indicated size (Column headings are particle sizes, in millimeters)												
Date	0.0625	0.125	0.25	0.50	1.	2.	4.	8.	16.	32.	64.	128.	256.
Puyallup River below Clarks Creek, near Puyallup, Washington													
12/06/84	0.3	2.6	32.1	96.4	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
08/06/86	2.0	7.7	56.5	98.6	99.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Puyallup River at Sumner, Washington, below Traffic Avenue Bridge													
10/10/86	1.9	11.1	61.0	95.1	99.1	99.6	99.7	100.0	100.0	100.0	100.0	100.0	100.0
Puyallup River at fish-study cross section at Alderton, Washington													
12/05/84	7.9	31.9	93.1	99.9	99.9	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
08/05/86	8.7	24.2	82.1	99.4	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Puyallup River under State Route 162 Bridge near McMillin, Washington													
08/07/86	15.2	47.2	93.1	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Puyallup River at High Cedars Golf Course near Orting, Washington													
12/05/84	1.1	5.2	32.7	91.2	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Puyallup River above Calistoga Avenue Bridge in Orting, Washington													
08/07/86	2.7	13.0	48.1	94.6	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Puyallup River above gage near Orting, Washington													
12/05/84	0.8	7.9	44.2	92.4	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
08/07/86	1.5	9.1	38.3	89.1	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
White River below Dieringer, Washington													
12/04/84	3.6	27.2	90.1	99.4	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
10/10/86	0.3	6.3	67.0	99.7	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
White River below Pacific, Washington													
12/05/84	0.7	10.4	63.6	98.4	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
08/05/86	3.3	15.7	42.2	96.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
White River above "R" Street Southeast Bridge at Auburn, Washington													
10/10/86	3.9	15.6	51.3	92.8	99.6	99.8	99.9	99.9	100.0	100.0	100.0	100.0	100.0
White River below power lines above Auburn, Washington													
12/04/84	2.2	15.4	78.7	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
08/05/86	5.0	30.0	87.3	99.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Carbon River near mouth													
10/10/86	3.6	17.8	62.5	96.1	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Carbon River at Orting, Washington													
12/06/84	5.7	20.6	71.0	99.1	99.8	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0
08/07/86	0.5	4.4	35.0	92.6	99.8	99.9	99.9	99.9	100.0	100.0	100.0	100.0	100.0
Carbon River above State Route 162 Bridge near Crocker, Washington													
12/06/84	3.4	16.4	65.5	98.7	99.8	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A6.--Field observations of particle-size distribution for bed materials below the surfaces of gravel bars. Samples of approximately 1/3 to 2/3 cubic foot in volume were collected by shovel, and subsequently analyzed by laboratory sieve analysis

	Percent by weight of particles smaller than the indicated size (Column headings are particle sizes, in millimeters)												
Date	0.0625	0.125	0.25	0.50	1.	2.	4.	8.	16.	32.	64.	128.	256.
Puyallup River below Clarks Creek, near Puyallup, Washington													
12/06/84	0.2	0.6	4.0	13.4	19.9	25.1	30.6	39.7	54.3	70.3	94.5	100.0	100.0
08/05/86	0.2	1.2	6.0	18.6	20.8	21.7	22.5	27.1	47.5	79.5	100.0	100.0	100.0
Puyallup River at Puyallup, Washington, sewage treatment plant													
10/10/86	0.8	1.7	5.1	10.5	14.5	17.3	20.3	26.1	39.7	56.8	83.1	100.0	100.0
Puyallup River at Sumner, Washington, below Traffic Avenue Bridge													
10/10/86	0.1	0.8	8.3	22.8	25.7	26.7	28.3	35.3	55.0	80.4	94.6	100.0	100.0
Puyallup River at fish-study cross section at Alderton, Washington													
12/05/84	0.5	2.2	9.5	15.9	16.8	17.8	18.8	20.9	26.5	40.4	77.2	100.0	100.0
08/05/86	0.4	1.6	6.4	12.0	13.4	16.2	18.9	22.2	36.0	52.7	76.5	100.0	100.0
Puyallup River under State Route 162 Bridge near McMillin, Washington													
08/07/86	1.0	2.6	9.0	14.8	15.5	16.8	18.6	22.7	36.1	55.1	88.0	100.0	100.0
Puyallup River at High Cedars Golf Course near Orting, Washington													
12/05/84	0.2	0.7	3.4	9.6	17.7	22.7	25.4	28.8	38.1	62.0	97.4	100.0	100.0
Puyallup River above Calistoga Avenue Bridge in Orting, Washington													
08/07/86	0.2	0.7	3.8	14.8	24.2	28.0	30.0	32.6	39.3	54.9	73.9	100.0	100.0
Puyallup River above gage near Orting, Washington													
08/07/86	0.6	2.2	7.3	16.0	20.8	21.9	22.1	22.7	26.5	34.0	55.1	100.0	100.0
White River below Dieringer, Washington													
12/04/84	0.2	1.0	5.5	12.1	14.5	16.6	19.6	25.5	39.1	63.0	95.7	100.0	100.0
10/10/86	0.4	1.5	5.8	12.7	16.2	18.2	20.6	25.7	38.4	59.4	100.0	100.0	100.0
White River below Pacific, Washington													
12/05/84	0.2	0.7	2.6	8.2	12.3	15.5	18.5	23.2	31.0	42.1	77.7	100.0	100.0
08/05/86	0.5	2.3	8.5	20.6	24.8	25.5	25.7	26.0	35.7	68.2	100.0	100.0	100.0
White River above "R" Street Southeast Bridge at Auburn, Washington													
10/10/86	0.4	0.9	2.4	6.5	11.1	14.9	17.7	20.9	27.1	36.0	45.2	65.7	100.0
White River below power lines above Auburn, Washington													
12/04/84	0.2	0.8	3.5	8.5	11.0	12.9	16.6	23.0	31.6	43.2	68.5	100.0	100.0
08/05/86	0.2	0.9	4.1	10.0	12.2	14.1	17.5	24.7	33.6	44.0	60.4	100.0	100.0
Carbon River near mouth													
10/10/86	0.7	1.2	2.8	7.8	13.8	18.1	21.3	26.4	33.5	43.2	60.5	85.0	100.0
Carbon River at Orting, Washington													
12/06/84	0.2	1.1	5.1	9.7	11.0	12.0	13.2	15.4	19.4	28.3	53.8	88.1	100.0
08/07/86	0.1	0.4	2.7	13.3	21.4	26.2	31.1	36.9	47.8	61.0	100.0	100.0	100.0

Table A7.--Field observations of suspended sediment for the Puyallup River at Puyallup. Concentrations and particle-size distributions of suspended sediment and associated data are given for sampling stations across the width of the river. Computed discharge-weighted averages (ave) for cross sections and data for composited duplicate samples (comp) are also given. Samples were collected using a P-61 or D-74 sampler with a 3/16-inch nozzle

[Station = sampling distance from point near left bank, in feet]

Date	Station	Time	Temperature (Degree C)	Streamflow (cubic feet per second)	Suspended sediment concentration, in milligrams per liter			Percent by weight finer than indicated size (Column headings are sizes, in millimeters)					
					Fines	Sand	Total	0.0625	0.125	0.250	0.500	1.00	2.00
Jan 19, 1986	60	0120	--	--	571	1,259	1,830	31	--	--	--	--	--
Do.	90	0145	--	--	555	1,155	1,710	32	--	--	--	--	--
Do.	130	0150	--	--	567	1,168	1,735	33	--	--	--	--	--
Do.	170	0200	--	--	533	842	1,375	39	--	--	--	--	--
Do.	220	0205	--	--	630	760	1,390	45	--	--	--	--	--
Do.	ave	0150	--	10,700	568	1,040	1,608	35	--	--	--	--	--
Do.	60	1105	5.8	--	--	--	1,500	--	--	--	--	--	--
Do.	90	1117	5.8	--	--	--	1,470	--	--	--	--	--	--
Do.	130	1125	5.8	--	--	--	1,610	--	--	--	--	--	--
Do.	170	1132	5.8	--	--	--	1,210	--	--	--	--	--	--
Do.	220	1142	5.8	--	--	--	1,150	--	--	--	--	--	--
Do.	ave	1125	5.8	12,100	--	--	1,397	--	--	--	--	--	--
Do.	comp	1125	5.8	12,100	500	820	1,320	38	58	80	97	100	100
Jan 20, 1986	60	0905	4.5	--	120	328	448	27	--	--	--	--	--
Do.	90	0910	4.5	--	120	340	460	26	--	--	--	--	--
Do.	130	0914	4.5	--	120	454	574	21	--	--	--	--	--
Do.	170	0920	4.5	--	114	236	350	33	--	--	--	--	--
Do.	220	0926	4.5	--	113	148	260	43	--	--	--	--	--
Do.	ave	0915	4.5	7,380	118	312	430	27	--	--	--	--	--
Feb 25, 1986	60	0825	--	--	--	--	1,860	--	--	--	--	--	--
Do.	90	0835	--	--	--	--	1,500	--	--	--	--	--	--
Do.	130	0840	--	--	--	--	1,960	--	--	--	--	--	--
Do.	170	0845	--	--	--	--	1,350	--	--	--	--	--	--
Do.	220	0850	--	--	--	--	1,500	--	--	--	--	--	--
Do.	ave	0840	--	17,500	--	--	1,618	--	--	--	--	--	--
Do.	comp	0840	--	17,500	658	872	1,530	43	69	93	98	100	100

Table A8.--Field observations of suspended sediment for the Puyallup River at Alderton. Concentrations and particle-size distributions of suspended sediment and associated data are given for sampling stations across the width of the river. Computed discharge-weighted averages (ave) for cross sections and data for composited duplicate samples (comp) are also given. Samples were collected using a P-61 or D-74 sampler with a 3/16-inch nozzle

[Station = sampling distance from point near left bank, in feet]

Date	Station	Time	Temperature (Degree C)	Streamflow (cubic feet per second)	Suspended sediment concentration, in milligrams per liter: Fines	Sand	Total	Percent by weight finer than indicated size (Column headings are sizes, in millimeters): 0.0625	0.125	0.250	0.500	1.00	2.00
Nov 6, 1985	ave	1330	--	4,060	36	330	366	10	--	--	--	--	--
Jan 18, 1986	65	2230	--	--	444	549	993	45	--	--	--	--	--
Do.	80	2240	--	--	472	703	1,175	40	--	--	--	--	--
Do.	95	2245	--	--	461	1,009	1,470	31	--	--	--	--	--
Do.	110	2255	--	--	476	1,289	1,765	27	--	--	--	--	--
Do.	140	2305	--	--	490	1,665	2,155	23	--	--	--	--	--
Do.	170	2320	--	--	508	1,512	2,020	25	--	--	--	--	--
Do.	ave	2255	--	7,000	474	1,133	1,607	29	--	--	--	--	--
Jan 19, 1986	65	0920	5.9	--	--	--	799	--	--	--	--	--	--
Do.	80	0940	5.9	--	--	--	938	--	--	--	--	--	--
Do.	95	0948	5.7	--	--	--	1,110	--	--	--	--	--	--
Do.	110	0957	5.7	--	--	--	1,070	--	--	--	--	--	--
Do.	140	1008	5.7	--	--	--	1,240	--	--	--	--	--	--
Do.	170	1014	5.7	--	--	--	1,210	--	--	--	--	--	--
Do.	ave	0950	--	6,800	--	--	1,067	--	--	--	--	--	--
Do.	comp	0950	--	6,800	344	639	983	35	54	83	99	100	100
Do.	65	1521	6.1	--	173	213	386	45	--	--	--	--	--
Do.	80	1530	5.9	--	200	288	488	41	--	--	--	--	--
Do.	95	1537	5.9	--	192	360	552	35	--	--	--	--	--
Do.	110	1544	5.9	--	197	377	574	34	--	--	--	--	--
Do.	140	1550	5.9	--	194	426	620	31	--	--	--	--	--
Do.	170	1556	5.9	--	190	544	734	26	--	--	--	--	--
Do.	ave	1540	--	5,400	192	359	550	35	--	--	--	--	--
Jan 20, 1986	65	0804	4.4	--	45	71	116	39	--	--	--	--	--
Do.	80	0811	4.4	--	49	110	159	31	--	--	--	--	--
Do.	95	0815	4.4	--	44	167	211	21	--	--	--	--	--
Do.	110	0821	4.4	--	53	190	243	22	--	--	--	--	--
Do.	140	0826	4.4	--	50	241	291	17	--	--	--	--	--
Do.	170	0831	4.4	--	51	232	283	18	--	--	--	--	--
Do.	ave	0817	4.4	3,300	49	161	210	23	--	--	--	--	--
Feb 24, 1986	65	1601	8.6	--	--	--	1,810	--	--	--	--	--	--
Do.	80	1606	8.2	--	--	--	2,050	--	--	--	--	--	--
Do.	95	1611	8.2	--	--	--	2,290	--	--	--	--	--	--
Do.	110	1631	8.0	--	--	--	2,380	--	--	--	--	--	--
Do.	140	1636	7.8	--	--	--	2,890	--	--	--	--	--	--
Do.	170	1645	7.5	--	--	--	2,880	--	--	--	--	--	--
Do.	ave	1620	--	11,800	--	--	2,405	--	--	--	--	--	--
Do.	comp	1620	--	11,800	953	1,317	2,270	42	65	93	99	100	100

Table A9.--Field observations of suspended sediment for the Puyallup River at Orting. Concentrations and particle-size distributions of suspended sediment, and associated data are given for sampling stations across the width of the river. Computed discharge-weighted averages (ave) for cross sections and data for composited duplicate samples (comp) are also given. Samples were collected using a P-61 or D-74 sampler with a 3/16-inch nozzle

[Station = sampling distance from point near left bank, in feet]

Date	Station	Time	Temperature (Degree C)	Streamflow (cubic feet per second)	Suspended sediment concentration, in milligrams per liter: Fines	Sand	Total	Percent by weight finer than indicated size (Column headings are sizes, in millimeters): 0.0625	0.125	0.250	0.500	1.00	2.00
Nov 5, 1985	ave	1350	--	1,620	32	237	269	12	--	--	--	--	--
Jan 18, 1986	25	1810	--	--	375	1,855	2,230	17	--	--	--	--	--
Do.	40	1820	10.5	--	422	1,568	1,990	21	--	--	--	--	--
Do.	65	1833	10.5	--	395	1,205	1,600	25	--	--	--	--	--
Do.	85	1843	10.5	--	386	894	1,280	30	--	--	--	--	--
Do.	120	1847	10.5	--	370	825	1,195	31	--	--	--	--	--
Do.	170	1857	10.5	--	429	625	1,055	41	--	--	--	--	--
Do.	ave	1835	10.5	2,600	394	1,212	1,606	25	--	--	--	--	--
Jan 19, 1986	25	1005	6.0	--	311	1,364	1,675	19	32	59	92	100	100
Do.	40	1012	5.8	--	262	3,063	3,325	8	15	35	78	100	100
Do.	65	1019	5.6	--	338	1,297	1,635	21	31	60	86	95	100
Do.	85	1025	5.6	--	297	1,133	1,430	21	34	65	94	100	100
Do.	120	1031	5.6	--	363	912	1,275	28	43	69	93	100	100
Do.	170	1036	5.8	--	306	743	1,049	29	48	77	96	100	100
Do.	ave	1020	--	3,020	316	1,364	1,680	19	31	57	88	99	100
Do.	25	1608	6.0	--	--	--	1,100	--	--	--	--	--	--
Do.	40	1618	6.0	--	--	--	1,970	--	--	--	--	--	--
Do.	65	1619	6.0	--	--	--	874	--	--	--	--	--	--
Do.	85	1622	6.0	--	--	--	716	--	--	--	--	--	--
Do.	120	1625	6.0	--	--	--	716	--	--	--	--	--	--
Do.	170	1630	6.0	--	--	--	578	--	--	--	--	--	--
Do.	ave	1620	6.0	2,400	--	--	982	--	--	--	--	--	--
Do.	comp	1620	6.0	2,400	166	708	874	19	--	--	--	--	--
Jan 20, 1986	25	0755	4.2	--	53	489	542	10	--	--	--	--	--
Do.	40	0800	4.2	--	51	244	295	17	--	--	--	--	--
Do.	65	0805	4.2	--	48	158	206	23	--	--	--	--	--
Do.	85	0808	4.2	--	50	218	268	19	--	--	--	--	--
Do.	120	0816	4.2	--	45	122	167	27	--	--	--	--	--
Do.	170	0825	4.2	--	45	103	148	30	--	--	--	--	--
Do.	ave	0810	4.2	1,650	49	255	304	16	--	--	--	--	--
Feb 24, 1986	25	1452	9.0	--	--	--	1,940	--	--	--	--	--	--
Do.	40	1456	9.0	--	--	--	3,000	--	--	--	--	--	--
Do.	65	1501	9.0	--	--	--	4,370	--	--	--	--	--	--
Do.	85	1505	9.0	--	--	--	3,180	--	--	--	--	--	--
Do.	120	1508	9.0	--	--	--	2,580	--	--	--	--	--	--
Do.	170	1511	9.0	--	--	--	1,890	--	--	--	--	--	--
Do.	ave	1505	9.0	4,600	--	--	2,650	--	--	--	--	--	--
Do.	comp	1505	9.0	4,600	970	1,650	2,620	37	53	77	94	100	100

Table A10.--Field observations of suspended sediment for the White River at Auburn. Concentrations and particle-size distributions of suspended sediment and associated data are given for sampling stations across the width of the river. Computed discharge-weighted averages (ave) for cross sections and data for composited duplicate samples (comp) are also given. Samples were collected using a P-61 or D-74 sampler with a 3/16-inch nozzle

[Station = sampling distance from point near left bank, in feet]

Date	Station	Time	Temperature (Degree C)	Streamflow (cubic feet per second)	Suspended sediment concentration, in milligrams per liter			Percent by weight finer than indicated size (Column headings are sizes, in millimeters)					
					Fines	Sand	Total	0.0625	0.125	0.250	0.500	1.00	2.00
Jan 19, 1986	75	1433	--	--	744	1,840	2,585	29	41	75	98	100	100
Do.	100	1440	--	--	675	1,820	2,490	27	41	69	95	100	100
Do.	130	1443	6.8	--	686	3,130	3,815	18	27	53	89	100	100
Do.	155	1447	6.8	--	666	1,630	2,295	29	43	67	92	100	100
Do.	185	1451	6.8	--	690	885	1,575	44	60	86	97	100	100
Do.	ave	1445	--	2,900	686	1,962	2,646	26	38	66	93	100	100
Jan 20, 1986	75	1023	4.7	--	169	299	468	36	--	--	--	--	--
Do.	100	1027	4.7	--	138	384	522	26	--	--	--	--	--
Do.	130	1030	4.7	--	151	715	866	17	--	--	--	--	--
Do.	155	1033	4.7	--	172	595	767	22	--	--	--	--	--
Do.	185	1037	4.7	--	163	214	377	43	--	--	--	--	--
Do.	ave	1030	4.7	1,800	157	482	638	25	--	--	--	--	--
Feb 24, 1986	75	2059	6.2	--	--	--	1,920	--	--	--	--	--	--
Do.	100	2110	6.2	--	--	--	2,730	--	--	--	--	--	--
Do.	130	2115	6.5	--	--	--	3,930	--	--	--	--	--	--
Do.	155	2120	6.5	--	--	--	3,310	--	--	--	--	--	--
Do.	185	2130	6.4	--	--	--	2,960	--	--	--	--	--	--
Do.	ave	2115	--	12,000	--	--	3,090	--	--	--	--	--	--
Do.	comp	2115	--	12,000	1,050	1,650	2,700	39	53	75	93	99	100

Table A11.--Field observations of suspended sediment for the Carbon River at Crocker. Concentrations and particle-size distributions of suspended sediment and associated data are given for sampling stations across the width of the river. Computed discharge-weighted averages (ave) for cross sections and data for composited duplicate samples (comp) are also given. Samples were collected using a P-61 or D-74 sampler with a 3/16-inch nozzle

[Station = sampling distance from point near left bank, in feet]

Date	Station	Time	Temperature (Degree C)	Streamflow (cubic feet per second)	Suspended sediment concentration, in milligrams per liter: Fines	Sand	Total	Percent by weight finer than indicated size (Column headings are sizes, in millimeters): 0.0625	0.125	0.250	0.500	1.00	2.00
Nov 5, 1985	ave	1000	--	1,460	44	132	176	25	--	--	--	--	--
Jan 18, 1986	60	2107	--	--	177	663	840	21	--	--	--	--	--
Do.	80	2112	--	--	161	609	770	21	--	--	--	--	--
Do.	100	2117	--	--	181	661	842	21	--	--	--	--	--
Do.	120	2123	--	--	180	1,345	1,525	12	--	--	--	--	--
Do.	170	2133	7.2	--	155	431	586	26	--	--	--	--	--
Do.	ave	2117	--	1,930	171	741	912	19	--	--	--	--	--
Jan 19, 1986	60	1050	5.6	--	--	--	388	--	--	--	--	--	--
Do.	80	1055	5.6	--	--	--	346	--	--	--	--	--	--
Do.	100	1100	5.6	--	--	--	439	--	--	--	--	--	--
Do.	120	1105	5.6	--	--	--	786	--	--	--	--	--	--
Do.	160	1107	5.3	--	--	--	212	--	--	--	--	--	--
Do.	ave	1100	--	1,700	--	--	466	--	--	--	--	--	--
Do.	comp	1100	--	1,700	171	305	476	36	49	71	94	100	100
Do.	60	1706	5.8	--	56	106	162	35	--	--	--	--	--
Do.	80	1710	5.8	--	62	102	164	38	--	--	--	--	--
Do.	100	1717	5.8	--	49	172	221	22	--	--	--	--	--
Do.	120	1720	5.8	--	57	263	320	18	--	--	--	--	--
Do.	175	1723	5.9	--	54	124	178	30	--	--	--	--	--
Do.	ave	1715	--	1,600	53	149	202	26	--	--	--	--	--
Jan 20, 1986	60	1110	4.8	--	12	22	34	35	--	--	--	--	--
Do.	80	1110	4.8	--	5	25	30	17	--	--	--	--	--
Do.	100	1110	4.8	--	6	33	39	15	--	--	--	--	--
Do.	120	1110	4.8	--	2	75	77	3	--	--	--	--	--
Do.	ave	1110	4.8	900	6	36	42	14	--	--	--	--	--
Feb 24, 1986	60	1235	6.5	--	--	--	3,110	--	--	--	--	--	--
Do.	80	1220	6.7	--	--	--	3,290	--	--	--	--	--	--
Do.	100	1212	6.7	--	--	--	7,350	--	--	--	--	--	--
Do.	120	1207	6.7	--	--	--	3,870	--	--	--	--	--	--
Do.	ave	1215	--	4,800	--	--	4,781	--	--	--	--	--	--
Do.	comp	1215	--	4,800	1,202	2,138	3,340	36	55	79	94	100	100

Table A12.--Field observations of suspended sediment for South Prairie Creek at Crocker. Concentrations and particle-size distributions of suspended sediment and associated data are given for sampling stations across the width of the river. Computed discharge-weighted averages (ave) for cross sections and data for composited duplicate samples (comp) are also given. Samples were collected using a P-61 or D-74 sampler with a 3/16-inch nozzle

[Station = sampling distance from point near left bank, in feet]

Date	Station	Time	Temperature (Degree C)	Streamflow (cubic feet per second)	Suspended sediment concentration, in milligrams per liter: Fines	Sand	Total	Percent by weight finer than indicated size (Column headings are sizes, in millimeters): 0.0625	0.125	0.250	0.500	1.00	2.00
Jan 19, 1986	comp	1000	6.5	730	23	59	82	28	--	--	--	--	--
Jan 20, 1986	comp	0020	--	680	81	124	205	40	62	84	97	100	100
Do.	comp	1005	4.8	560	7	15	22	32	--	--	--	--	--
Feb 24, 1986	comp	1530	8.1	--	217	161	378	57	73	91	99	100	100

Table A13.--Field observations of bedload. Discharge and particle-size distributions for bedload and associated data are given for sampling stations across the width of the river. Cross-sectional average distributions were obtained using a sediment-discharge weighted mean. Total bedload discharge through the cross section is also shown. Samples were collected with a Helley-Smith bedload sampler, and analyzed by laboratory sieve analysis

[Station = sampling distance from a point near the left bank, in feet; xsect = cross-sectional average sediment distribution, and total cross-sectional sediment discharge; Rate = bedload transport rate, in tons per day, per foot across the river (for individual stations), or in tons per day (for cross-sectional total); Q = water discharge, in cubic feet per second]

				Percent by weight of particles finer than the indicated size (Column headings are particle sizes, in millimeters)											
Date	Station	Time	Rate	0.0625	0.125	0.250	0.500	1.00	2.00	4.00	8.00	16.0	32.0	64.0	128.0
PUYALLUP RIVER AT ORTING															
Jan 19, 1986	28	1415	1.49	0.6	3.3	22.5	72.8	97.9	99.8	99.8	99.9	100.	100.	100.	100.
Do.	40	1506	1.84	0.5	2.7	19.3	69.3	96.5	99.4	99.6	99.8	99.8	100.	100.	100.
Do.	65	1526	0.28	1.5	7.1	36.1	89.3	99.1	99.6	99.6	99.8	100.	100.	100.	100.
Do.	85	1546	0.35	0.8	4.0	22.1	57.3	64.8	65.5	65.8	66.0	66.9	66.9	100.	100.
Do.	120	1604	0.12	0.9	6.1	35.0	93.1	99.5	99.7	99.8	100.	100.	100.	100.	100.
Do.	170	1624	0.12	1.2	7.1	41.5	95.1	99.7	99.8	99.9	100.	100.	100.	100.	100.
Do. Q=2,600	xsect	1515	80.2	0.7	3.8	24.2	73.3	93.3	95.1	95.2	95.3	95.5	95.6	100.	100.
Feb 24, 1986	25	1425	2.36	0.7	4.0	27.8	78.3	92.5	93.5	93.8	94.0	95.2	98.8	100.	100.
Do.	40	1415	2.63	0.6	2.8	17.9	57.8	75.6	79.3	81.3	83.1	86.5	92.3	100.	100.
Do.	65	1347	0.96	1.2	6.3	32.3	80.5	97.9	99.7	99.8	99.8	100.	100.	100.	100.
Do.	85	1325	1.12	1.2	6.3	32.3	74.9	91.0	93.3	93.5	93.6	93.8	96.2	100.	100.
Do.	120	1305	2.56	0.5	2.3	10.9	30.6	34.7	35.4	35.6	35.9	36.1	39.0	43.9	100.
Do.	170	1235	0.31	2.9	13.5	52.6	96.5	98.9	99.1	99.2	99.3	99.3	100.	100.	100.
Do. Q=4,800	xsect	1330	252.1	0.8	4.1	21.6	56.4	67.1	68.6	69.1	69.5	70.4	73.4	77.3	100.
PUYALLUP RIVER AT ALDERTON															
Feb 24, 1986	65	1625	0.03	1.4	8.3	43.6	97.2	98.9	99.4	99.4	100.	100.	100.	100.	100.
Do.	80	1640	2.57	0.3	1.5	6.3	9.8	10.0	10.0	10.0	10.0	11.0	25.4	100.	100.
Do.	95	1730	6.95	0.2	0.9	4.2	6.9	7.0	7.0	7.0	7.1	7.8	22.8	83.5	100.
Do.	110	1750	5.25	0.4	1.6	7.1	11.4	11.8	12.0	13.6	18.6	29.9	68.5	100.	100.
Do.	140	1805	1.70	1.5	6.5	30.4	49.8	53.1	53.7	54.3	55.7	61.8	84.6	100.	100.
Do.	170	1827	1.67	0.9	5.7	33.9	67.4	74.4	75.6	76.1	76.7	77.7	81.7	100.	100.
Do. Q=11,000	xsect	1730	333.7	0.6	3.0	15.1	26.7	28.7	29.1	29.6	31.1	35.1	54.5	94.8	100.
PUYALLUP RIVER AT PUYALLUP															
Feb 25, 1986	60	0915	0.42	3.7	18.6	85.8	98.9	99.3	99.6	99.7	99.9	100.	100.	100.	100.
Do.	90	0930	0.43	3.4	18.4	82.8	98.4	98.9	99.2	99.5	99.9	100.	100.	100.	100.
Do.	130	0945	1.09	2.0	9.6	49.9	79.9	94.6	96.6	97.4	98.3	99.6	100.	100.	100.
Do.	170	1008	0.30	2.3	11.4	60.6	82.5	90.5	91.6	93.0	95.3	100.	100.	100.	100.
Do.	220	1015	0.27	3.3	18.4	86.8	98.7	99.3	99.6	99.7	99.8	100.	100.	100.	100.
Do. Q=17,000	xsect	0945	97.3	2.6	13.5	65.9	88.0	95.9	97.1	97.7	98.5	99.8	100.	100.	100.

Table A13.--Field observations of bedload. Discharge and particle-size distributions for bedload and associated data are given for sampling stations across the width of the river. Cross-sectional average distributions were obtained using a sediment-discharge weighted mean. Total bedload discharge through the cross section is also shown. Samples were collected with a Helley-Smith bedload sampler, and analyzed by laboratory sieve analysis -- (continued)

[Station = sampling distance from a point near the left bank, in feet; xsect = cross-sectional average sediment distribution, and total cross-sectional sediment discharge; Rate = bedload transport rate, in tons per day, per foot across the river (for individual stations), or in tons per day (for cross-sectional total); Q = water discharge, in cubic feet per second]

				Percent by weight of particles finer than the indicated size (Column headings are particle sizes, in millimeters)											
Date	Station	Time	Rate	0.0625	0.125	0.250	0.500	1.00	2.00	4.00	8.00	16.0	32.0	64.0	128.0
CARBON RIVER AT CROCKER															
Jan 19, 1986	60	1157	0.10	0.5	3.4	25.3	88.9	98.9	99.7	99.8	100.	100.	100.	100.	100.
Do.	80	1234	1.54	0.1	0.9	8.8	45.4	49.5	49.7	49.8	49.9	49.9	49.9	100.	100.
Do.	100	1258	1.20	0.1	0.5	4.5	48.6	87.8	96.1	97.3	97.9	98.9	100.	100.	100.
Do.	120	1323	0.78	0.5	2.1	15.0	73.5	98.1	99.7	99.8	99.9	100.	100.	100.	100.
Do. Q=1,600	xsect	1235	66.9	0.2	1.1	9.4	53.8	72.7	75.6	76.0	76.3	76.6	76.9	100.	100.
Feb 24, 1986	60	1315	17.66	0.2	0.5	1.3	3.8	4.5	5.1	8.9	23.5	47.7	78.1	96.5	100.
Do.	80	1400	17.09	0.3	1.1	4.9	16.2	24.6	29.2	32.6	36.1	42.2	54.2	80.9	100.
Do.	100	1415	5.43	0.7	2.9	13.0	44.7	62.6	68.2	72.1	76.9	84.7	94.7	100.	100.
Do.	120	1445	1.35	1.1	4.0	17.1	44.3	51.7	53.3	54.3	55.7	59.1	72.1	100.	100.
Do. Q=4,700	xsect	1355	817.	0.3	1.1	4.7	15.1	21.1	24.0	27.5	35.8	49.8	69.6	90.5	100.
WHITE RIVER AT AUBURN															
Feb 24, 1986	75	2308	63.25	0.0	0.2	0.5	1.2	1.4	1.7	3.9	12.1	29.9	57.4	85.8	100.
Do.	100	2345	5.08	0.1	0.6	8.7	26.1	30.4	31.6	33.2	36.9	49.2	62.3	100.	100.
Do.	130	0105	7.25	1.1	4.2	20.7	51.9	69.3	78.0	82.5	84.5	85.7	88.4	90.2	100.
Do.	155	0129	13.17	0.4	1.4	9.3	22.7	31.0	38.2	42.0	45.0	51.5	67.4	100.	100.
Feb 25, 1986															
Q=11,000	xsect	0015	2,291.	0.2	0.9	5.2	13.2	17.4	20.3	23.1	29.1	42.0	63.2	90.8	100.

APPENDIX B: DISCHARGE HYDROGRAPHS

This appendix contains stream discharge hydrographs as used in the modeling. Table B1 lists locations and the derivation of the discharge hydrograph for the various locations in the river system. Because HEC-6 uses a step-backwater hydraulic computation, discharges are equal at all cross sections between tributary inflow points. This enforced simultaneity of discharge events in the reaches was accommodated by referencing all timing to the Puyallup River at Puyallup station. Discharge hydrographs measured at upstream gaging stations were lagged by the hydrodynamic travel times from the given stations to the Puyallup River at Puyallup station. Figures B1 to B24 show the lagged discharge hydrographs as used in the modeling.

Figures B1 through B4 show the hydrographs for the Puyallup, White, and Carbon Rivers from July 10, 1984, to July 31, 1987 -- a time interval that contains the modeling period of the main body of the text, as well as the extended period of Appendix D. In figures B5 through B24, which show the details of storm hydrographs within the longer interval, day numbers correspond to those on figures B1 through B4. The discharge axes of figures B5 through B24 have been extended to higher values than figure B1 through B4 to show the storm peaks.

Table B1.--Stream discharge stations and method of computing discharge at each. The lags are hydrodynamic travel times from the given station to the Puyallup River at Puyallup gaging station

[Q(T), stream discharge, in cubic feet per second, at time T, in days; hrs, hours]

Station	Distance upstream (feet)	On river	Lag (hrs.)	Abbreviation	How computed
Puyallup River at Puyallup	34,600	Puyallup	0	PRAP	$Q_{PRAP}(T) = Q_{gaged}(T)$
Puyallup River at Orting	137,100	Puyallup	5	PRAO	$Q_{PRAO}(T) = Q_{gaged}(T - 5/24)$
White River at Buckley	147,300	White	5	WRAB	$Q_{WRAB}(T) = Q_{gaged}(T - 5/24)$
Lake Tapps Diversion at Dieringer	19,200	White	2	LTAD	$Q_{LTAD}(T) = Q_{gaged}(T - 2/24)$
White River at Mouth	54,100	White	1	WRAM	$Q_{WRAM}(T) = Q_{WRAB}(T) + Q_{LTAD}(T)$
White River at Auburn	30,800	White	3	WRAA	$Q_{WRAA}(T) = Q_{WRAB}(T)$
Puyallup River at Alderton	62,500	Puyallup	2	PRAA	$Q_{PRAA}(T) = Q_{PRAP}(T) - Q_{WRAM}(T)$
Carbon River at Mouth	93,800	Carbon	3	CRAM	$Q_{CRAM}(T) = Q_{PRAA}(T) - Q_{PRAO}(T)$
Voight Creek at Crocker (at mouth)	19,900	Carbon	4	VCAC	$Q_{VCAC}(T) = 0.1 \times Q_{CRAM}(T)$
Carbon River below Crocker	25,100	Carbon	4	CRBC	$Q_{CRBC}(T) = Q_{CRAM}(T) - Q_{VCAC}(T)$
South Prairie Creek at Crocker (at mouth)	30,300	Carbon	4	SPAC	$Q_{SPAC}(T) = 0.3 \times Q_{CRAM}(T)$
Carbon River at Crocker	31,500	Carbon	4	CRAC	$Q_{CRAC}(T) = Q_{CRBC}(T) - Q_{SPAC}(T)$

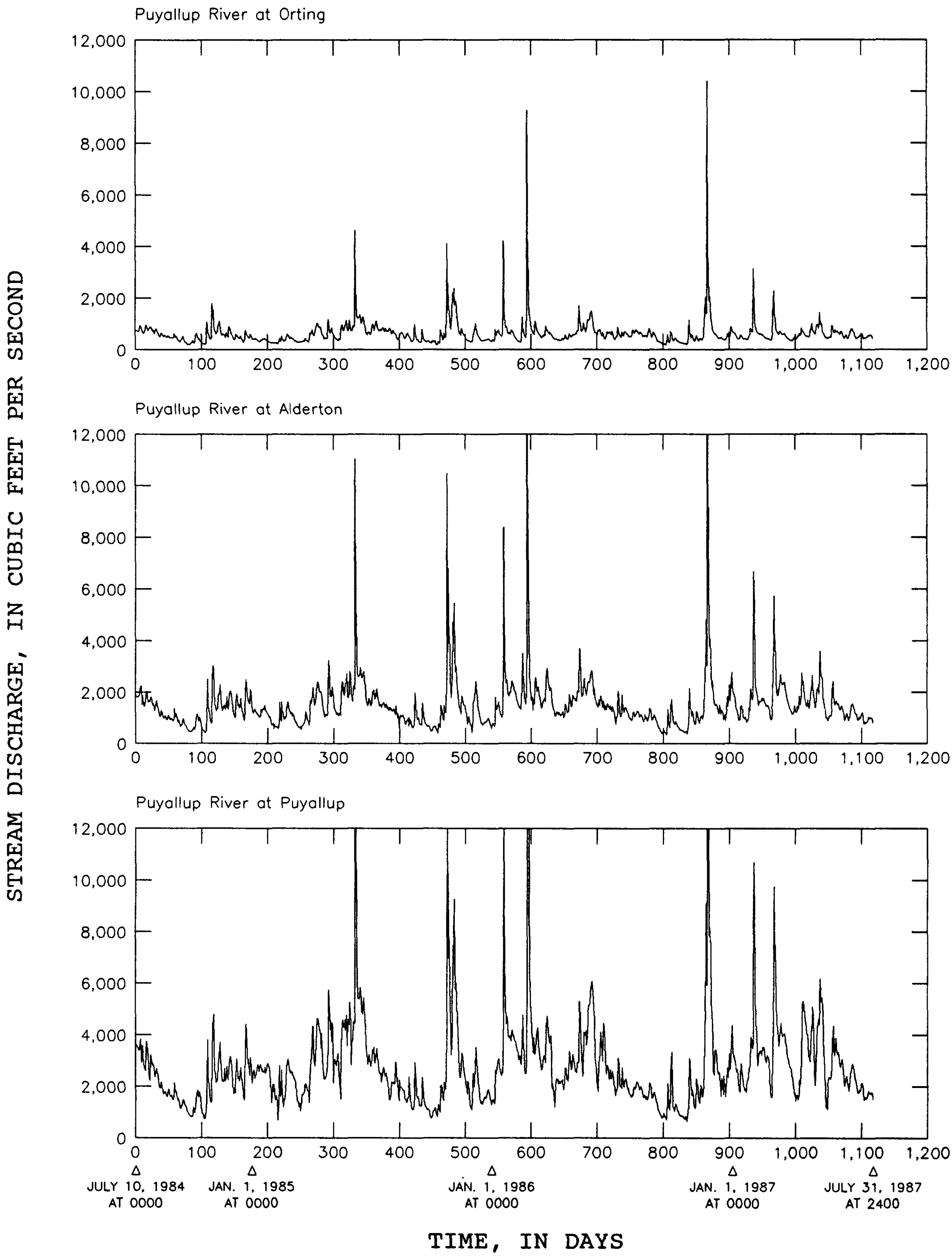


FIGURE B1.--Stream discharge in the Puyallup River from July 10, 1984 to July 31, 1987.

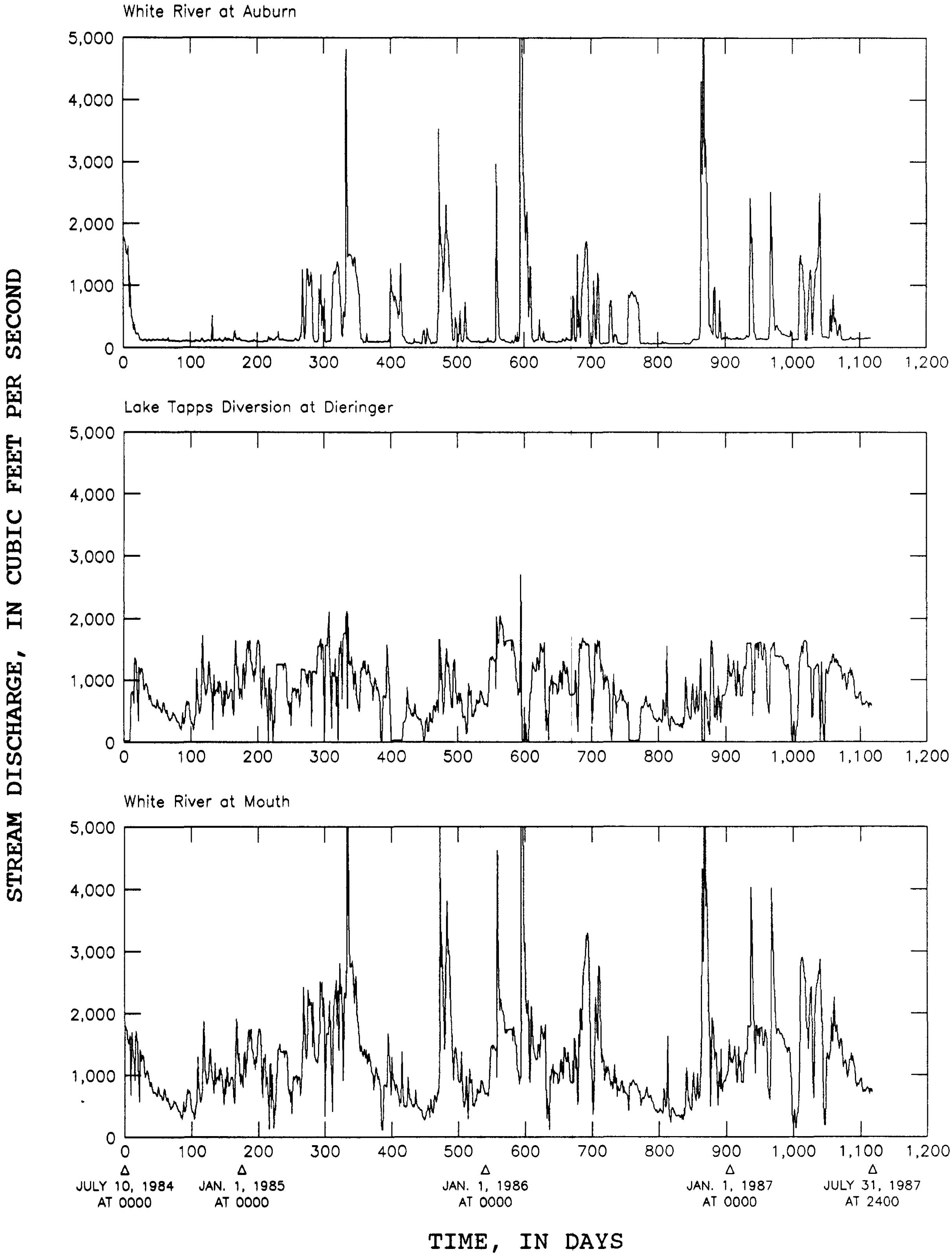


FIGURE B2.--Stream discharge in the White River and tributary from July 10, 1984, to July 31, 1987.

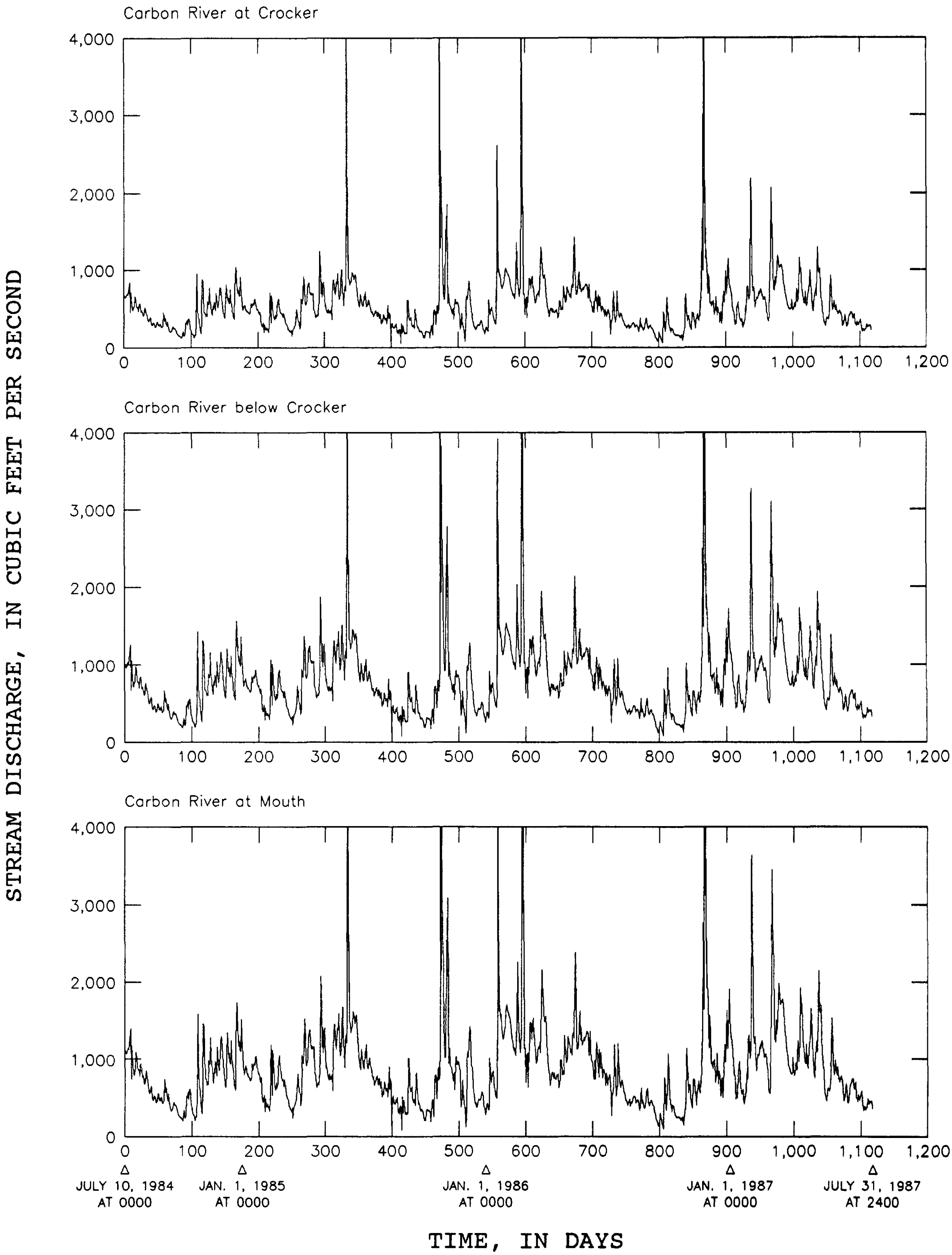


FIGURE B3.--Stream discharge in the Carbon River from July 10, 1984, to July 31, 1987.

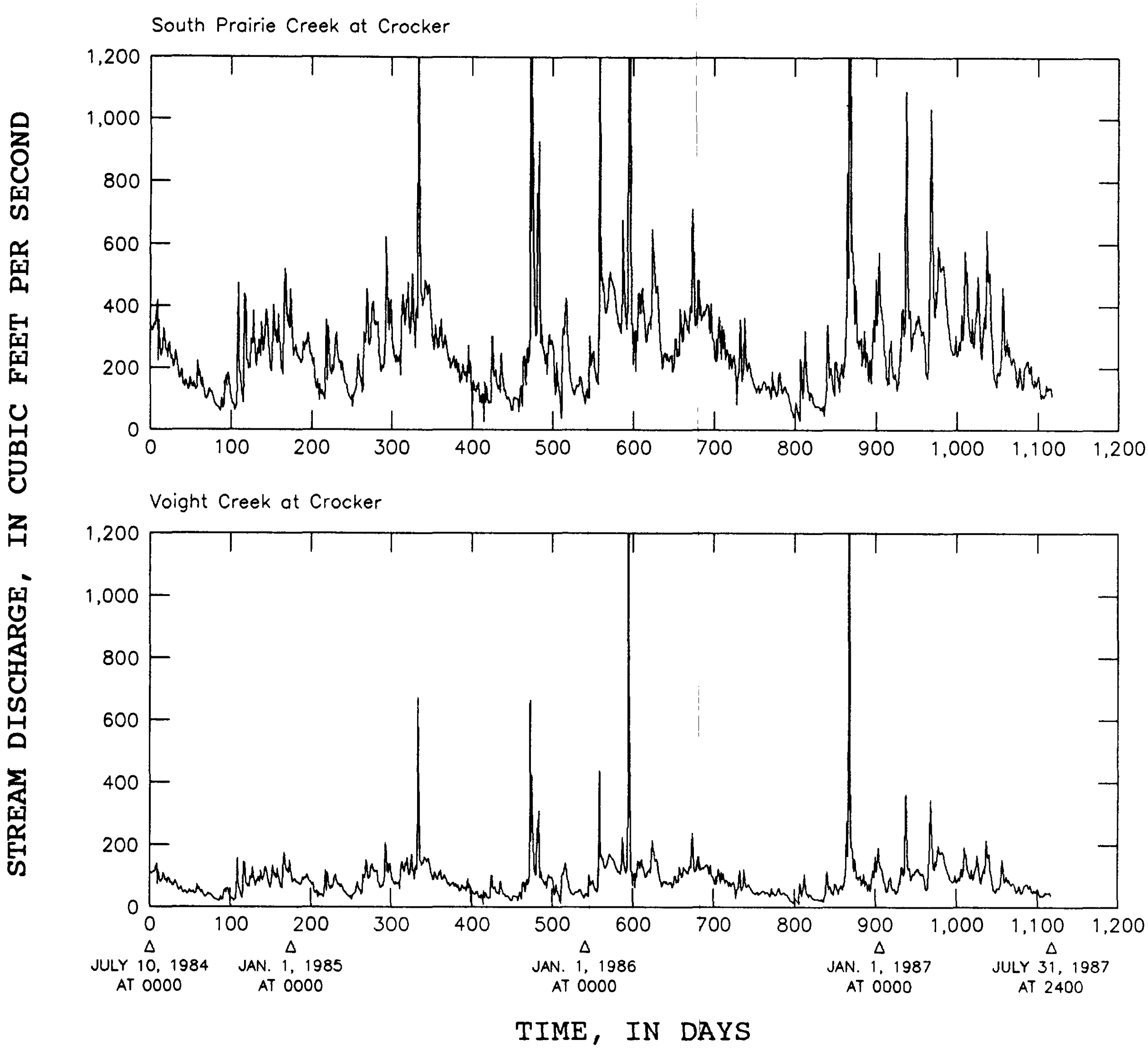


FIGURE B4.--Stream discharge in tributaries of the Carbon River from July 10, 1984, to July 31, 1987.

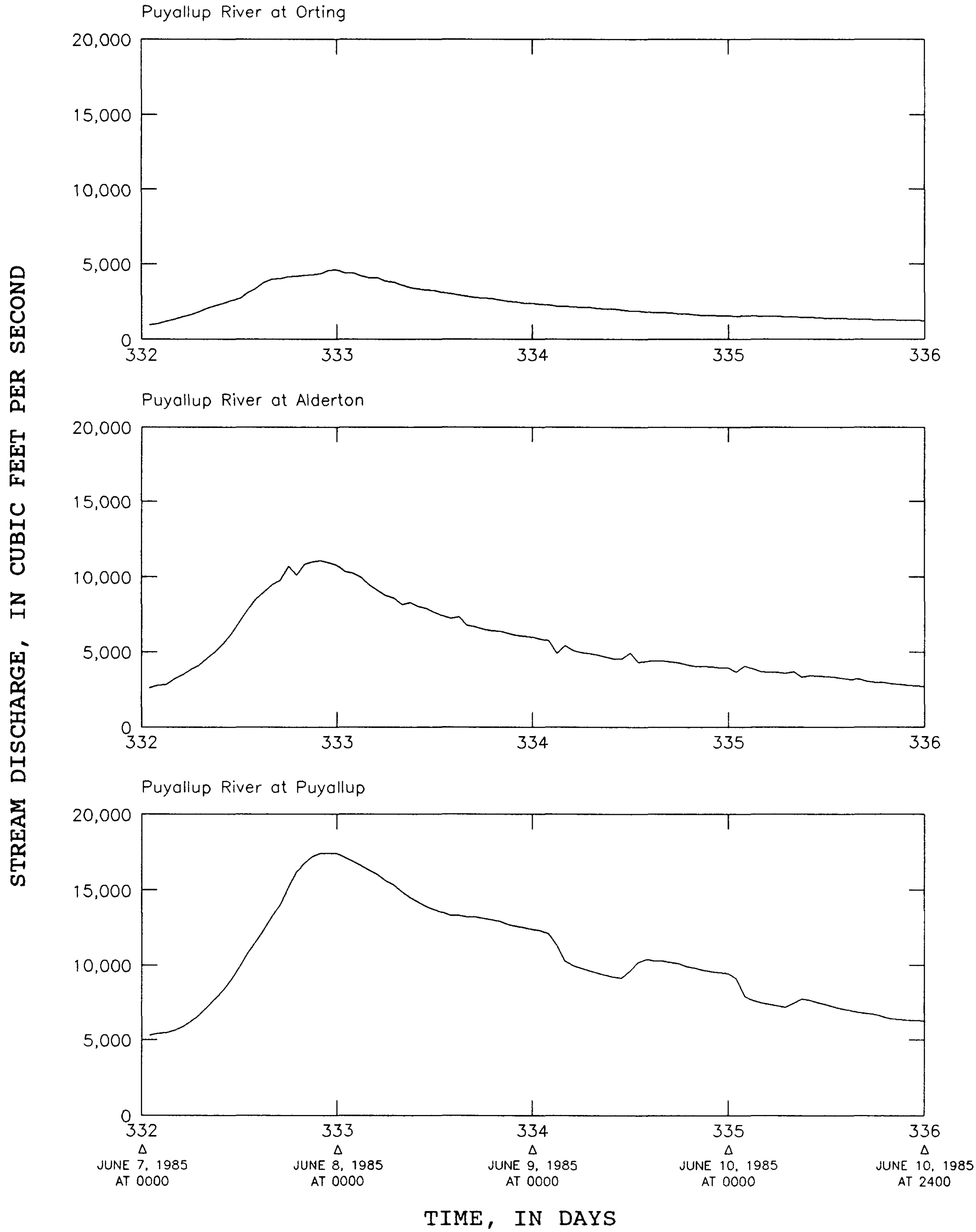


FIGURE B5.--Stream discharge in the Puyallup River during a storm from June 7 to 10, 1985.

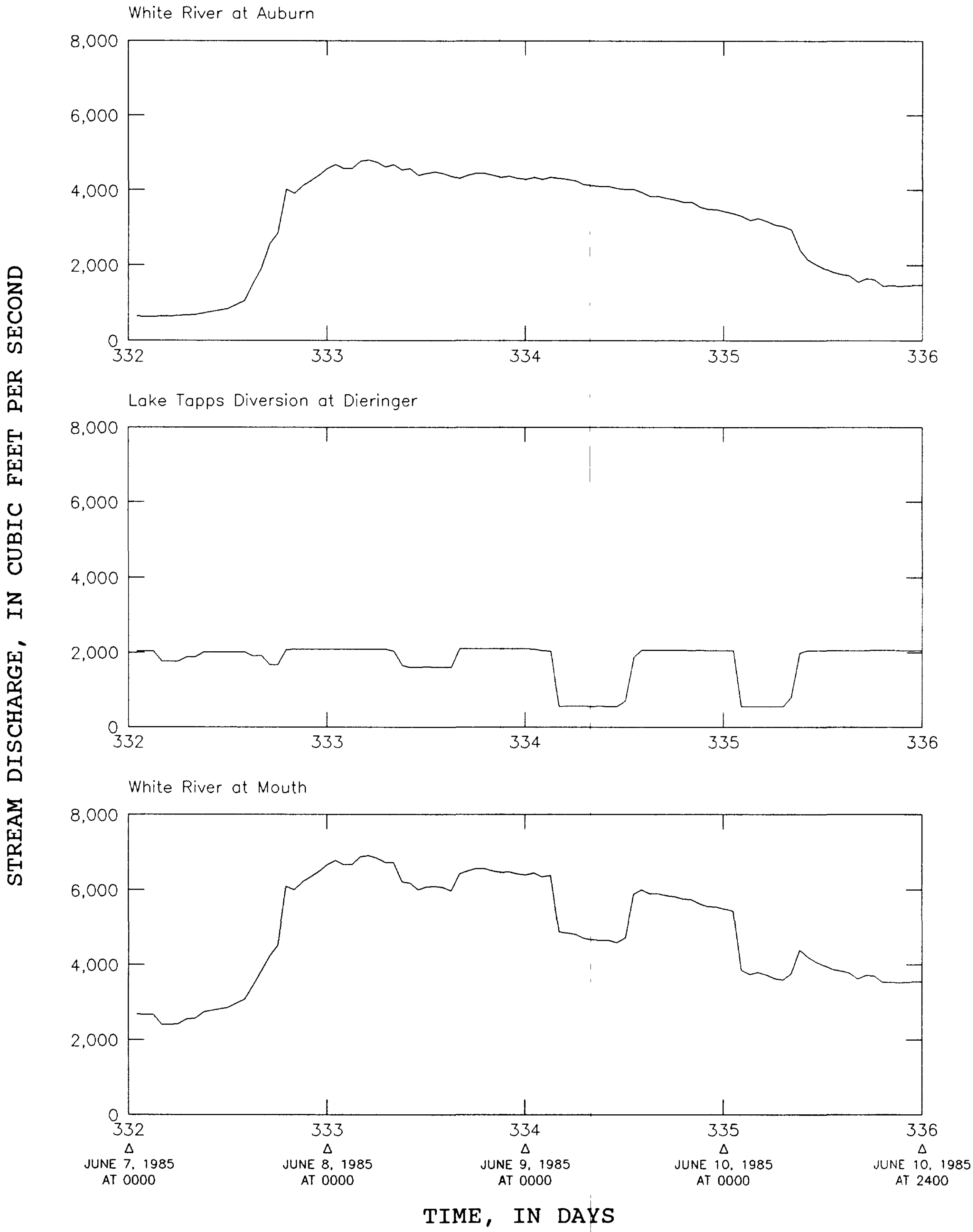


FIGURE B6.–Stream discharge in the White River and tributary during a storm from June 7 to 10, 1985.

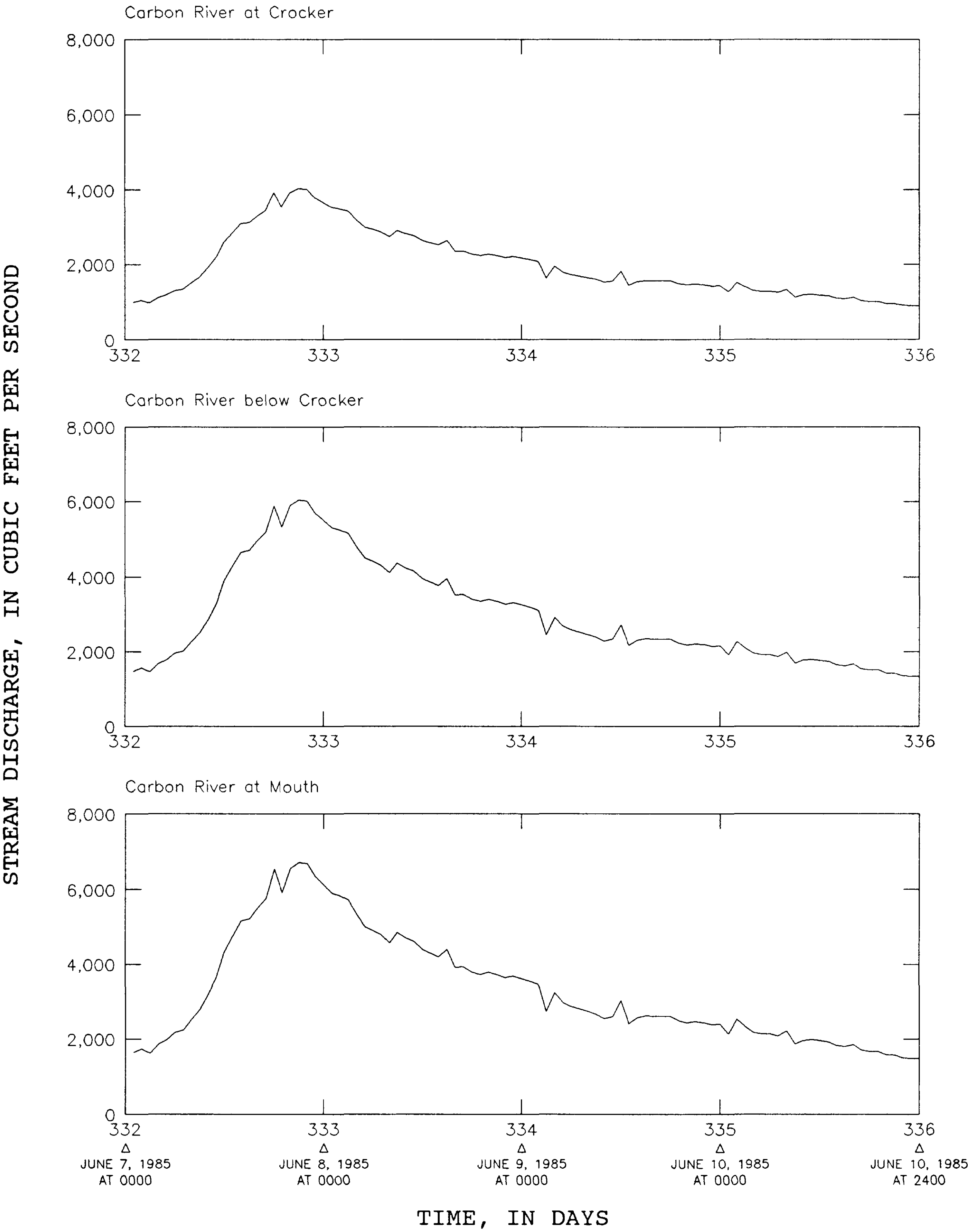


FIGURE B7.--Stream discharge in the Carbon River during a storm from June 7 to 10, 1985.

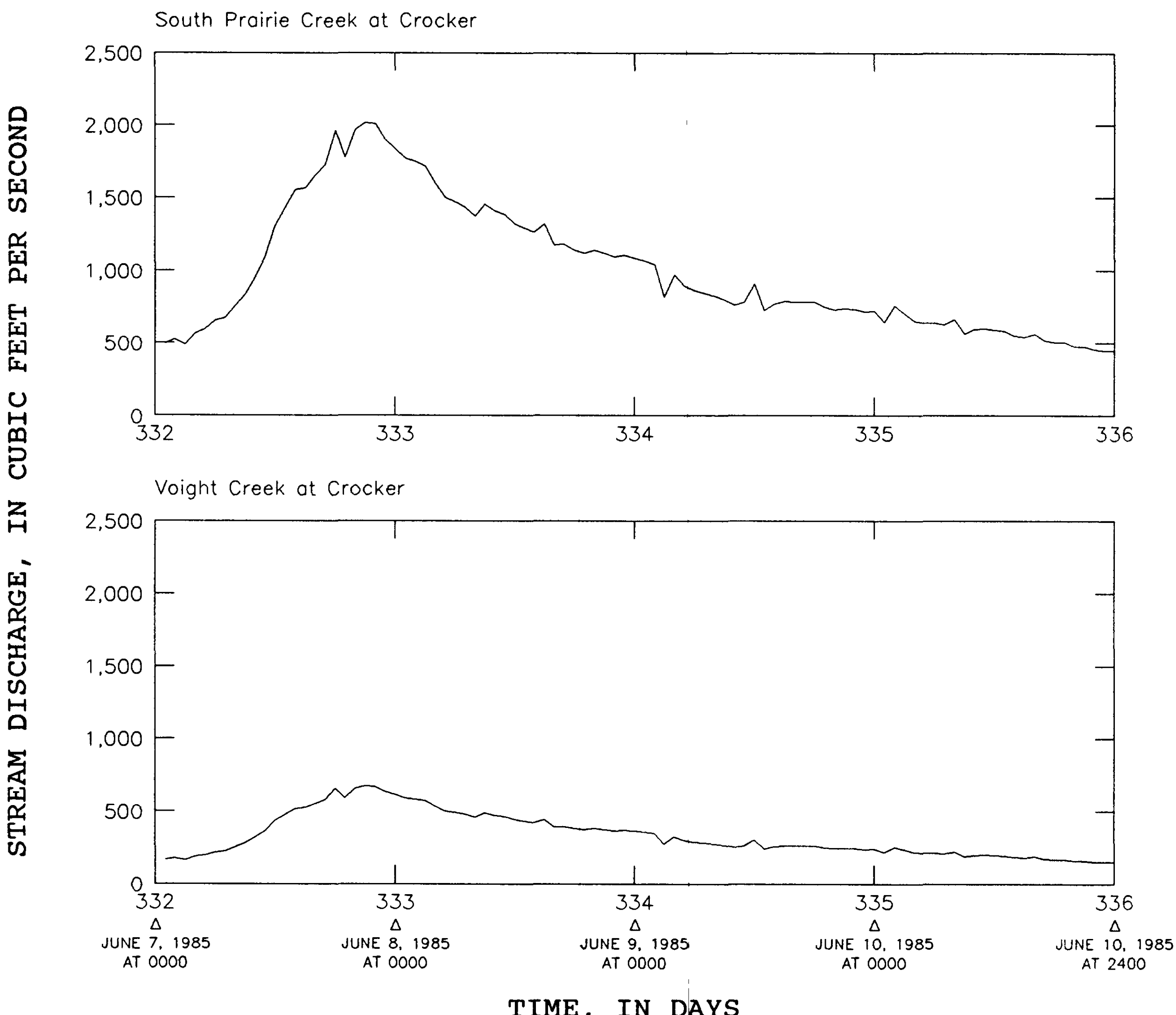


FIGURE B8.--Stream discharge in tributaries of the Carbon River during a storm June 7 to 10, 1985.

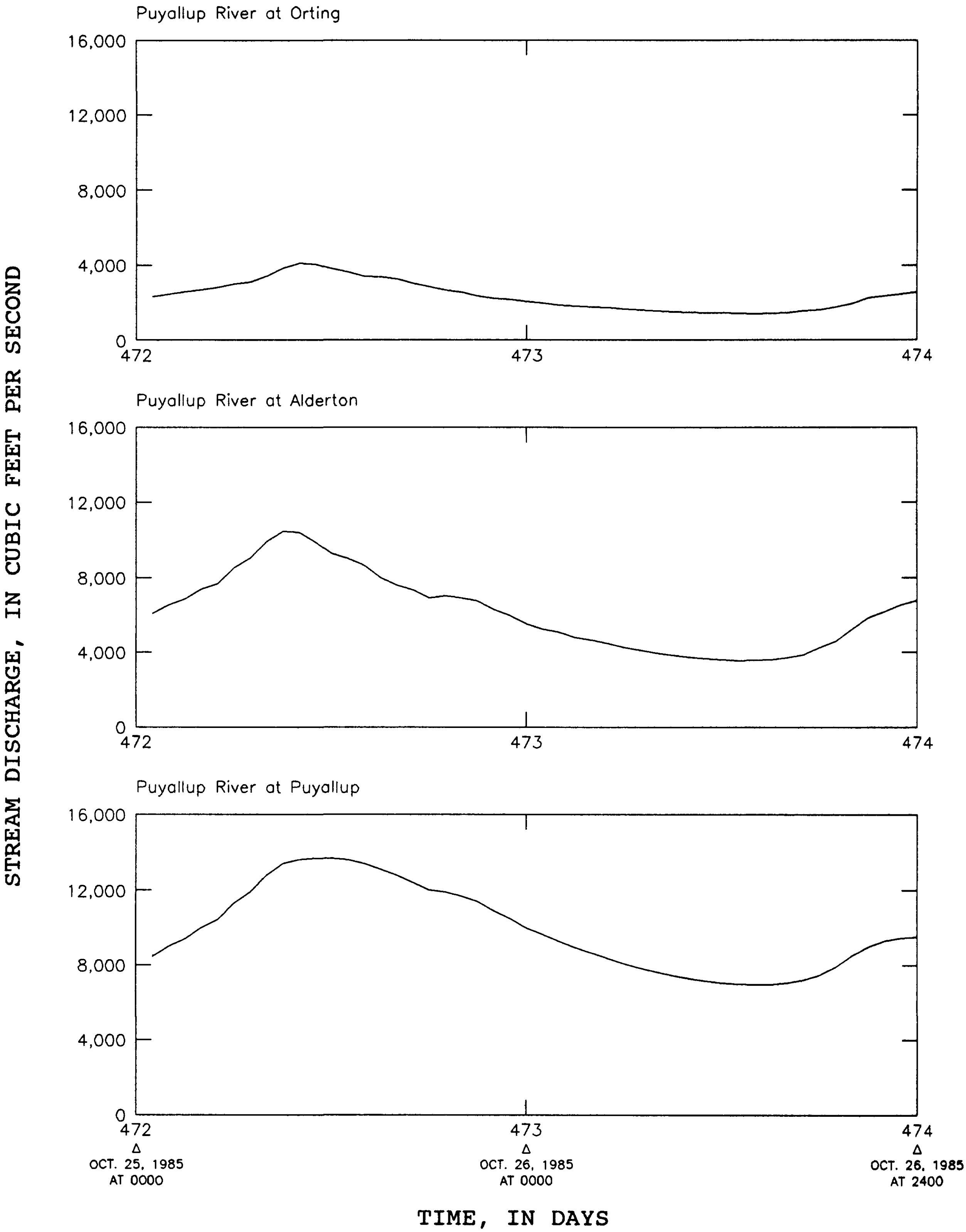


FIGURE B9.--Stream discharge in the Puyallup River during a storm from October 25 to 26, 1985.

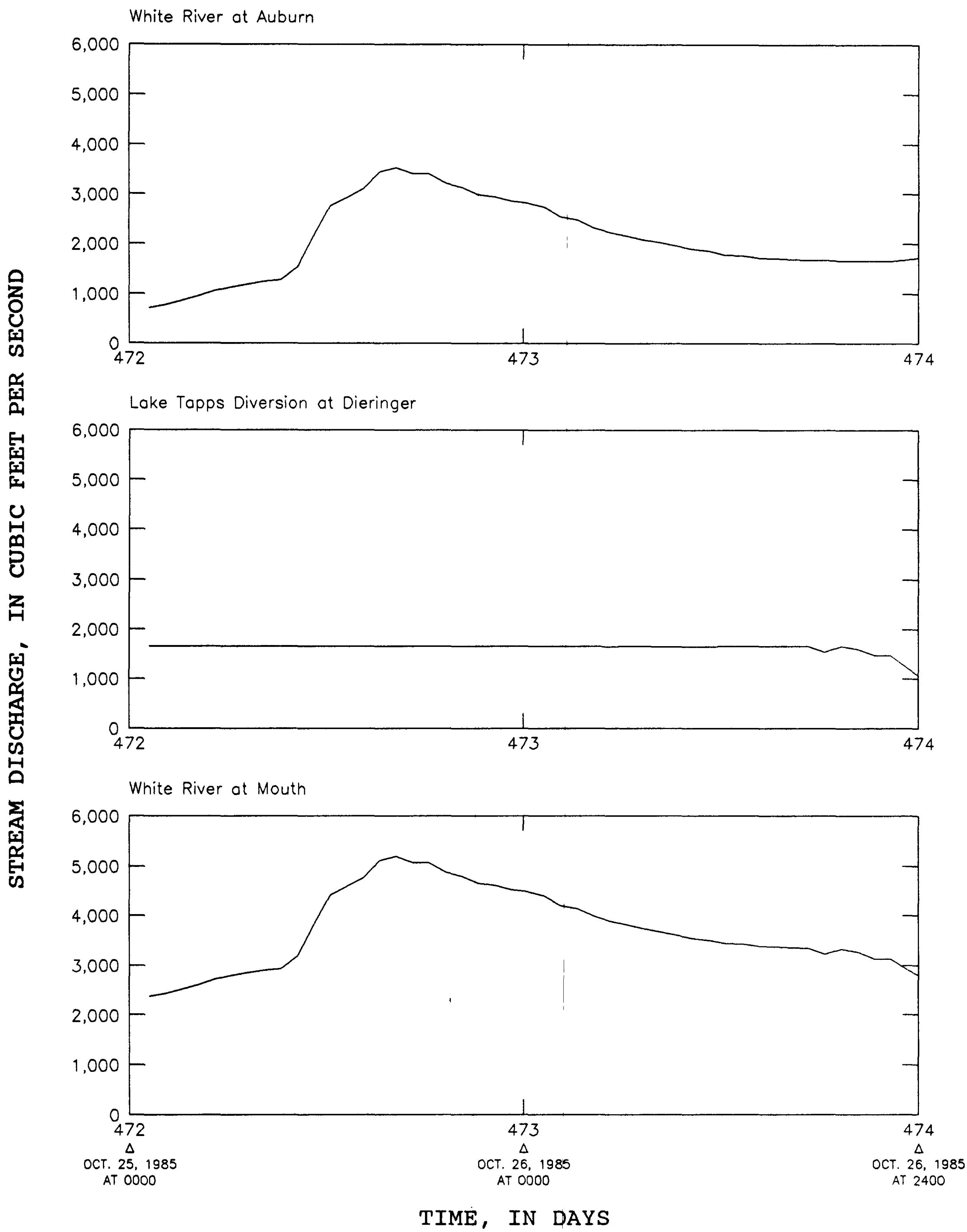


FIGURE B10.--Stream discharge in the White River and tributary during a storm from October 25 to 26, 1985.

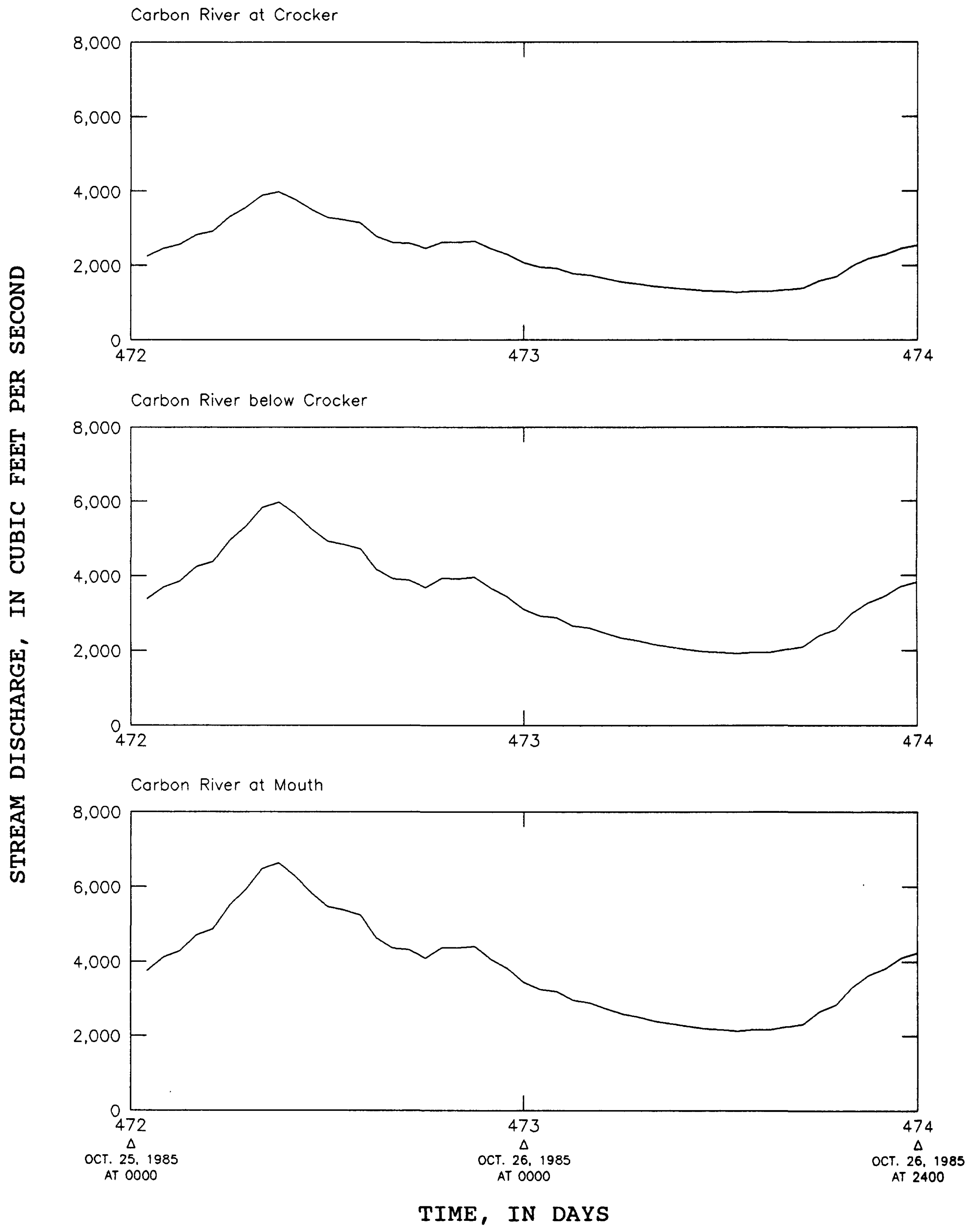


FIGURE B11.--Stream discharge in the Carbon River during a storm from October 25 to 26, 1985.

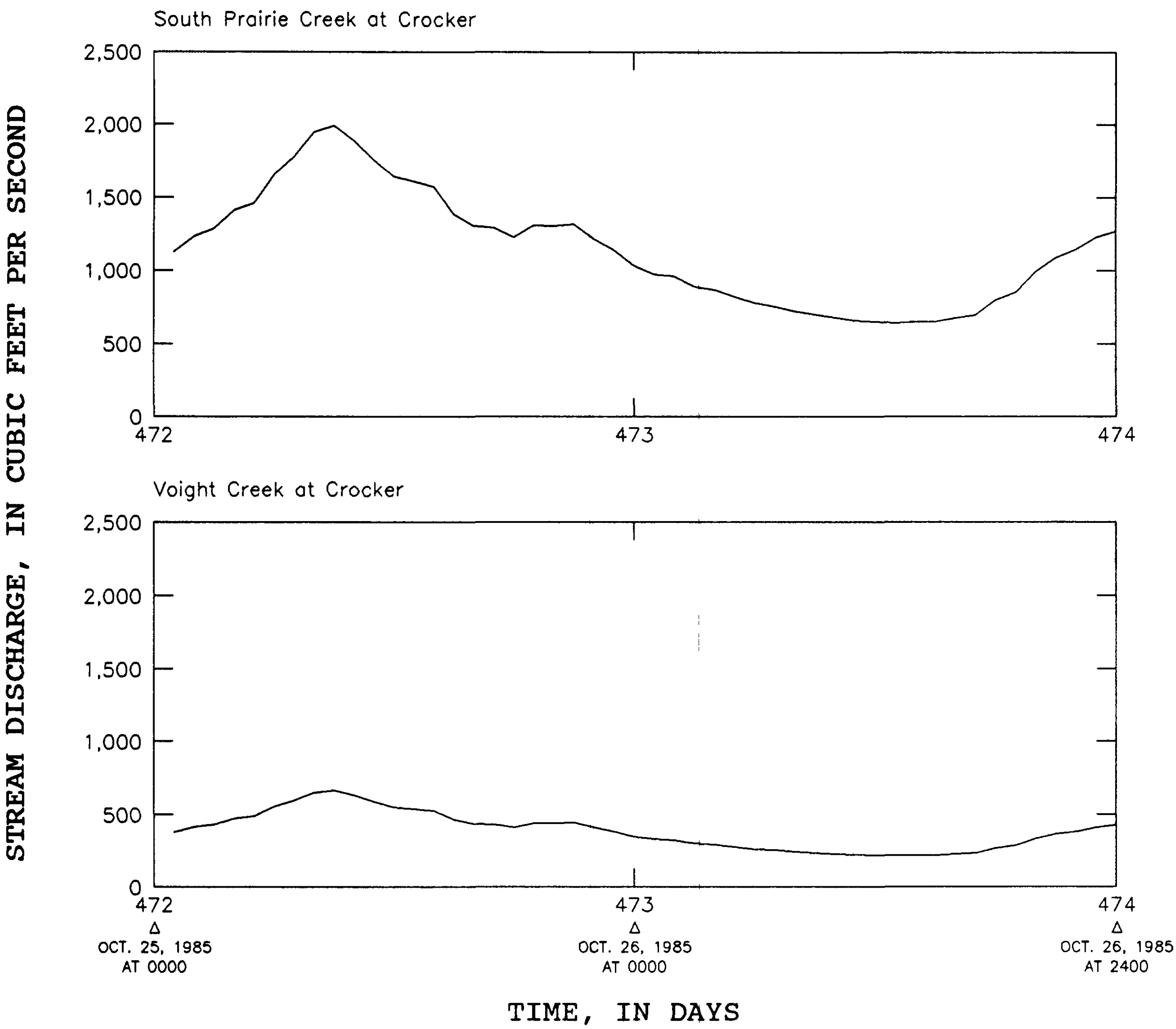


FIGURE B12.--Stream discharge in tributaries of the Carbon River during a storm from October 25 to 26, 1985.

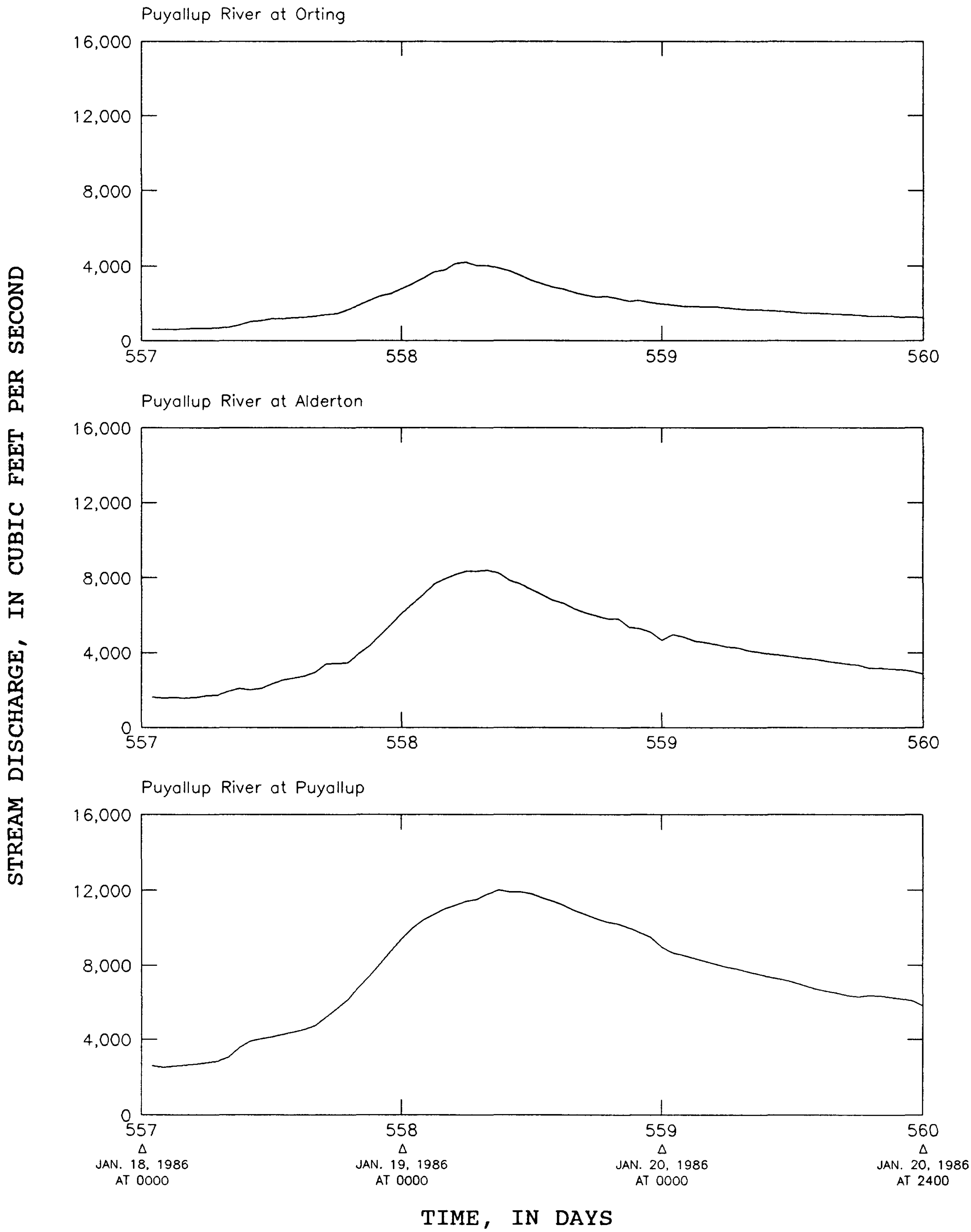


FIGURE B13.–Stream discharge in the Puyallup River during a storm from January 18 to 20, 1986.

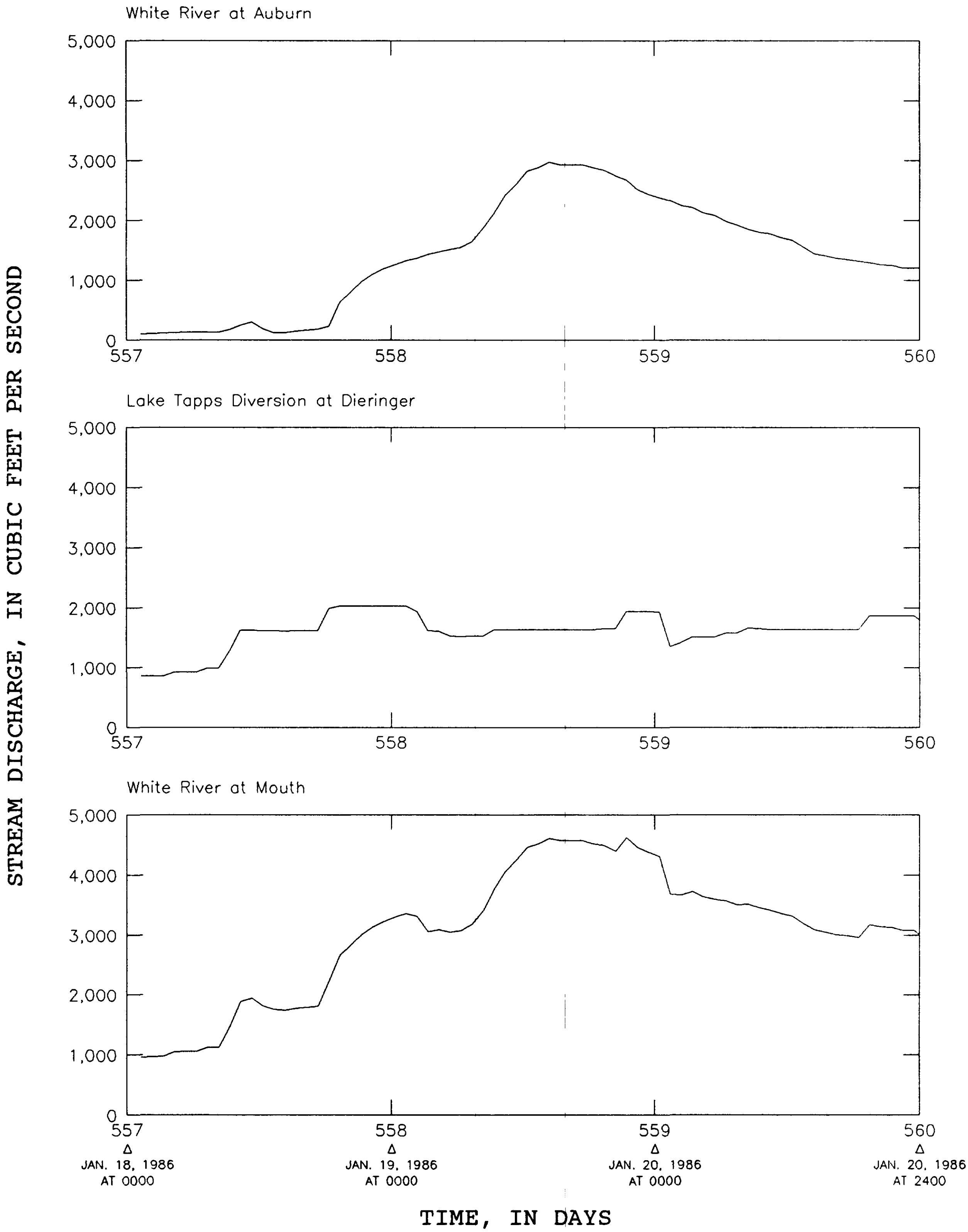


FIGURE B14.--Stream discharge in the White River and tributary during a storm from January 18 to 20, 1986.

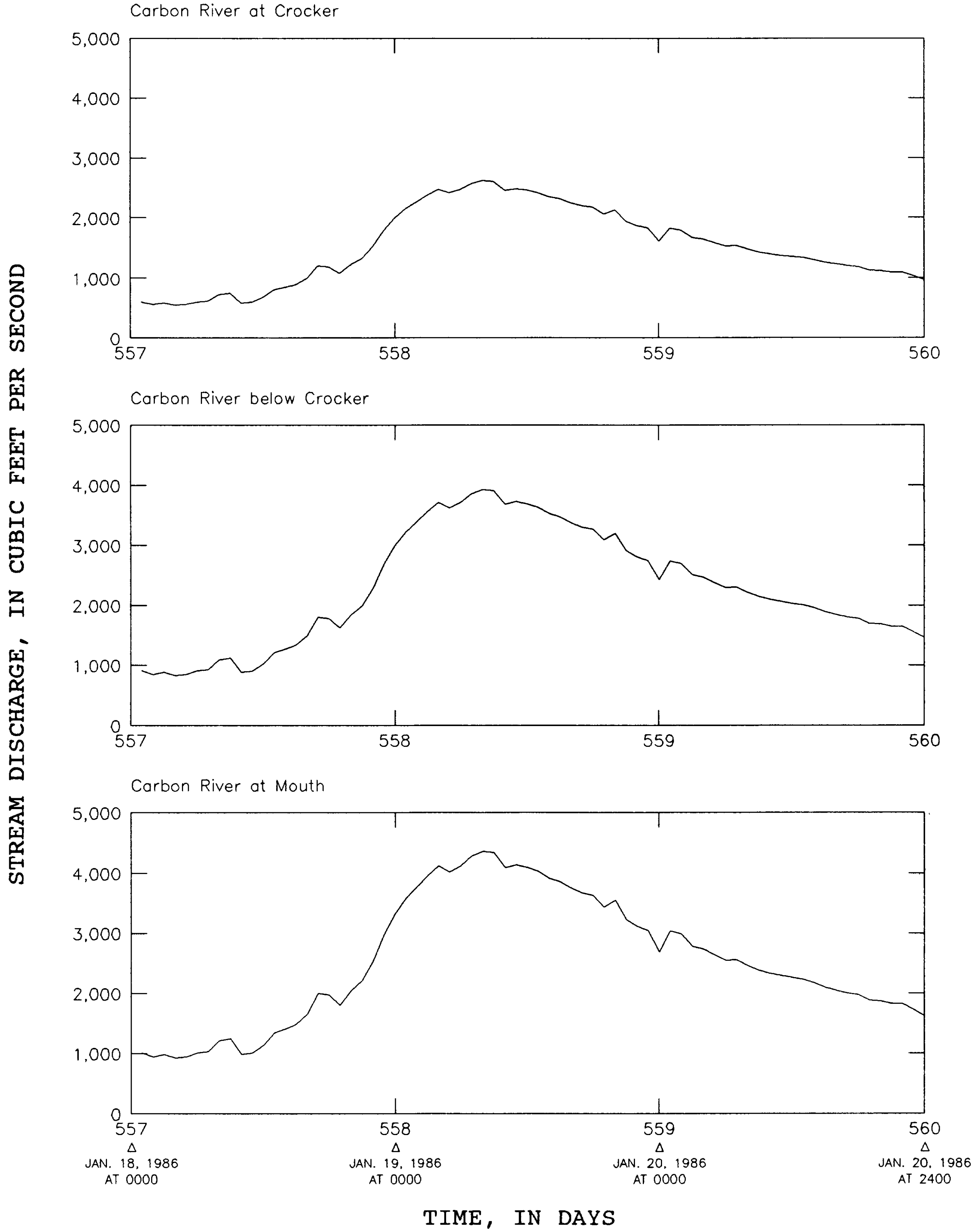


FIGURE B15.--Stream discharge in the Carbon River during a storm from January 18 to 20, 1986.

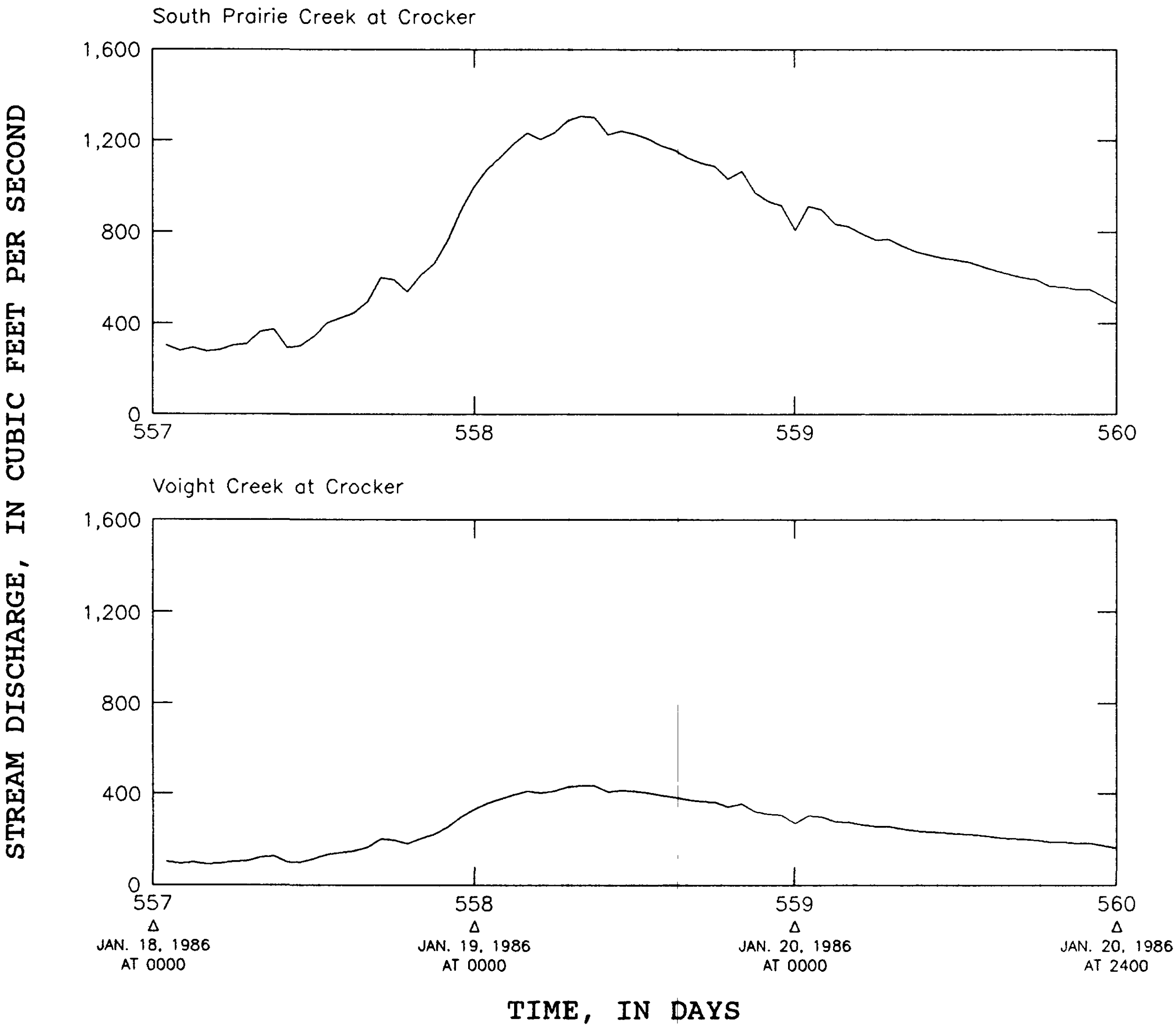


FIGURE B16.–Stream discharge in tributaries of the Carbon River during a storm from January 18 to 20, 1986.

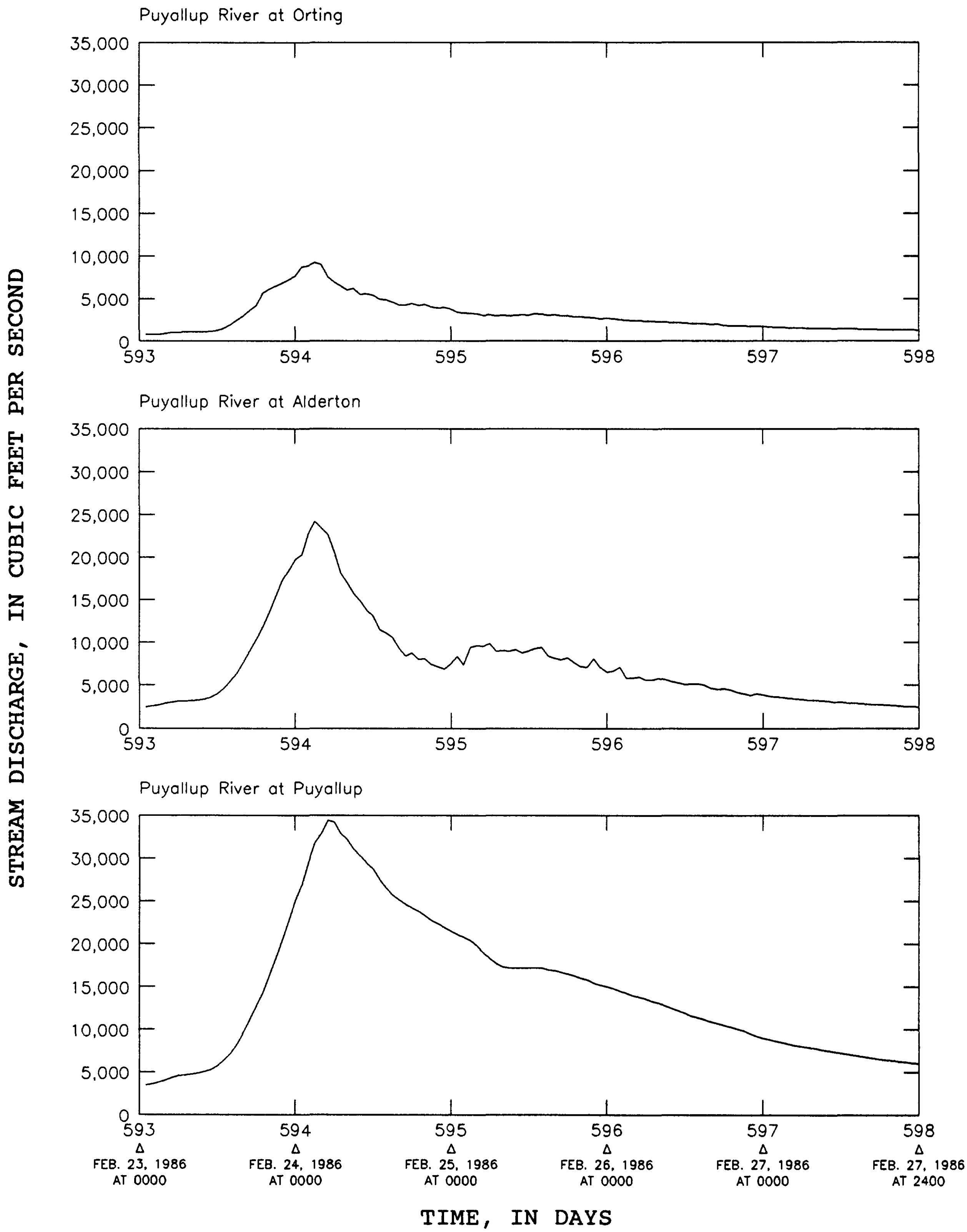


FIGURE B17.--Stream discharge in the Puyallup River during a storm from February 23 to 27, 1986.

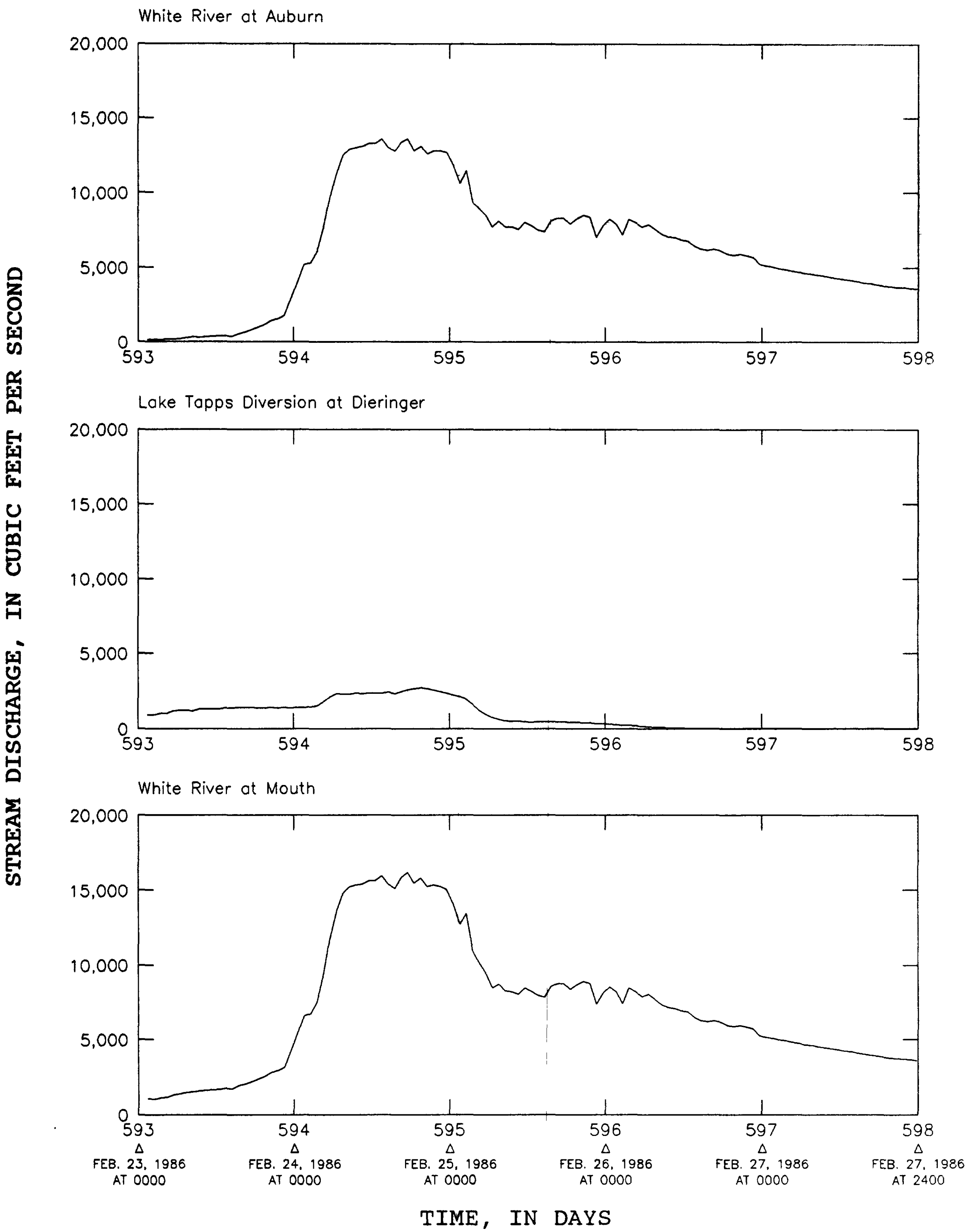


FIGURE B18.--Stream discharge in the White River and tributary during a storm from February 23 to 27, 1986.

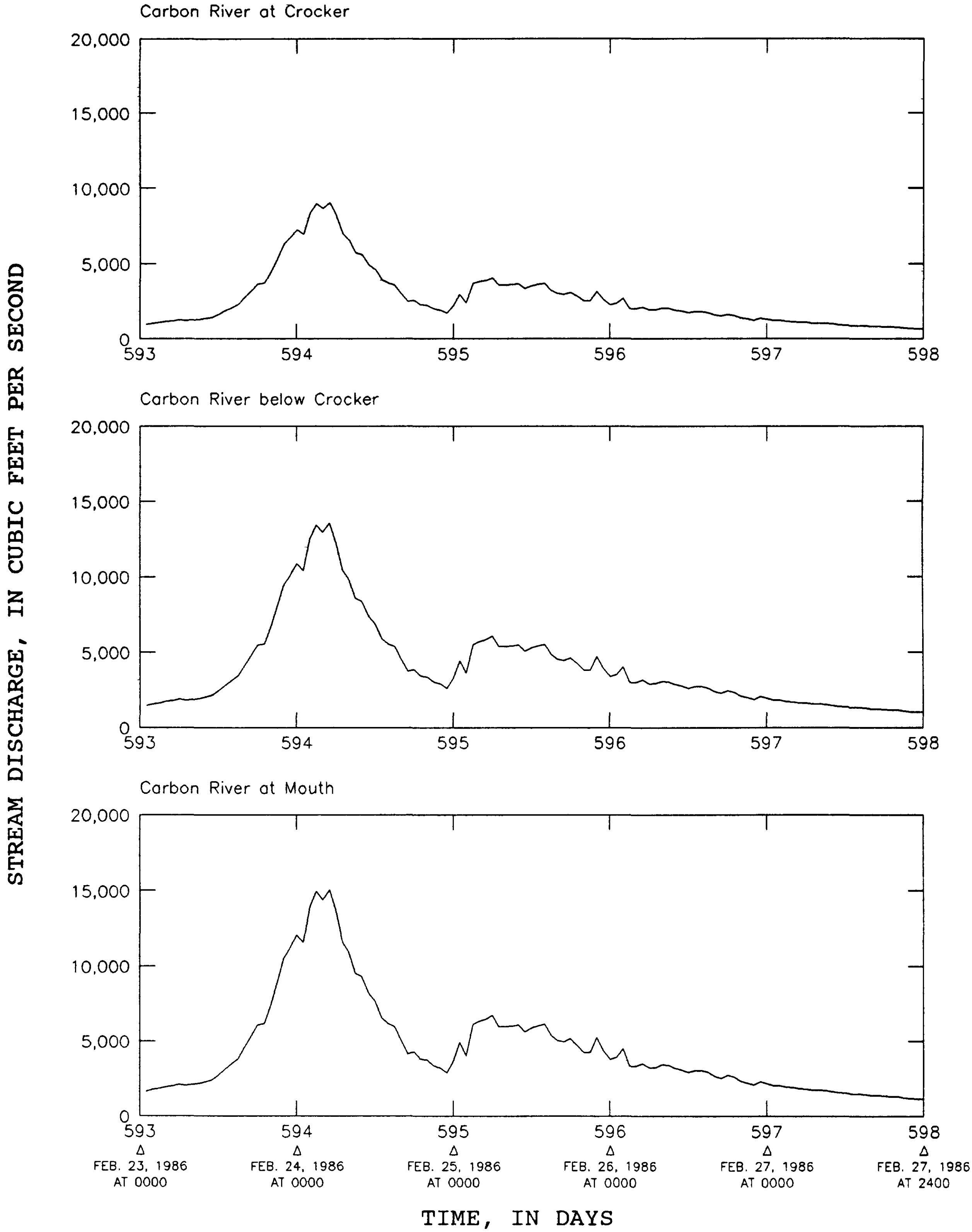


FIGURE B19.--Stream discharge in the Carbon River during a storm from February 23 to 27, 1986.

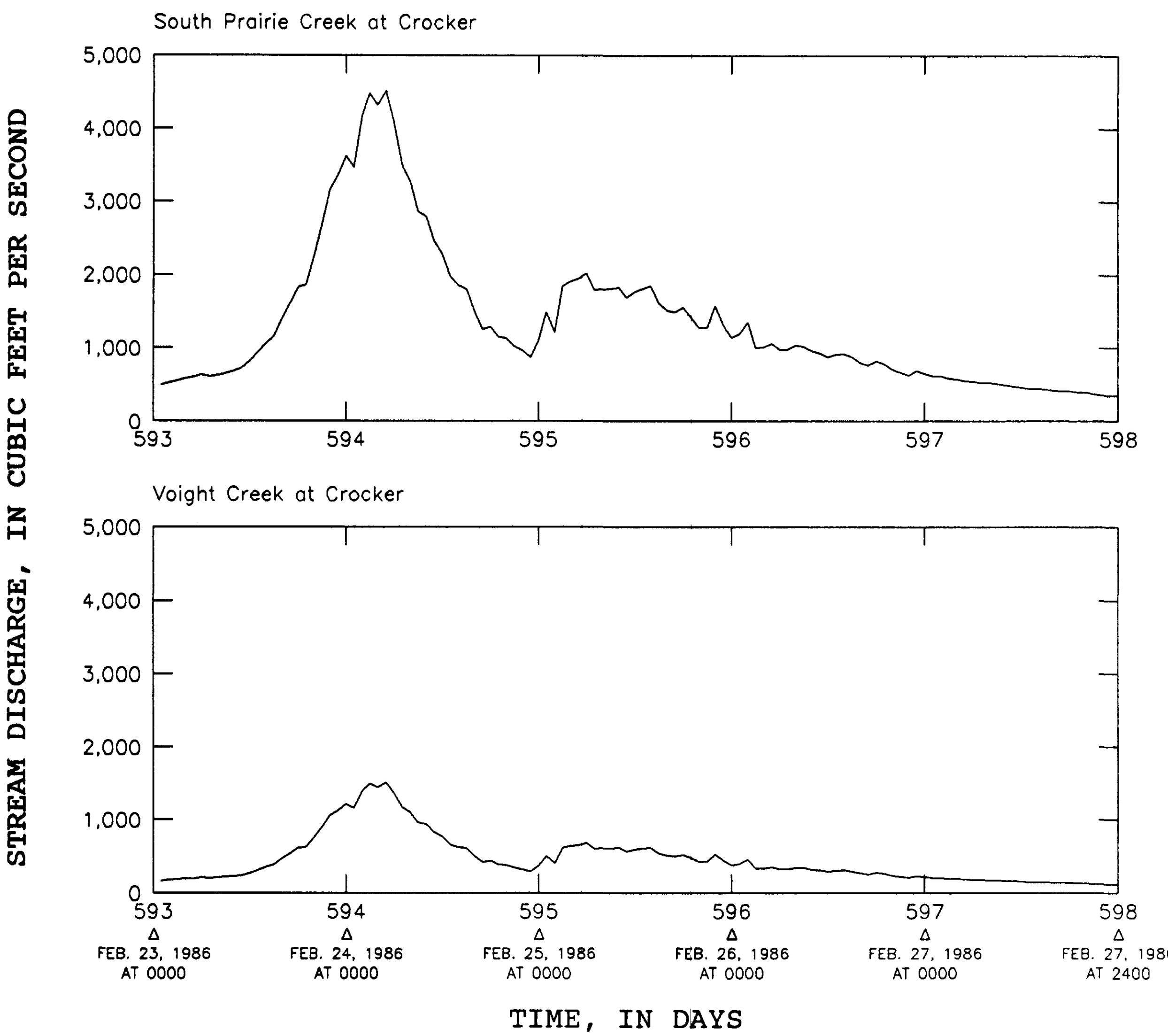


FIGURE B20.–Stream discharge in tributaries of the Carbon River during a storm from February 23 to 27, 1986.

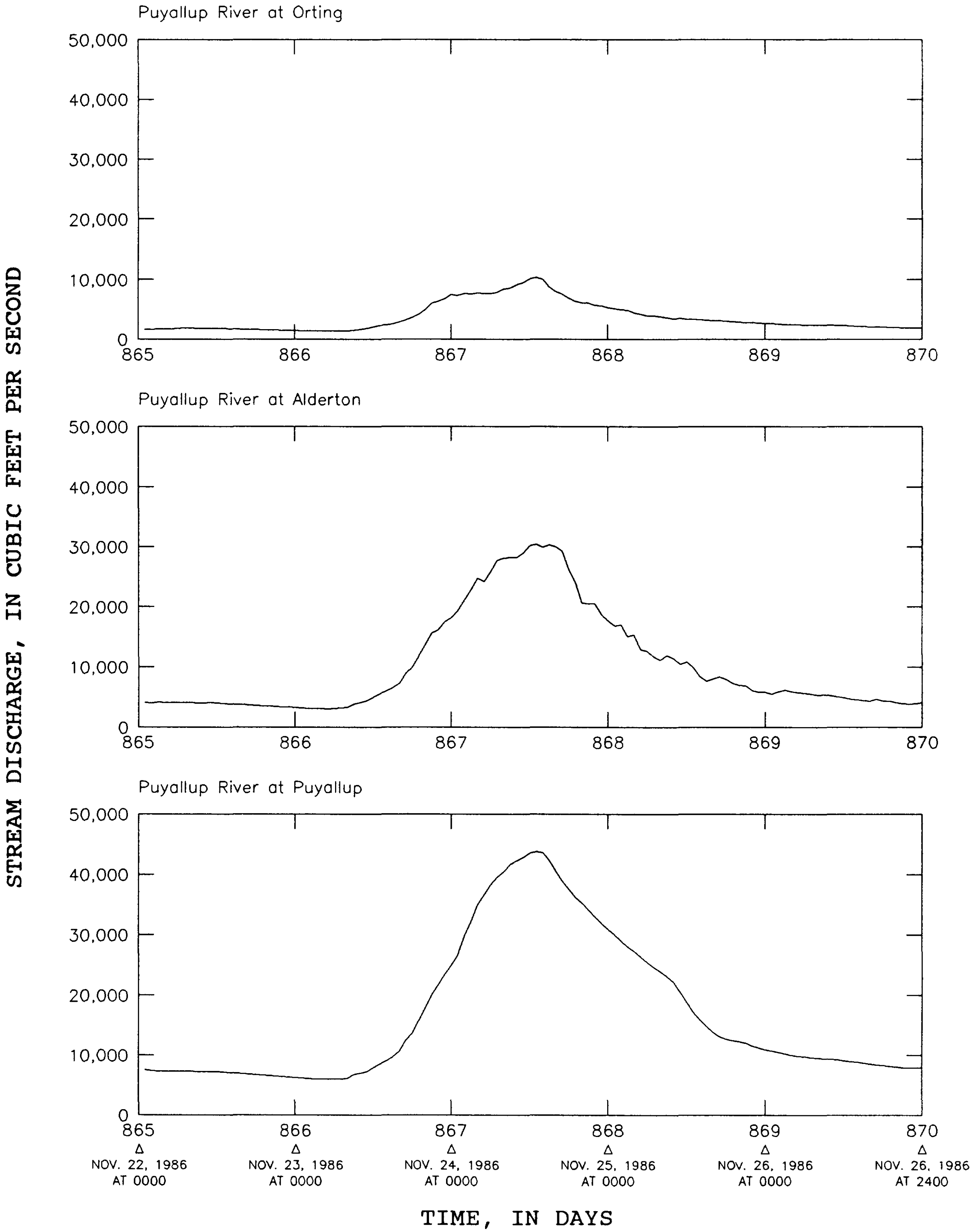


FIGURE B21.–Stream discharge in the Puyallup River during a storm from November 22 to 26, 1986.

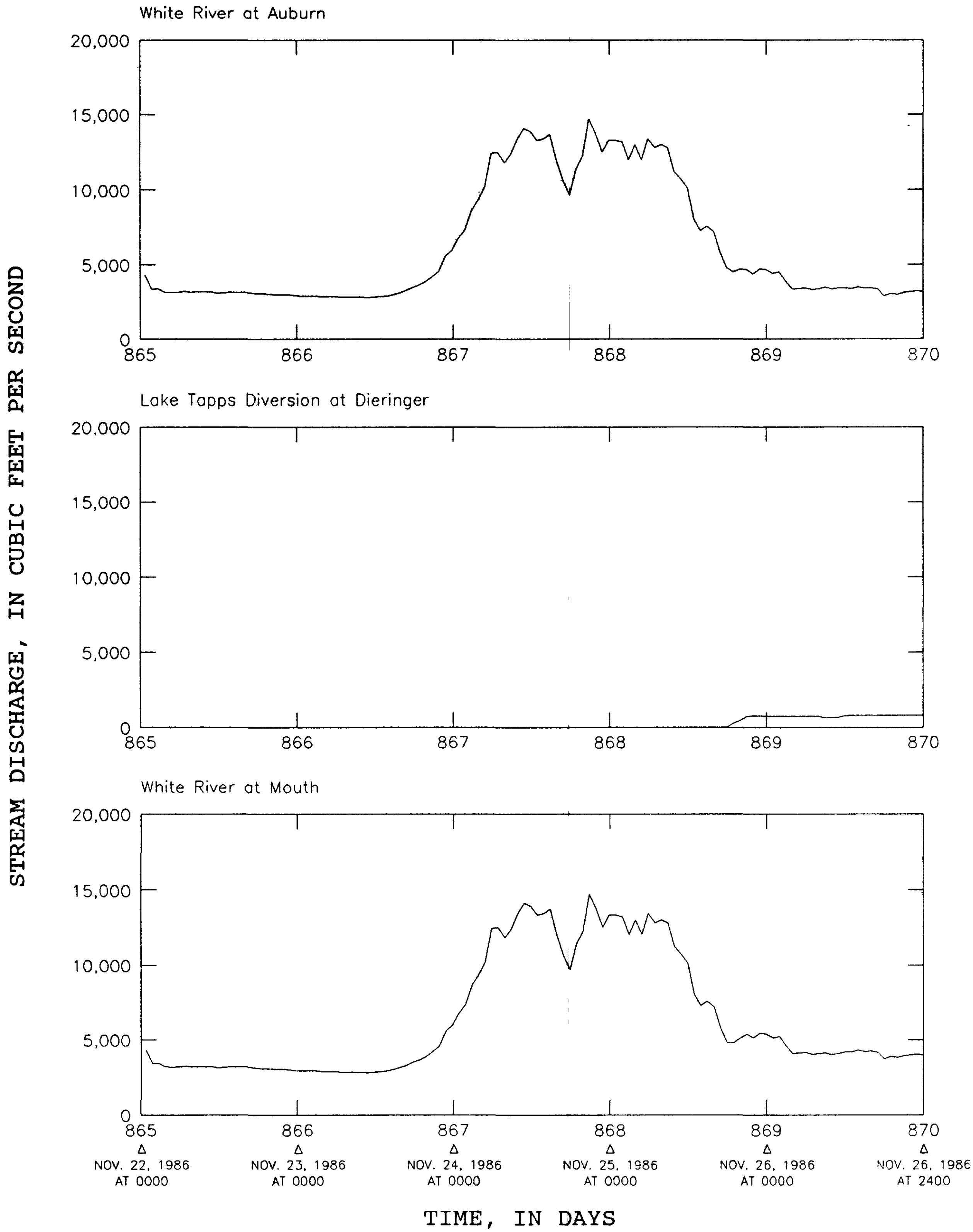


FIGURE B22.–Stream discharge in the White River and tributary during a storm from November 22 to 26, 1986.

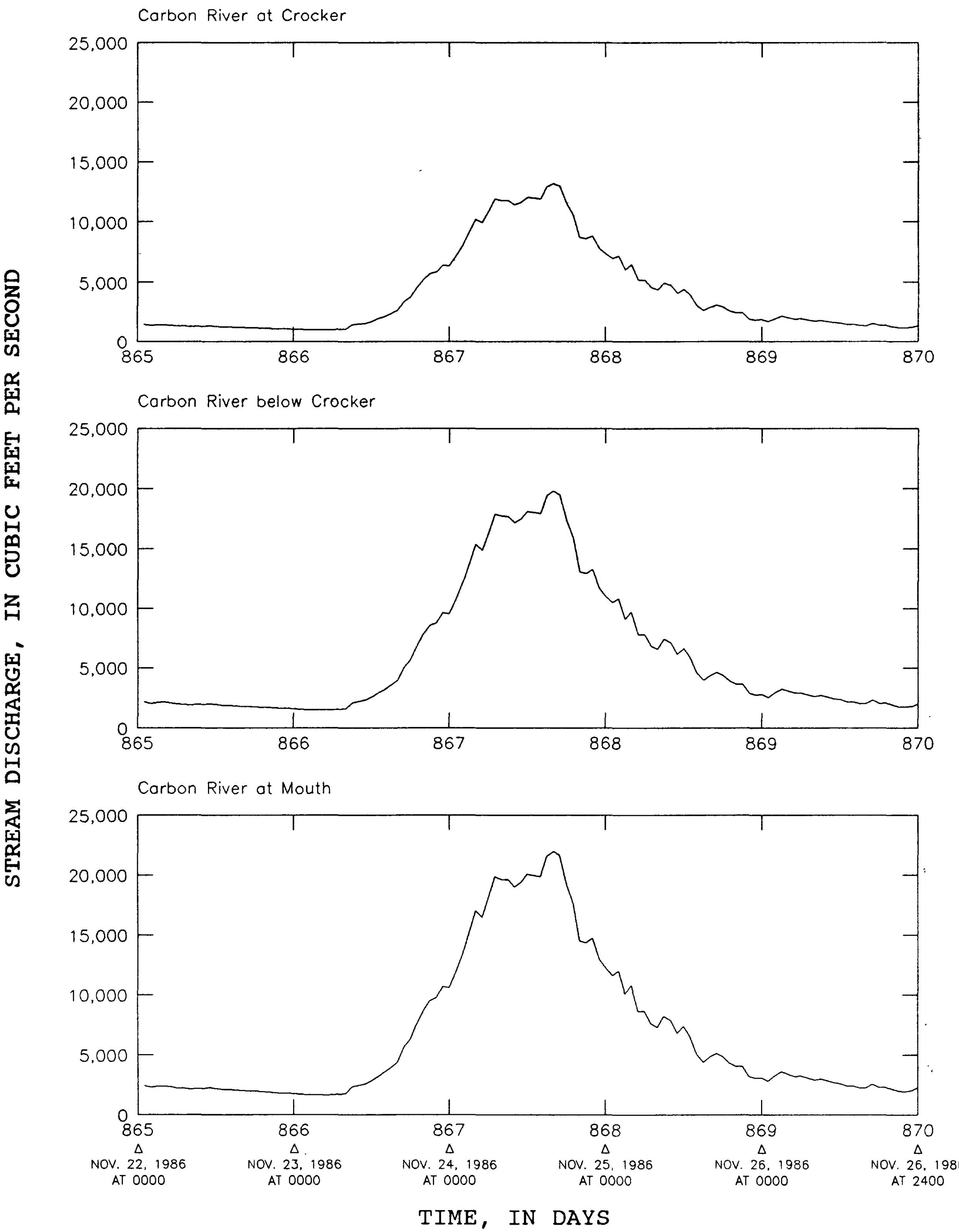


FIGURE B23.--Stream discharge in the Carbon River during a storm from November 22 to 26, 1986.

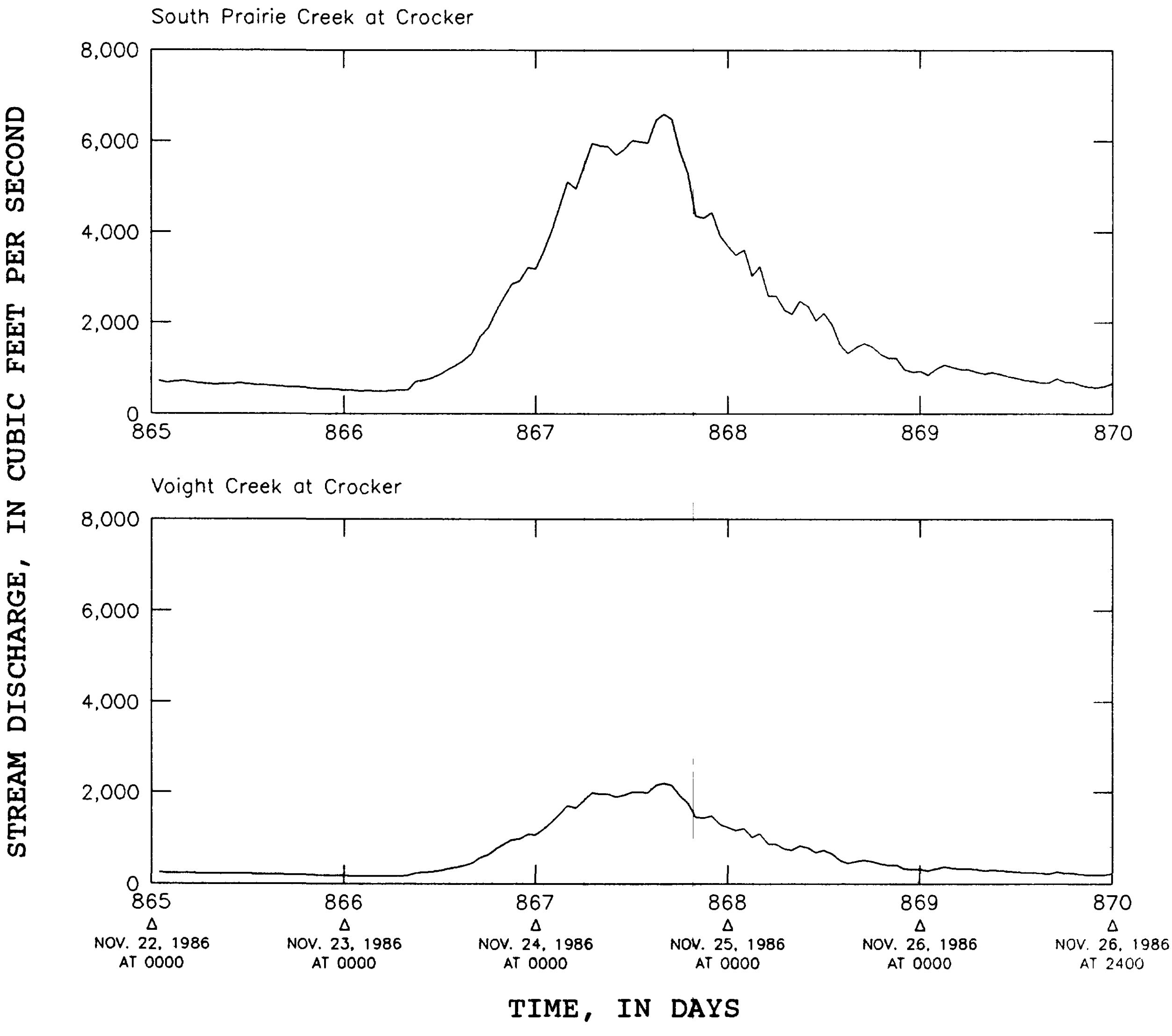


FIGURE B24.--Stream discharge in tributaries of the Carbon River during a storm from November 22 to 26, 1986.

APPENDIX C: MODIFICATIONS TO HEC-6 SUBROUTINES

The computer program HEC-6 (U.S. Army Corps of Engineers, 1977) was modified for this study. A detailed comparison follows showing places in the FORTRAN source code where changes occur. In each case, a section of the original code is followed by the code as used in this study. In general terms, changes can be described as follows:

1. The original code used an equilibrium-depth concept to define the armor layer. Deposition and scour modeled with this definition of the armor layer in place did not match surveyed bed-elevation changes. Throughout most of the river system, neither deposition nor scour would occur, despite data showing more dynamic bed conditions. It was felt that the equilibrium-depth concept and the equations of the sediment transport equation worked against each other. The equilibrium depth was replaced by defining the armor layer thickness as eight times the smallest nonmoving particle size. This size was computed by the sediment transport equation, and varied spatially and temporally during the run (Bennett and Nordin, 1977; Karim and others, 1983). This definition has the property of defining an armor layer thickness in terms of the present state of the physics of the river, rather than a future state the river is seeking. In addition, the sediment transport equation is an integral part of the definition.

2. In the original code, a surface-area-exposed factor was involved in the equilibrium-depth definition of the armor layer. The factor referred to the fraction of surface area not taken up by material too large to move. Evaluation of the factor in the program involved the evaluation of the equilibrium depth itself, which in turn depended on the Manning, Strickler, and Einstein's equations. It also was modified by Gessler's probabilistic statement of the stability of the armor layer. The surface-area-exposed factor was used to reduce the potential sediment discharge of all moving grain sizes. This reduction meant that potential sediment discharge, beyond that which was just sufficient to pass the incoming sediment discharge, was reduced for all moving grain sizes by a factor equal to the square root of the surface area exposed factor. Since the equilibrium-depth concept was no longer used in defining the armor layer, the surface-area-exposed factor was no longer needed. Again it was felt that the concepts involved in the definition of this factor were working against one another in the program. The reduction of potential sediment discharge for all moving sediment sizes by application of the same factor also did not seem desirable, based on data or theory. The surface-area-exposed factor was set to unity throughout (Karim and others, 1983). The movement or non-movement of individual size classes is now defined by the sediment transport equation itself.

3. An additional intermediate layer, the inactive deposition layer, was introduced between the active and inactive layers (Bennett and Nordin, 1977). All deposited material beyond the thickness of the armor layer is placed in the inactive deposition layer. This layer is scoured first if re-entrainment occurs at higher flows. This provides some additional buffered armoring above the fine material in the original bed material, since the finer fractions are, in general, swept farther downstream and not deposited in this layer. A better fit to the data is obtained with the inclusion of this layer. The layer provides the type of interaction between deposited and subsequently re-entrained volumes that one would expect.

4. Gravel mining was assumed to take place sequentially through the active, inactive deposition, and inactive layers. This replaced proportional removal from the active and inactive layers. This seemed to fit the natural sequence of gravel removal.

5. An extra sand class was used for modeling silt. This replaced a special silt class that lacked scour and resuspension capabilities.

6. Three extra classes were added for larger particles in the small cobble, large cobble, and small boulder sizes. These extra classes were necessary because of the steep slopes in the upstream reaches of the rivers of this study, especially the Carbon River. This coarse material provided material for armoring the bed. Some movement of these size classes, at least of the small cobble size, did occur during storms.

7. Yang's gravel coefficients (Yang, 1984) were used for gravel and coarser material. The coefficients are based on sediment data in the gravel size range, and are more appropriate for coarser material.

8. The program was modified to allow sediment hydrograph tributary inputs from the Carbon and White Rivers during the Puyallup River run. The hydrographs replaced rating tables of sediment discharge as a function of water discharge. Although the rating tables produced sediment discharges approximating outflow from the Carbon and White Rivers, a unique correspondence between water and sediment discharges did not exist. The lack of a one-to-one relation resulted in inaccuracy, and required redefinition of the rating tables for any modification of the tributary models. The inclusion of the exact sediment hydrograph from the tributary runs provided the best information on sediment discharge that was available from those runs. The use of the tributary hydrographs also simplified the interplay of the tributary and Puyallup model runs.

9. The subroutine SRMOD5 was split to allow compilation on microcomputers. As it was, the subroutine overflowed module size limitations within the FORTRAN compilers on the machines tried.

10. Printed output was modified. Statements were added to integrate sediment discharges, aggradation, and degradation in time, by size groups. These accumulated quantities, as well as active and active plus inactive size distributions, were available for printing when requested. This additional information was needed in analyzing what was taking place on the river system.

11. Input data on the Puyallup River model was modified to raise the entire river uniformly by 100 feet. Although not a modification of the computer program, this change was needed because the Puyallup River ends in Commencement Bay with streambed elevations below sea level. These negative elevations resulted in incorrect results apparently due to an incorrect cross-sectional area evaluation.

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OK, CMPF DUBOY.ORG DUBOY.F77
 [CMPF 19.4.4]

 A13            COMMON /FALLVE/  CL, H(10),ACGR                              4525
 CHANGED TO
 B13       C.... INCREASE THE DIMENSION OF H FROM 10 TO 24.
 B14            COMMON /FALLVE/  CL, H(-7:16),ACGR

 COMPARISON FINISHED.
 1 DISCREPANCY FOUND.
```

```
OK, CMPF ELMOD7.ORG ELMOD7.F77
 [CMPF 19.4.4]

 A23            COMMON /FALLVE/  CL,H(10),ACGR                               3060
 CHANGED TO
 B23       C.... INCREASE THE DIMENSION OF H FROM 10 TO 24.
 B24            COMMON /FALLVE/  CL,H(-7:16),ACGR

 COMPARISON FINISHED.
 1 DISCREPANCY FOUND.
```

```
OK, CMPF FALVEL.ORG FALVEL.F77
 [CMPF 19.4.4]

 A22            COMMON /FALLVE/  CL,   H(10),ACGR                            3529
 A23            DIMENSION CL(4)                                              3530
 A24            DIMENSION CD(10),RE(10),SD(15)                               3531
 CHANGED TO
 B22       C.... INCREASE THE DIMENSION OF H FROM 10 TO 24.
 B23            COMMON /FALLVE/  CL,   H(-7:16),ACGR
 B24            DIMENSION CL(4)                                              3530
 B25       C.... INCREASE THE DIMENSION OF CD AND RE FROM 10 TO 24.
 B26            DIMENSION CD(-7:16),RE(-7:16),SD(15)


 B84       C.... THIS IS APPARENTLY AN ITERATIVE SOLUTION OF FIGURE 2.1 PAGE 23
 B85       C.... OF SEDIMENTATION ENGINEERING.  THE LINE BELOW THE MAY 85 ERROR
 B86       C.... CORRECTION IS APPARENTLY SOME SORT OF INITIAL APPROXIMATION TO
 B87       C.... FALL VELOCITY H(I) FOR STARTUP.  THE LOOP "DO 2840" IS THE
 B88       C.... ITERATIVE SOLUTION OF THE FIGURE.  THE LOG10 OF THE DRAG
 B89       C.... COEFFICIENT HAS BEEN EXPANDED AS A FOURTH DEGREE POLYNOMIAL IN
 B90       C.... LOG10 OF THE REYNOLDS NUMBER.  THE EXPRESSION FOR VPRIME IN LINE
 B91       C.... 3612 IS EQUATION 2.3 PAGE 23 OF SEDIMENTATION ENGINEERING.  THERE
 B92       C.... IS NO EXPLICIT LIMITATION ON THIS PROCEDURE BECAUSE OF PARTICLE
 B93       C.... SIZE, SO IT SHOULD WORK FOR THE EXTENSION TO COBBLES AND BOULDERS.
 INSERTED BEFORE
 A82            DO 2855 I=IASA,LASA                                          3585
```

```
COMPARISON FINISHED.
2 DISCREPANCIES FOUND.
```

```
OK, CMPF HEC6.ORG HEC6.F77
 [CMPF 19.4.4]

 A126            OPEN(11,STATUS='SCRATCH')
 A127            OPEN(12,STATUS='SCRATCH')
 A128            OPEN(13,STATUS='SCRATCH')
 A129            OPEN(14,STATUS='SCRATCH')
 CHANGED TO
 B126            OPEN(11,FORM='UNFORMATTED')
 B127            OPEN(12,FORM='UNFORMATTED')
 B128            OPEN(13,FORM='UNFORMATTED')
 B129            OPEN(14,FORM='UNFORMATTED')


 A139            OPEN(7,STATUS='SCRATCH')
 A140            OPEN(8,STATUS='SCRATCH')
 A141            OPEN(9,STATUS='SCRATCH')
 A142            OPEN(95,STATUS='SCRATCH')
 CHANGED TO
 B139      C.... THE STATEMENTS TO OPEN INPUT AND OUTPUT FILES ARE NEEDED.
 B140            OPEN(IN,FILE='HEC6.IN')
 B141            OPEN(LP,FILE='HEC6.OUT')
 B142            OPEN(7)
 B143            OPEN(8)
 B144            OPEN(9)
 B145            OPEN(95,FORM='UNFORMATTED')
 B146      C.... OPEN FILES FOR TRANSFER OF SEDIMENT DISCHARGE HYDROGRAPHS FROM
 B147      C.... TRIBUTARY RUNS ON THE CARBON AND WHITE RIVERS, TO THE PUYALLUP
 B148      C.... RIVER RUN.
 B149            OPEN(77,FILE='SEDHYD.OUT',FORM='UNFORMATTED')
 B150            OPEN(78,FILE='SEDHYD.WHI',FORM='UNFORMATTED')
 B151            OPEN(79,FILE='SEDHYD.CAR',FORM='UNFORMATTED')


 A248            ALER=.05                                                  1154
 CHANGED TO
 B257      C.... CHANGE ALLOWABLE ERROR FROM .05 TO .005
 B258            ALER=.005


 A1110           IF(ABS(EMB).LT.0.0001)EMB=YMN-10
 CHANGED TO
 B1120     C.... INCREASE DEPTH OF INACTIVE LAYER TO 30 FEET.
 B1121     C     IF(ABS(EMB).LT.0.0001)EMB=YMN-10
 B1122           IF(ABS(EMB).LT.0.0001)EMB=YMN-30.

 COMPARISON FINISHED.
 4 DISCREPANCIES FOUND.
```

```
OK, CMPF SPOWER.ORG SPOWER.F77
 [CMPF 19.4.4]

 A17            COMMON /FALLVE/  CL, H(10),ACGR                                4460
 CHANGED TO
 B17      C.... INCREASE THE DIMENSION OF H FROM 10 TO 24.
 B18            COMMON /FALLVE/  CL, H(-7:16),ACGR


 B30            CONC = 0.
 INSERTED BEFORE
 A29      C     SRNO= SHEAR VELOCITY REYNOLDS NO.                              4471


 B39      C     FVRNL=FALL VELOCITY REYNOLDS NUMBER WITH LOG TRANSFORM(WD/NU)
 B40            FVRNL= ALOG10(H(J)*SD(I)/XNU)
 B41      C     DSVL= DIMENSIONLESS SHEAR/FALL VELOCITY WITH LOG TRANSFORM(U*/W)
 B42            DSVL=ALOG10(USTR/H(J))
 INSERTED BEFORE
 A37            ARGU=SLO*((VEL/H(J))-VCRF)                                     4479


 A41      C     FVRNL=FALL VELOCITY REYNOLDS NUMBER WITH LOG TRANSFORM(WD/NU)    4483
 A42            FVRNL= ALOG10(H(J)*SD(I)/XNU)                                  4484
 A43      C     DSVL= DIMENSIONLESS SHEAR/FALL VELOCITY WITH LOG TRANSFORM(U*/W) 4485
 A44            DSVL=ALOG10(USTR/H(J))                                         4486
 A45      C     POTENTIAL TRANSPORT CAPACITY FOR EACH GRAIN-SIZE               4487
 A46            CTL=       (5.435-0.286*FVRNL-0.457*DSVL+(1.799-0.409*FVRNL-   4488
 A47           .  0.314*DSVL)*ESPL)                                            4489
 CHANGED TO
 B47      C     POTENTIAL TRANSPORT CAPACITY FOR EACH GRAIN-SIZE               4487
 B48            IF(SD(I).LT.0.006562)THEN
 B49               CTL=       (5.435-0.286*FVRNL-0.457*DSVL+(1.799-0.409*FVRNL-
 B50           .      0.314*DSVL)*ESPL)
 B51            ELSE
 B52      C.... ADD YANG'S NEW COEFFICIENTS FOR GRAVEL.
 B53               CTL=       (6.681-0.633*FVRNL-4.816*DSVL+(2.784-0.305*FVRNL-
 B54           .      0.282*DSVL)*ESPL)
 B55            END IF

 COMPARISON FINISHED.
 4 DISCREPANCIES FOUND.
```

```
OK, CMPF SRMOD5.ORG SRMOD5_SRMO52_CONCAT
 [CMPF 19.4.4]

 B58      C.... ARRAY FOR VARIABLE ARMOR LAYER THICKNESS.
 B59            SAVE NONMOV
 B60            DIMENSION NONMOV(150)
19NSERTED BEFORE
 A58            COMMON TOG,TRD,TWO                                             4630
```

```
A90           DIMENSION DYO(150),GPS(450),WSP(150),TWP(150)                    4655
CHANGED TO
B93       C.... SHIFT ARRAY GPS TO COMMON, SINCE NEEDED IN THE SECOND MODULE
B94       C.... SRMO52.
B95       C     DIMENSION DYO(150),GPS(450),WSP(150),TWP(150)                  4655
B96             DIMENSION DYO(150),WSP(150),TWP(150)


B100      C.... ADD VARIABLES FOR INTEGRATING MASS CONSERVATION IN TIME, BY CROSS
B101      C.... SECTION, BY SEDIMENT SIZE GROUPING.
B102            COMMON/GROUPS/XSSILT(150),XSSAND(150),XSGRAV(150),XSCOBB(150),
B103           * XSBOUL(150),TSSILT(150),TSSAND(150),TSGRAV(150),TSCOBB(150),
B104           * TSBOUL(150),
B105      C.... ADD VARIABLES FOR GROUPING SEDIMENT TRANSPORT.
B106           * QSSILT(150),QSSAND(150),QSGRAV(150),QSCOBB(150),
B107           * QSBOUL(150),
B108      C.... ADD VARIABLES FOR BED MATERIAL AND ARMOR LAYER COMPOSITION.
B109           * BMSILT(150),BMSAND(150),BMGRAV(150),BMCOBB(150),
B110           * BMBOUL(150),ALSILT(150),ALSAND(150),ALGRAV(150),ALCOBB(150),
B111           * ALBOUL(150),
B112      C.... ADD ARRAY GPS BECAUSE IT IS NEEDED IN SRMO52.
B113           * GPS(450),
B114      C.... ADD ARRAY GDID FOR INACTIVE DEPOSITION LAYER, AND VSFID FOR TOTAL
B115      C.... WEIGHT IN THE LAYER.
B116           * GDID(15,150),VSFID(150)
B117      C.... FLAG TO INITIALIZE ARRAYS FOR INTEGRATION.
B118            DATA IXSFL/0/
INSERTED BEFORE
A94             DATA PI/15*0.0/                                                4659


A127            DATA GPS/450*0./
CHANGED TO
B152      C.... MUST INITIALIZE GPS ALONG WITH INTEGRATION ARRAYS.  A DATA
B153      C.... STATEMENT CANNOT BE USED IF GPS IS IN COMMON.
B154      C     DATA GPS/450*0./
B155      C.... INITIALIZE ARRAYS FOR INTEGRATION.
B156            IF(IXSFL.EQ.0)THEN
B157               IXSFL = 1
B158               DO 5051 I=1,NR
B159               XSSILT(I) = 0.
B160               XSSAND(I) = 0.
B161               XSGRAV(I) = 0.
B162               XSCOBB(I) = 0.
B163               XSBOUL(I) = 0.
B164               TSSILT(I) = 0.
B165               TSSAND(I) = 0.
B166               TSGRAV(I) = 0.
B167               TSCOBB(I) = 0.
B168               TSBOUL(I) = 0.
B169      C....    INITIALIZE FIRST NONMOVING SIZE TO SILT GROUP SIZE
B170      C....    = 0.00391 MM.
B171               NONMOV(I) = 1
B172      C....    INITIALIZE INACTIVE DEPOSITION LAYER.
```

```
B173              DO 5049 IGRP=IGS,LGS
B174              GDID(IGRP,I) = 0.
B175       5049   CONTINUE
B176              VSFID(I) = 0.
B177       5051   CONTINUE
B178      C....   INITIALIZE GPS HERE INSTEAD OF BY A DATA STATEMENT, SINCE IT
B179      C....   IS NOW IN COMMON.
B180              DO 5052 I=1,450
B181              GPS(I) = 0.
B182       5052   CONTINUE
B183           END IF
B184      C.... INITIALIZE SGC TO ZERO -- IT IS NOT USED IN THE MODULE, BUT IS
B185      C.... PRINTED OUT AT LINE 5317.
B186            SGC = 0.


A147            BSAE=CAR(5)                                                  4704
CHANGED TO
B206      C.... DO NOT REDUCE TRANSPORT CAPACITY.
B207      C     BSAE=CAR(5)                                                  4704
B208            BSAE = 1.


A152            HVT = SD(LGS)
CHANGED TO
B213      C.... MAKE ARMOR LAYER THICKNESS EQUAL TO 8 TIMES THE FIRST
B214      C.... NONMOVING PARTICLE SIZE, BUT AT LEAST 8 TIMES SILT GROUP
B215      C.... SIZE = 8 * 0.00391 MM = 0.031 MM.
B216      C.... CAUTION: DO NOT USE THE ELEVATION EMB OF MODEL BOTTOM PARAMETER
B217      C.... ON THE H CARD.  THE MODEL WILL NOT WORK PROPERLY IF THE ACTIVE
B218      C.... LAYER IS ALLOWED TO DISAPPEAR.  INSTEAD, MODEL SUCH SITUATIONS
B219      C.... BY USING LARGE SIZES IN THE BED MATERIAL COMPOSITION IN ORDER TO
B220      C.... RESTRICT SCOUR.  THE STATEMENT MUST BE MOVED TO INSIDE THE
B221      C.... DO 5875 LOOP.
B222      C     HVT = SD(LGS)
B223      C.... HVT = 8. * MAX(SD(1),SD(NONMOV(IR)))


B350      C.... MAKE ARMOR LAYER THICKNESS EQUAL TO 8 TIMES THE FIRST
B351      C.... NONMOVING PARTICLE SIZE, BUT AT LEAST 8 TIMES SILT GROUP
B352      C.... SIZE = 8 * 0.00391 MM = 0.031 MM.
B353      C.... CAUTION: DO NOT USE THE ELEVATION EMB OF MODEL BOTTOM PARAMETER
B354      C.... ON THE H CARD.  THE MODEL WILL NOT WORK PROPERLY IF THE ACTIVE
B355      C.... LAYER IS ALLOWED TO DISAPPEAR.  INSTEAD, MODEL SUCH SITUATIONS
B356      C.... BY USING LARGE SIZES IN THE BED MATERIAL COMPOSITION IN ORDER TO
B357      C.... RESTRICT SCOUR.
B358      C     HVT = SD(LGS)
B359            HVT = 8. * MAX(SD(1),SD(NONMOV(IR)))
INSERTED BEFORE
A279            LPR=0                                                        4831


A302            CALL INLOAD (QX,NAQT,LQT,NGS,GST,CAR)                        4854
CHANGED TO
```

```
B383      C.... USE SEDIMENT HYDROGRAPHS FOR WHITE AND CARBON RIVERS AS
B384      C.... TRIBUTARIES TO THE PUYALLUP, BUT CONTINUE TO USE RATING TABLES
B385      C.... FOR THE TRIBUTARIES TO THE CARBON.
B386            IF(NR.LE.50)THEN
B387               CALL INLOAD (QX,NAQT,LQT,NGS,GST,CAR)
B388            ELSE
B389               IF(INTL.EQ.1)READ(78)(GST(I),I=1,NGS)
B390               IF(INTL.EQ.2)READ(79)(GST(I),I=1,NGS)
B391            END IF


B437      C.... FOR TRIBUTARY, INTEGRATE SILT, SAND, GRAVEL, COBBLES, AND
B438      C.... BOULDERS.
B439      C.... SILT:
B440            MAXXS = MIN(1,LGS)
B441            DO 8061 I=1,MAXXS
B442            TSSILT(IR) = TSSILT(IR) + GST(I)*DD(N)/(UWD*ACFT)
B443       8061 CONTINUE
B444      C.... SAND:
B445            MAXXS = MIN(6,LGS)
B446            DO 5221 I=2,MAXXS
B447            TSSAND(IR) = TSSAND(IR) + GST(I)*DD(N)/(UWD*ACFT)
B448       5221 CONTINUE
B449      C.... GRAVEL:
B450            MAXXS = MIN(11,LGS)
B451            DO 5222 I=7,MAXXS
B452            TSGRAV(IR) = TSGRAV(IR) + GST(I)*DD(N)/(UWD*ACFT)
B453       5222 CONTINUE
B454      C.... COBBLES:
B455            MAXXS = MIN(13,LGS)
B456            DO 5223 I=12,MAXXS
B457            TSCOBB(IR) = TSCOBB(IR) + GST(I)*DD(N)/(UWD*ACFT)
B458       5223 CONTINUE
B459      C.... BOULDERS:
B460            MAXXS = MIN(14,LGS)
B461            DO 5224 I=14,LGS
B462            TSBOUL(IR) = TSBOUL(IR) + GST(I)*DD(N)/(UWD*ACFT)
B463       5224 CONTINUE
INSERTED BEFORE
A348            IF(INTL.LE.0) GO TO 5225                                  4900


A434            VSFI=HVT*WMB*DIST*VSF*UWD                                 4978
A435            VSFA=GD(L5)+VSFI                                          4979
CHANGED TO
B550      C.... THE LENGTH HVT WAS ORIGINALLY THE LARGEST PARTICLE SIZE.  THE
B551      C.... ASSOCIATED WEIGHT WAS ADDED INTO THE TONS VSFA IN THE ACTIVE
B552      C.... LAYER AND THE TONS VSFI IN THE INACTIVE LAYER, WITH THE INTENT OF
B553      C.... ADDING A SMALL QUANTITY TO AVOID SOME NUMERICAL PROBLEMS.  SET
B554      C.... VSFH = TONS ASSOCIATED WITH A LAYER OF THICKNESS HVT, AND DO NOT
B555      C.... ADD THIS QUANTITY TO VSFA OR TO VSFI.  HERE HVT IS DEFINED TO BE A
B556      C.... MULTIPLE OF THE FIRST NONMOVING PARTICLE SIZE.
B557      C     VSFI=HVT*WMB*DIST*VSF*UWD                                 4978
B558            VSFH=HVT*WMB*DIST*VSF*UWD
```

```
B559      C      VSFA=GD(L5)+VSFI                                                   4979
B560             VSFA = GD(L5)
B561             VSFI = 0.


A445             IF(MTC.GT.0) WTMB=WTMB+CAR(K5)+GD(L5)                              4988
CHANGED TO
B571      C....  ADD WEIGHT OF INACTIVE DEPOSITION LAYER TO THE TOTAL WEIGHT OF
B572      C....  THE MOVABLE BED.
B573      C      IF(MTC.GT.0) WTMB=WTMB+CAR(K5)+GD(L5)                              4988
B574             IF(MTC.GT.0) WTMB=WTMB+CAR(K5)+VSFID(IR)+GD(L5)


A456             PI(1)=(CAR(KF+1)+GD(LF+1))/WTMB                                    4999
CHANGED TO
B585      C....  ADD THE WEIGHT OF THAT PORTION OF THE INACTIVE DEPOSITION LAYER
B586      C....  IN THIS SIZE CLASS.
B587      C      PI(1)=(CAR(KF+1)+GD(LF+1))/WTMB                                    4999
B588             PI(1)=(CAR(KF+1)+GDID(1,IR)+GD(LF+1))/WTMB


A465             PI(I)=(CAR(ISUB)+GD(JSUB))/WTMB                                    5006
CHANGED TO
B597      C....  ADD THE WEIGHT OF THAT PORTION OF THE INACTIVE DEPOSITION LAYER
B598      C....  IN THIS SIZE CLASS.
B599      C      PI(I)=(CAR(ISUB)+GD(JSUB))/WTMB                                    5006
B600             PI(I)=(CAR(ISUB)+GDID(I,IR)+GD(JSUB))/WTMB


B610             IF(KSW(12).GT.0)THEN
B611      C....     GROUP BED MATERIAL INTO SILT, SAND, GRAVEL, COBBLES, AND
B612      C....     BOULDERS.
B613      C....     SILT:
B614                MAXXS = MIN(1,LGS)
B615                BMSILT(IR) = 0.
B616                DO 8071 I=1,MAXXS
B617                BMSILT(IR) = BMSILT(IR) + PI(I)
B618       8071     CONTINUE
B619                BMSILT(IR) = BMSILT(IR) * 100.
B620      C....     SAND:
B621                MAXXS = MIN(6,LGS)
B622                BMSAND(IR) = 0.
B623                DO 5276 I=2,MAXXS
B624                BMSAND(IR) = BMSAND(IR) + PI(I)
B625       5276     CONTINUE
B626                BMSAND(IR) = BMSAND(IR) * 100.
B627      C....     GRAVEL:
B628                MAXXS = MIN(11,LGS)
B629                BMGRAV(IR) = 0.
B630                DO 5277 I=7,MAXXS
B631                BMGRAV(IR) = BMGRAV(IR) + PI(I)
B632       5277     CONTINUE
B633                BMGRAV(IR) = BMGRAV(IR) * 100.
B634      C....     COBBLES:
```

```
B635              MAXXS = MIN(13,LGS)
B636              BMCOBB(IR) = 0.
B637              DO 5278 I=12,MAXXS
B638              BMCOBB(IR) = BMCOBB(IR) + PI(I)
B639        5278  CONTINUE
B640              BMCOBB(IR) = BMCOBB(IR) * 100.
B641       C....  BOULDERS:
B642              MAXXS = MIN(14,LGS)
B643              BMBOUL(IR) = 0.
B644              DO 5279 I=14,LGS
B645              BMBOUL(IR) = BMBOUL(IR) + PI(I)
B646        5279  CONTINUE
B647              BMBOUL(IR) = BMBOUL(IR) * 100.
B648            END IF
INSERTED BEFORE
A475            IF(KSW(13).LE.0) GO TO 5295                                 5016


A622            VSE=HVT                                                     5134
CHANGED TO
B796       C.... LENGTH HVT (ORIGINALLY THE LARGEST PARTICLE SIZE) WAS USED ON THE
B797       C.... RIGHT SIDE OF LINE 5134 WITH THE INTENT OF REPLACING 0 WITH A
B798       C.... SMALL QUANTITY TO AVOID SOME NUMERICAL PROBLEMS.  REPLACE WITH 0.
B799       C.... I WILL NOT ALLOW WTMB TO BE ZERO ANYWAY.
B800       C     VSE=HVT                                                     5134
B801             VSE = 0.


A643             SAE=GD(ISUB)                                                5155
CHANGED TO
B822       C.... FORCE SAE TO BE 1.
B823       C     SAE=GD(ISUB)                                                5155
B824             SAE = 1.


A716             SAE=1.-BSF*(1.-SAE)/STC                                     5228
A717       C     SAE IS A FRACTION AND SHOULD ALWAYS BE BETWEEN 0 AND 1      5229
A718       C                          BRANCH TO  5415 FROM  5385.02  5410.03 5230
A719        5415 IF(SAE.LE.0.) SAE=.000001                                   5231
A720             IF(SAE.GT.1.) SAE=1.                                        5232
CHANGED TO
B897       C.... FORCE SAE TO BE 1.
B898       C     SAE=1.-BSF*(1.-SAE)/STC                                     5228
B899             SAE = 1.
B900       C     SAE IS A FRACTION AND SHOULD ALWAYS BE BETWEEN 0 AND 1      5229
B901       C`                         BRANCH TO  5415 FROM  5385.02  5410.03 5230
B902       C.... FORCE SAE TO BE 1.
B903       C5415 IF(SAE.LE.0.) SAE=.000001                                   5231
B904        5415 SAE = 1.
B905       C.... SAE HAS JUST BEEN FORCED TO 1.
B906       C     IF(SAE.GT.1.) SAE=1.                                        5232


A816             GD(L5)=0.                                                   5328
```

```
A817          DO 5480 I=IGS,LGS                                           5329
A818          ISUB=KF+I                                                   5330
A819          JSUB=LF+I                                                   5331
A820          CAR(ISUB)=CAR(ISUB)+GD(JSUB)                                5332
A821          GD(L5)=GD(L5)+SD(I)                                         5333
A822     C                             BRANCH TO  5480 FROM  5475.06      5334
A823      5480 GD(JSUB)=SD(I)                                             5335
A824          WSNI=WSNI+WSNA                                              5336
A825          CAR(K5)=WSNI                                                5337
A826          WSNA=0.                                                     5338
A827          GO TO 5550                                                  5339
CHANGED TO
B1002    C.... OMIT THE FOLLOWING SECTION ENTIRELY.  I AM NOT USING THE
B1003    C.... EQUILIBRIUM DEPTH.
B1004    C    GD(L5)=0.                                                   5328
B1005    C    DO 5480 I=IGS,LGS                                           5329
B1006    C    ISUB=KF+I                                                   5330
B1007    C    JSUB=LF+I                                                   5331
B1008    C    CAR(ISUB)=CAR(ISUB)+GD(JSUB)                                5332
B1009    C    GD(L5)=GD(L5)+SD(I)                                         5333
B1010    C                             BRANCH TO  5480 FROM  5475.06      5334
B1011    C5480 GD(JSUB)=SD(I)                                             5335
B1012    C    WSNI=WSNI+WSNA                                              5336
B1013    C    CAR(K5)=WSNI                                                5337
B1014    C    WSNA=0.                                                     5338
B1015    C    GO TO 5550                                                  5339


A852      5510 DSE=EXB-EBE                                                5364
A853          IF(DSE.LE.HVT) DSE=HVT+1.E-7                                5365
A854          VSE=VSF*DSE*WMB*DIST*UWD                                    5366
A855     C                                                                5367
A856     C    RE ASSIGN MATERIAL BETWEEN CAR AND GS-ARRAYS                5368
A857          CPV=VSE-VSFA                                                5369
A858          IF(CPV)5515,5550,5520                                       5370
A859      5515 RTO=CPV/VSFA                                               5371
A860          GO TO 5525                                                  5372
A861     C                             BRANCH TO  5520 FROM  5510.04      5373
A882      5520 IF(VSFI.LT.CPV) CPV=VSFI                                   5374
A863          RTO=CPV/VSFI                                                5375
A864     C                             BRANCH TO  5525 FROM  5515.01      5376
A865      5525 IF(KSW(14).GT.0) WRITE (LP,5530) RTO,CPV,VSFA,VSFI,DSE     5377
A866      5530 FORMAT (  22H RTO,CPV,VSFA,VSFI,DSE ,29X,5E15.8)           5378
A867          DO 5545 I=IGS,LGS                                           5379
A868          IF(CPV.GE.0.) GO TO 5535                                    5380
A869          ISUB=LF+I                                                   5381
A870          TMP=RTO*GD(ISUB)                                            5382
A871          GO TO 5540                                                  5383
A872     C                             BRANCH TO  5535 FROM  5530.02      5384
A873      5535 ISUB=KF+I                                                  5385
A874          TMP=RTO*CAR(ISUB)                                           5386
A875     C                             BRANCH TO  5540 FROM  5530.05      5387
A876      5540 ISUB=LF+I                                                  5388
A877          GD(ISUB)=GD(ISUB)+TMP                                       5389
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```
A878          ISUB=KF+I                                                     5390
A879          CAR(ISUB)=CAR(ISUB)-TMP                                       5391
A880          GD(L5)=GD(L5)+TMP                                             5392
A881          CAR(K5)=CAR(K5)-TMP                                           5393
A882     C                               BRANCH TO  5545 FROM  5530.01      5394
A883      5545 CONTINUE                                                     5395
A884     C                               BRANCH TO  5550 FROM  5480.04  5510.04 5396
A885      5550 IF(SAE.LT.1.E-7) SAE=1.E-7                                   5397
A886          VSE=(HVT+GD(L5))/SAE                                          5398
CHANGED TO
B1040    C.... DEFINE THE ACTIVE LAYER THICKNESS IN TERMS OF DEPTH HVT, INSTEAD
B1041    C.... OF USING THE EQUILIBRIUM DEPTH CONCEPT.  HVT IS IN TURN A MULTIPLE
B1042    C.... OF THE FIRST NONMOVING PARTICLE SIZE.
B1043    C5510 DSE=EXB-EBE                                                  5364
B1044     5510 DSE = HVT
B1045    C.... NO NEED FOR THE 1.E-7.
B1046    C     IF(DSE.LE.HVT) DSE=HVT+1.E-7                                 5365
B1047    C     IF(DSE.LE.HVT)DSE = HVT
B1048          VSE=VSF*DSE*WMB*DIST*UWD                                     5366
B1049    C                                                                  5367
B1050    C.... REWRITE THE FOLLOWING SECTION TO ALLOW FOR A THIRD LAYER -- THE
B1051    C.... INACTIVE DEPOSITION LAYER.
B1052    C     RE ASSIGN MATERIAL BETWEEN CAR AND GS-ARRAYS                 5368
B1053    C     CPV=VSE-VSFA                                                 5369
B1054    C     IF(CPV)5515,5550,5520                                        5370
B1055    C5515 RTO=CPV/VSFA                                                 5371
B1056    C     GO TO 5525                                                   5372
B1057    C                               BRANCH TO  5520 FROM  5510.04      5373
B1058    C5520 IF(VSFI.LT.CPV) CPV=VSFI                                     5374
B1059    C     RTO=CPV/VSFI                                                 5375
B1060    C                               BRANCH TO  5525 FROM  5515.01      5376
B1061    C5525 IF(KSW(14).GT.0) WRITE (LP,5530) RTO,CPV,VSFA,VSFI,DSE       5377
B1062    C5530 FORMAT (  22H RTO,CPV,VSFA,VSFI,DSE ,29X,5E15.8)             5378
B1063    C     DO 5545 I=IGS,LGS                                            5379
B1064    C     IF(CPV.GE.0.) GO TO 5535                                     5380
B1065    C     ISUB=LF+I                                                    5381
B1066    C     TMP=RTO*GD(ISUB)                                             5382
B1067    C     GO TO 5540                                                   5383
B1068    C                               BRANCH TO  5535 FROM  5530.02      5384
B1069    C5535 ISUB=KF+I                                                    5385
B1070    C     TMP=RTO*CAR(ISUB)                                            5386
B1071    C                               BRANCH TO  5540 FROM  5530.05      5387
B1072    C5540 ISUB=LF+I                                                    5388
B1073    C     GD(ISUB)=GD(ISUB)+TMP                                        5389
B1074    C     ISUB=KF+I                                                    5390
B1075    C     CAR(ISUB)=CAR(ISUB)-TMP                                      5391
B1076    C.... REPLACE THE FOLLOWING TWO STATEMENTS BY RECOMPUTATION OF TOTALS.
B1077    C     GD(L5)=GD(L5)+TMP                                            5392
B1078    C     CAR(K5)=CAR(K5)-TMP                                          5393
B1079    C                               BRANCH TO  5545 FROM  5530.01      5394
B1080    C5545 CONTINUE                                                     5395
B1081          IF(VSFA.GT.VSE)THEN
B1082    C....    TOO MUCH MATERIAL IN THE ACTIVE LAYER.  REDUCE WEIGHT TO VSE.
B1083             CPV = VSFA - VSE
```

```
          RTO = CPV/VSFA
          DO 5545 I=IGS,LGS
          TMP = RTO*GD(LF+I)
C....     SUBTRACT FROM ACTIVE LAYER SIZE GROUP.
          GD(LF+I) = GD(LF+I) - TMP
C....     ADD TO INACTIVE DEPOSITION LAYER SIZE GROUP.
          GDID(I,IR) = GDID(I,IR) + TMP
 5545     CONTINUE
        ELSE IF(VSFA.LT.VSE)THEN
C....     TOO LITTLE MATERIAL IN THE ACTIVE LAYER.  ADD FIRST FROM THE
C....     INACTIVE DEPOSITION LAYER, AND THEN FROM THE INACTIVE LAYER.
          CPV = VSE - VSFA
          CPVID = MIN(CPV,VSFID(IR))
          CPVI = CPV - CPVID
          CPVI = MIN(CPVI,VSFI)
          IF(VSFID(IR).GT.0.001)THEN
             RTOID = CPVID/VSFID(IR)
          ELSE
             RTOID = 0.
          END IF
          RTOI = CPVI/VSFI
          DO 5546 I=IGS,LGS
          TMPID = RTOID * GDID(I,IR)
          TMPI = RTOI * CAR(KF+I)
C....     ADD TO ACTIVE LAYER SIZE GROUP.
          GD(LF+I) = GD(LF+I) + TMPID + TMPI
C....     SUBTRACT FROM INACTIVE DEPOSITION LAYER SIZE GROUP.
          GDID(I,IR) = GDID(I,IR) - TMPID
C....     SUBTRACT FROM INACTIVE LAYER SIZE GROUP.
          CAR(KF+I) = CAR(KF+I) - TMPI
 5546     CONTINUE
        END IF
C.... RE-SUM TOTAL WEIGHT GD(L5) IN ACTIVE LAYER, VSFID(IR) IN THE
C.... INACTIVE DEPOSITION LAYER, AND CAR(K5) IN THE INACTIVE LAYER, TO
C.... AVOID NUMERICAL DRIFT FROM VALUES THAT CORRESPOND TO THE PARTS.
      GDSUM = 0.
      CARSUM = 0.
      GDIDSU = 0.
      DO 5547 I=IGS,LGS
      GDSUM = GDSUM + GD(LF+I)
      GDIDSU = GDIDSU + GDID(I,IR)
      CARSUM = CARSUM + CAR(KF+I)
 5547 CONTINUE
      GD(L5) = GDSUM
      VSFID(IR) = GDIDSU
      CAR(K5) = CARSUM
C                               BRANCH TO  5550 FROM  5480.04  5510.04 5396
C.... FORCE SAE TO BE 1.
C5550 IF(SAE.LT.1.E-7) SAE=1.E-7                                      5397
 5550 SAE = 1.
C.... LENGTH HVT (ORIGINALLY THE LARGEST PARTICLE SIZE) WAS USED ON THE
C.... RIGHT SIDE OF LINE 5398 WITH THE INTENT OF ADDING A SMALL QUANTITY
C.... TO AVOID SOME NUMERICAL PROBLEMS.  OMIT ADDITION OF HVT TO THE
C.... WEIGHT GD(L5) IN THE ACTIVE LAYER.
```

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B1138      C     VSE=(HVT+GD(L5))/SAE                                      5398
B1139            VSE = GD(L5)/SAE


B1172      C.... IF CAR(ISUB) IS TOO SMALL, REPLACE WITH EXACT ZERO TO AVOID
B1173      C.... UNDERFLOW THAT MAY OCCUR HERE ON THE PRIME.
B1174            IF(CAR(ISUB).LT.1.E-16*TMP)CAR(ISUB)=0.
INSERTED BEFORE
A919        5575 PI(I)=CAR(ISUB)/TMP                                       5431


B1181      C.... IF(GD(ISUB) IS TOO SMALL, REPLACE WITH EXACT ZERO TO AVOID
B1182      C.... UNDERFLOW THAT MAY OCCUR HERE ON THE PRIME.
B1183            IF(GD(ISUB).LT.1.E-16*TMP)GD(ISUB)=0.
INSERTED BEFORE
A925        5585 PI(I)=GD(ISUB)/TMP                                        5437


B1187            IF(KSW(12).GT.0)THEN
B1188      C....    GROUP ARMOR LAYER INTO SILT, SAND, GRAVEL, COBBLES, AND
B1189      C....    BOULDERS.
B1190      C....    SILT:
B1191               MAXXS = MIN(1,LGS)
B1192               ALSILT(IR) = 0.
B1193               DO 8081 I=1,MAXXS
B1194               ALSILT(IR) = ALSILT(IR) + PI(I)
B1195       8081    CONTINUE
B1196               ALSILT(IR) = ALSILT(IR) * 100.
B1197      C....    SAND:
B1198               MAXXS = MIN(6,LGS)
B1199               ALSAND(IR) = 0.
B1200               DO 5291 I=2,MAXXS
B1201               ALSAND(IR) = ALSAND(IR) + PI(I)
B1202       5291    CONTINUE
B1203               ALSAND(IR) = ALSAND(IR) * 100.
B1204      C....    GRAVEL:
B1205               MAXXS = MIN(11,LGS)
B1206               ALGRAV(IR) = 0.
B1207               DO 5292 I=7,MAXXS
B1208               ALGRAV(IR) = ALGRAV(IR) + PI(I)
B1209       5292    CONTINUE
B1210               ALGRAV(IR) = ALGRAV(IR) * 100.
B1211      C....    COBBLES:
B1212               MAXXS = MIN(13,LGS)
B1213               ALCOBB(IR) = 0.
B1214               DO 5293 I=12,MAXXS
B1215               ALCOBB(IR) = ALCOBB(IR) + PI(I)
B1216       5293    CONTINUE
B1217               ALCOBB(IR) = ALCOBB(IR) * 100.
B1218      C....    BOULDERS:
B1219               MAXXS = MIN(14,LGS)
B1220               ALBOUL(IR) = 0.
B1221               DO 5294 I=14,LGS
B1222               ALBOUL(IR) = ALBOUL(IR) + PI(I)
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B1223      5294   CONTINUE
B1224               ALBOUL(IR) = ALBOUL(IR) * 100.
B1225            END IF
INSERTED BEFORE
A928             IF(KSW(13).LE.0) GO TO 5610                                   5440


B1298      C.... DETERMINE FIRST NONMOVING PARTICLE SIZE.
B1299            DO 5663 I=LGS-1,IGS,-1
B1300            IF(GP(I).GT.0.001)GO TO 5664
B1301       5663 CONTINUE
B1302            I = IGS - 1
B1303       5664 NONMOV(IR) = I + 1
INSERTED BEFORE
A1000      C                             BRANCH TO  5670 FROM  5715.05         5510


A1070            VRD=GD(L5)+HVT                                                5567
A1071            IF(SAE.GE.0.) GO TO 5730                                      5568
A1072            SAE=0.                                                        5569
A1073            GSAE=0.0
CHANGED TO
B1374      C.... LENGTH HVT (ORIGINALLY THE LARGEST PARTICLE SIZE) WAS USED ON THE
B1375      C.... RIGHT SIDE OF LINE 5567 WITH THE INTENT OF ADDING A SMALL QUANTITY
B1376      C.... TO AVOID SOME NUMERICAL PROBLEMS.  OMIT ADDITION OF HVT TO THE
B1377      C.... WEIGHT GD(L5) IN THE ACTIVE LAYER.
B1378      C     VRD=GD(L5)+HVT                                                5567
B1379            VRD = GD(L5)
B1380      C.... FORCE SAE AND GSAE TO BE 1.
B1381            SAE = 1.
B1382            GSAE = 1.
B1383            IF(SAE.GE.0.) GO TO 5730                                      5568
B1384      C     SAE=0.                                                        5569
B1385      C     GSAE=0.0
B1386      C.... FORCE SAE AND GSAE TO BE 1.
B1387            SAE = 1.
B1388            GSAE = 1.


A1079       5735 GSAE=SAE**BSAE
CHANGED TO
B1394      C5735 GSAE=SAE**BSAE
B1395      C.... FORCE GSAE TO BE 1.
B1396       5735 GSAE = 1.


A1085            PI(L)=(GD(LL)+GSD)/VRD                                        5580
CHANGED TO
B1402      C.... LENGTH GSD (THE SIZE OF PARTICLES ON THE LL'TH CLASS) WAS USED ON
B1403      C.... THE RIGHT SIDE OF LINE 5580 WITH THE INTENT OF ADDING A SMALL
B1404      C.... QUANTITY TO AVOID SOME NUMERICAL PROBLEMS.  OMIT ADDITION OF GSD
B1405      C.... TO THE TONS GD(LL) IN THE LL'TH CLASS.
B1406      C     PI(L)=(GD(LL)+GSD)/VRD                                        5580
B1407      C.... IF GD(LL) IS TOO SMALL, SET IT TO EXACT ZERO TO AVOID UNDERFLOW
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B1408      C.... THAT MAY OCCUR HERE ON THE PRIME
B1409            IF(GD(LL).LT.1.E-16*VRD)GD(LL)=0.
B1410            PI(L)=GD(LL)/VRD


A1102       5745 CSAE=GS(L)/GPR                                              5597
A1103            FSAE=CSAE+(1.-CSAE)*GSAE                                    5598
CHANGED TO
B1427      C.... DO NOT USE CSAE -- THE RATIO OF INFLOWING LOAD GS(L) IN THE
B1428      C.... L'TH CLASS, TO GPR, THE POTENTIAL TRANSPORT GP(L) IN THE L'TH
B1429      C.... CLASS (AS IF THAT WERE THE ONLY CLASS) REDUCED ACCORDING TO THE
B1430      C.... FRACTION PI(I) THAT THE CLASS REPRESENTS IN THE ARMOR LAYER.
B1431      C5745 CSAE=GS(L)/GPR                                              5597
B1432       5745 CSAE = 1.
B1433      C.... DO NOT REDUCE TRANSPORT CAPACITY -- FORCE FSAE TO BE 1.
B1434      C     FSAE=CSAE+(1.-CSAE)*GSAE                                    5598
B1435            FSAE = 1.


B1462      C.... RE-SUM TOTAL WEIGHT GD(L5) IN ACTIVE LAYER TO AVOID NUMERICAL
B1463      C.... DRIFT FROM VALUES THAT CORRESPOND TO THE PARTS.
B1464            GDSUM = 0.
B1465            DO 5771 L=IGS,LGS
B1466            GDSUM = GDSUM + GD(LF+L)
B1467       5771 CONTINUE
B1468            GD(L5) = GDSUM
INSERTED BEFORE
A1130            IF(KSW(14).LE.0) GO TO 5785                                 5625


A1139       5785 SAE=(GD(L5)+HVT)/VSE                                        5634
CHANGED TO
B1478      C.... FORCE SAE TO BE 1.
B1479      C.... LENGTH HVT (ORIGINALLY THE LARGEST PARTICLE SIZE) WAS USED ON THE
B1480      C.... RIGHT SIDE OF LINE 5634 WITH THE INTENT OF ADDING A SMALL QUANTITY
B1481      C.... TO AVOID SOME NUMERICAL PROBLEMS.  OMIT ADDITION OF HVT TO THE
B1482      C.... TONS GD(L5) IN THE ACTIVE LAYER, EXCEPT THAT SAE IS FORCED TO 1
B1483      C.... ANYWAY.
B1484      C5785 SAE=(GD(L5)+HVT)/VSE                                        5634
B1485       5785 SAE = 1.


A1152            ISUB=LBSA+IRC                                               5647
A1153            GPS(ISUB)=GT                                                5648
A1154            VNM=(GD(L5)+CAR(K5))/UWD                                    5649
CHANGED TO
B1498      C.... INTEGRATE SILT, SAND, GRAVEL, COBBLES, AND BOULDERS.
B1499      C.... SILT:
B1500            MAXXS = MIN(1,LGS)
B1501            QSSILT(IR) = 0.
B1502            DO 8055 I=1,MAXXS
B1503            XSSILT(IR) = XSSILT(IR) + GS(I)*DD(N)/(UWD*ACFT)
B1504            QSSILT(IR) = QSSILT(IR) + GS(I)
B1505       8055 CONTINUE
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B1506    C.... SAND:
B1507          MAXXS = MIN(6,LGS)
B1508          QSSAND(IR) = 0.
B1509          DO 5796 I=2,MAXXS
B1510          XSSAND(IR) = XSSAND(IR) + GS(I)*DD(N)/(UWD*ACFT)
B1511          QSSAND(IR) = QSSAND(IR) + GS(I)
B1512     5796 CONTINUE
B1513    C.... GRAVEL:
B1514          MAXXS = MIN(11,LGS)
B1515          QSGRAV(IR) = 0.
B1516          DO 5797 I=7,MAXXS
B1517          XSGRAV(IR) = XSGRAV(IR) + GS(I)*DD(N)/(UWD*ACFT)
B1518          QSGRAV(IR) = QSGRAV(IR) + GS(I)
B1519     5797 CONTINUE
B1520    C.... COBBLES:
B1521          MAXXS = MIN(13,LGS)
B1522          QSCOBB(IR) = 0.
B1523          DO 5798 I=12,MAXXS
B1524          XSCOBB(IR) = XSCOBB(IR) + GS(I)*DD(N)/(UWD*ACFT)
B1525          QSCOBB(IR) = QSCOBB(IR) + GS(I)
B1526     5798 CONTINUE
B1527    C.... BOULDERS:
B1528          MAXXS = MIN(14,LGS)
B1529          QSBOUL(IR) = 0.
B1530          DO 5799 I=14,LGS
B1531          XSBOUL(IR) = XSBOUL(IR) + GS(I)*DD(N)/(UWD*ACFT)
B1532          QSBOUL(IR) = QSBOUL(IR) + GS(I)
B1533     5799 CONTINUE
B1534          ISUB=LBSA+IRC                                                  5647
B1535          GPS(ISUB)=GT                                                   5648
B1536    C.... ADD INACTIVE DEPOSITION LAYER TO THE FOLLOWING TOTAL.
B1537    C     VNM=(GD(L5)+CAR(K5))/UWD                                       5649
B1538          VNM = (GD(L5) + VSFID(IR) + CAR(K5)) / UWD


A1170          WRITE(LP,5803) IRC,XSMINE(IRC)
A1171     5803 FORMAT(2X,'GRAVEL MINING IS OCCURRING AT CROSS SECTION NUMBER',I3,
A1172         1/,10X,' AT THE RATE OF',F15.2,'  CUBIC YARDS PER DAY')
A1173          WRITE (LP,5805)IRC,DLY(IRC),DLYGM(IRC),VSF,DIST,WMB,VOL,VGM,VNM,
A1174         1VSD,VCL,GMRATO
A1175     5801 CONTINUE
A1176          DO 5804 L=1,LGS
A1177          LL=LF + L
A1178          GD(LL) = GD(LL)*GMRATO
A1179          KK=KF+L
A1180          CAR(KK)=CAR(KK)*GMRATO
A1181     5804 CONTINUE
A1182          GD(L5) = GD(L5)*GMRATO
A1183          CAR(K5) = CAR(K5)*GMRATO
CHANGED TO
B1554    C.... COMMENT OUT THIS VOLUMINOUS PRINT.
B1555    C     WRITE(LP,5803) IRC,XSMINE(IRC)
B1556    C5803 FORMAT(2X,'GRAVEL MINING IS OCCURRING AT CROSS SECTION NUMBER',I3,
B1557    C    1/,10X,' AT THE RATE OF',F15.2,'  CUBIC YARDS PER DAY')
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```
C     WRITE (LP,5805)IRC,DLY(IRC),DLYGM(IRC),VSF,DIST,WMB,VOL,VGM,VNM,
C    1VSD,VCL,GMRATO
 5801 CONTINUE
C.... CHANGE THE METHOD OF GRAVEL MINING REMOVAL.  THE OLD METHOD WAS
C.... TO REMOVE FROM THE ACTIVE AND INACTIVE LAYERS IN EQUAL PROPORTION.
C.... REPLACE WITH REMOVAL FROM THE ACTIVE LAYER, THEN THE INACTIVE
C.... DEPOSITION LAYER, AND THEN THE INACTIVE LAYER.
C     DO 5804 L=1,LGS
C     LL=LF + L
C     GD(LL) = GD(LL)*GMRATO
C     KK=KF+L
C     CAR(KK)=CAR(KK)*GMRATO
C5804 CONTINUE
C.... VGMWT = WEIGHT OF GRAVEL, IN TONS, TO BE PARALLEL WITH OTHER
C.... QUANTITIES.
      VGMWT = VGM * UWD
C.... VGMA = WEIGHT OF GRAVEL REMOVED FROM ACTIVE LAYER.
      VGMA = MIN(VGMWT,GD(L5))
      IF(GD(L5).GT.0.001)THEN
         RTOA = VGMA / GD(L5)
      ELSE
         RTOA = 0.
      END IF
C.... VGMID = WEIGHT OF GRAVEL REMOVED FROM INACTIVE DEPOSITION LAYER.
      VGMID = MIN(VGMWT - VGMA, VSFID(IR))
      IF(VSFID(IR).GT.0.001)THEN
         RTOID = VGMID / VSFID(IR)
      ELSE
         RTOID = 0.
      END IF
C.... VGMI = WEIGHT OF GRAVEL REMOVED FROM INACTIVE LAYER.
      VGMI = MIN(VGMWT - VGMA - VGMID, CAR(K5))
      RTOI = VGMI / CAR(K5)
C.... REMOVE APPROPRIATE WEIGHTS FROM THE SIZE GROUPS, IN EACH OF
C.... THE THREE LAYERS.
      DO 5804 L=1,LGS
      GD(LF+L) = (1. - RTOA) * GD(LF+L)
      GDID(L,IR) = (1. - RTOID) * GDID(L,IR)
      CAR(KF+L) = (1.-RTOI) * CAR(KF+L)
 5804 CONTINUE
C.... RE-SUM TOTAL WEIGHT GD(L5) IN ACTIVE LAYER, VSFID(IR) IN THE
C.... INACTIVE DEPOSITION LAYER, AND CAR(K5) IN THE INACTIVE LAYER, TO
C.... AVOID NUMERICAL DRIFT FROM VALUES THAT CORRESPOND TO THE PARTS.
C     GD(L5) = GD(L5)*GMRATO
C     CAR(K5) = CAR(K5)*GMRATO
      GDSUM = 0.
      GDIDSU = 0.
      CARSUM = 0.
      DO 5806 I=IGS,LGS
      GDSUM = GDSUM + GD(LF+I)
      GDIDSU = GDIDSU + GDID(I,IR)
      CARSUM = CARSUM + CAR(KF+I)
 5806 CONTINUE
      GD(L5) = GDSUM
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B1612          VSFID(IR) = GDIDSU
B1613          CAR(K5) = CARSUM


A1209     5835 IF(KSW(13).LE.0) GO TO 5855                                    5677
CHANGED TO
B1639     5835 CONTINUE
B1640     C.... WRITE OUT SEDIMENT DISCHARGE HYDROGRAPH.
B1641          IF(IR.EQ.NR)WRITE(77)(GS(I),I=IGS,LGS)
B1642          IF(KSW(13).LE.0) GO TO 5855


B1685     C.... BREAK UP THE MODULE, BECAUSE IT IS TOO LARGE FOR THE COMPILER
B1686     5885 CALL SRMO52(INFO1)
B1687     C                                                                   5821
B1688     C    RETURN TO BWMOD4                                               5822
B1689          RETURN                                                         5823
B1690          END                                                            5824
B1691          SUBROUTINE SRMO52(INFO1)                                       4574
B1692     C    VERSION 2.3/2.3 05NOV1974                                      4575
B1693     C    VERSION 2.1/2.2 28JAN1973                                      4576
B1694     C    VERSION 2.0/2.0  22JAN73                                       4577
B1695     C    VERSION 1.6/1.9 20FEB1973                                      4578
B1696     C    VERSION 1.5/1.8 15DEC1972                                      4579
B1697     C    VERSION 1.4/1.7 6NOV1972                                       4580
B1698     C    VERSION 1.3   28JLY72                                          4581
B1699     C    VERSION 1.2  27APR72                                           4582
B1700     C    VERSION 1.1 30MAR72                                            4583
B1701     C    VERSION 1.0  12JAN1972                                         4584
B1702     C    *                                                              4585
B1703     C    THIS MODULE REQUIRES SUBROUTINES *****CITIN,EFFDIA,BEDGRA*****  4586
B1704     C    THIS SUBROUTINE CALLS  ***CITIN,EFFDIA,BEDGRA,DUBOY,ELMOD7,INLOAD, 4587
B1705     C                              SPOWER,TFMOD6***                     4588
B1706     C    *                                                              4569
B1707     C    SEDIMENT ROUTING PROGRAM                                       4590
B1708     C    GD ARRAY=GRAIN SIZE DATA, DEPOSITS IN RESERVOIR,               4591
B1709     C    CAR ARRAY=COEFFICIENT ARRAY                                    4592
B1710     C                                                                   4593
B1711     C    STORAGE MAP CAR(ARRAY)                                         4594
B1712     C    SPI                     1                                      4595
B1713     C    TON/UWD                 2                                      4596
B1714     C    UWW                     3                                      4597
B1715     C    SUK                     4                                      4598
B1716     C    BSAE                    5                                      4599
B1717     C    VOLUME SHAPE FACTOR     +NR                                    4600
B1718     C    NOT USED                +NR                                    4601
B1719     C    DS COEFFICIENTS         +3*NGS                                 4602
B1720     C    N-CORRECTION COEF.      1*NGS                                  4603
B1721     C    Q-QS RATING TABLE       +LQ*(NGS+1)                            4604
B1722     C    VOLUME VS DEPTH FUNCTION+NR                                    4605
B1723     C    INACTIVE STORAGE        +NR*(NGS+1)                            4606
B1724     C    TOTAL                   LQ*(NGS+1)+3*(NGS+1)+NR*(NGS+4)+5      4607
B1725     C                                                                   4608
B1726     C    STORAGE MAP GD(ARRAY)                                          4609
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C     ACTIVE STORAGE      L5=(NGS+1)                                    4610
C     REACH LENGTH            +1                                        4611
C     AVG. SEC. NO.           +2                                        4612
C     IDENTIFY USE OF SAE     +3                                        4613
C     SAE                     +4                                        4614
C     P1                      +5                                        4615
C     D1                      +6                                        4616
C     D2                      +7                                        4617
C     MODEL BOTTOM            +8                                        4618
C     NOT USED                +9                                        4619
C     SLOPE               LF +NQ                                        4620
C     N-VALUE                 +NQ                                       4621
C     TOP WIDTH               +NQ                                       4622
C     DEPTH                   +NQ                                       4623
C     VELOCITY                +NQ                                       4624
C     WATER SURFACE           +NQ                                       4625
C     EQUILIBRIUM BED ELEV    +NQ                                       4626
C     DISCHARGE               +NQ                                       4627
C     TOTAL                   (NGS+8*NQ+10)*NR                          4628
C                                                                       4629
C     INTEGER*6 IOTB
      COMMON TOG,TRD,TWO                                                4630
      COMMON KSL(14),KSW(14)                                            4631
      COMMON NEC,NEQ                                                    4632
      COMMON IGS,LGS,LC,LQ,MTC,NAP,NAQ,NGS,NIS,NK,NQ,NR,NYV,NVS         4633
      COMMON DD(10),WT(10)                                              4634
      COMMON Q(10),WS(10)                                               4635
C                                                                       4636
      COMMON /  IO  / IN,LP                                             4637
C     COMMON BLOCK FOR TAPE 95
      COMMON /TP95/ CHNGE(150),CHNGM(150),TV(7),CCHRL,
     1GSRA(150,15)
      COMMON / CLAY / MTCL,ICS,LCS,DTCL,STCD,UWCL,CCCD,PUCD,FVCL        4638
      COMMON / SILT / MTSL,ISGS,LSGS,DTSL,STSD,UWSL,CCSD,PUSD,FVSL(4),  4639
     .                IASL,LASL                                         4640
      COMMON /CLILT / VCDI,VSDI                                         4641
      COMMON /INITAL/  TIME,ADAY                                        4642
      COMMON /NUMLET/ ITL(40)                                           4643
      COMMON /OPRULE/ MSOR,LSOR(20),LALP,NTCV(20)                       4644
      COMMON / PLOT / IPLOT,IPF                                         4645
      COMMON /SIMTAP/ MNQ,NXS,NSE,DLYST(150),CAR(6000),GD(5100),NCAR,NGD 4646
      COMMON /TITLEO/ NSFR,LBCL,LBSL,LBSA,IOTB(3)                       4647
C     SPECIAL COMMON IO,CLAY,SILT,CLILT,INITAL,NUMLET,OPRULE,
C    1 PLOT,SIMTAP,TITLEO,TRIBIF,CONST,PROSED,NETCOF,MINING,TP95
      EQUIVALENCE  (DLY(1),DLYST(1))                                    4648
      DIMENSION DLY(150)                                                4649
C                                                                       4650
      COMMON /TRIBIF/ MNTL,NTEL(10),LTGM(20),QTEP(20),LTSR(20),NPTSR(20) 4651
      COMMON /CONST / ISA,LDA,LDM,LEB,LGA,LMB,LPA,LSA,MSD               4652
      COMMON /PROSED/  SD,SPSS,GSF                                      4653
      COMMON /NETCOF/  DBI,DBN,XID,XIN,XIU,UBI,UBN                      4654
      COMMON /MINING/ IGMINE,FGMINE,GMINE(11),DLYGM(150),VGM,XSMINE(150)
     . ,GMRATO
C.... REMOVE GPS FROM DIMENSION STATEMENT, AND INCLUDE IN
```

```
B1781     C.... COMMON/GROUPS/.
B1782     C     DIMENSION DYO(150),GPS(450),WSP(150),TWP(150)                    4655
B1783           DIMENSION DYO(150),WSP(150),TWP(150)
B1784           DIMENSION ASIO(3),TEFF(3),TEMP(3)                                4656
B1785           DIMENSION GP(15),GS(15),GSR(15),PI(15),SD(15),GST(15)            4657
B1786           DIMENSION PBT(40)                                                4658
B1787     C.... ADD VARIABLES FOR INTEGRATING MASS CONSERVATION IN TIME, BY CROSS
B1788     C.... SECTION, BY SEDIMENT SIZE GROUPING.
B1789           COMMON/GROUPS/XSSILT(150),XSSAND(150),XSGRAV(150),XSCOBB(150),
B1790          * XSBOUL(150),TSSILT(150),TSSAND(150),TSGRAV(150),TSCOBB(150),
B1791          * TSBOUL(150),
B1792     C.... ADD VARIABLES FOR GROUPING SEDIMENT TRANSPORT.
B1793          * QSSILT(150),QSSAND(150),QSGRAV(150),QSCOBB(150),
B1794          * QSBOUL(150),
B1795     C.... ADD VARIABLES FOR BED MATERIAL AND ARMOR LAYER COMPOSITION.
B1796          * BMSILT(150),BMSAND(150),BMGRAV(150),BMCOBB(150),
B1797          * BMBOUL(150),ALSILT(150),ALSAND(150),ALGRAV(150),ALCOBB(150),
B1798          * ALBOUL(150),
B1799     C.... ADD GPS TO ARRAY BECAUSE IT IS DEFINED IN THE FIRST PART OF
B1800     C.... SRMOD5.
B1801          * GPS(450),
B1802     C.... ADD ARRAY GDID FOR INACTIVE DEPOSITION LAYER, AND VSFID FOR TOTAL
B1803     C.... WEIGHT IN THE LAYER.
B1804          * GDID(15,150),VSFID(150)
B1805     C.... REINITIALIZE KAST FROM SRMOD5.
B1806           DATA KAST/38/
B1807     C.... REDEFINE NCT AND ICMT FROM SRMOD5.
B1808           ICMT = 35
B1809           NGR = NVS + NR
B1810     C.... REINITIALIZE INTL FROM SRMOD5.
B1811           INTL = 0
B1812           IF(INFO1.GT.0) GO TO 5885                                        4692
INSERTED BEFORE
A1252     C                                                                      5716


B1908     C.... WRITE OUT INTEGRATED DEPOSITION.
B1909           IF(KSW(12).GT.0)THEN
B1910              WRITE(LP,6010)
B1911      6010    FORMAT(//1X,'SEDIMENT LOAD BY SIZE GROUP IN TONS PER DAY.')
B1912              WRITE(LP,6011)
B1913      6011    FORMAT(1X,'      SEC.','      SILT',
B1914          *     '      SAND','    GRAVEL','   COBBLES','  BOULDERS')
B1915              IT = NGS+3+NKNR
B1916              DO 6012 K=1,NR
B1917              WRITE(LP,6013)GD(IT),QSSILT(K),QSSAND(K),QSGRAV(K),QSCOBB(K),
B1918          *      QSBOUL(K)
B1919      6013    FORMAT(1X,F10.3,5F10.0)
B1920              IT = IT - NK
B1921      6012    CONTINUE
B1922              WRITE(LP,5956)
B1923      5956    FORMAT(//1X,'ACCUMULATED AC-FT THROUGH SECTIONS BY SIZE',
B1924          *     ' GROUP.')
B1925              WRITE(LP,5957)
```

```
 5957   FORMAT(1X,'      SEC.','      SILT',
     *   '       SAND','    GRAVEL','   COBBLES','  BOULDERS')
        IT = NGS+3+NKNR
        DO 5958 K=1,NR
        WRITE(LP,5959)GD(IT),XSSILT(K),XSSAND(K),XSGRAV(K),XSCOBB(K),
     *     XSBOUL(K)
 5959   FORMAT(1X,F10.3,5F10.2)
        IT = IT - NK
 5958   CONTINUE
        WRITE(LP,5980)
 5980   FORMAT(//1X,'ACCUMULATED AC-FT FROM TRIBUTARIES BY SIZE',
     *   ' GROUP.')
        WRITE(LP,5981)
 5981   FORMAT(1X,'      SEC.','      SILT',
     *   '       SAND','    GRAVEL','   COBBLES','  BOULDERS')
        IT = NGS + 3 + NKNR
        DO 5982 K=1,NR
        IF(ABS(TSSILT(K)).GT.0.005)WRITE(LP,5983)GD(IT),TSSILT(K),
     *   TSSAND(K),TSGRAV(K),TSCOBB(K),TSBOUL(K)
 5983   FORMAT(1X,F10.3,5F10.2)
        IT = IT - NK
 5982   CONTINUE
        WRITE(LP,5966)
 5966   FORMAT(//1X,'ACCUMULATED AC-FT WITHIN REACHES BY SIZE GROUP.')
        WRITE(LP,5967)
 5967   FORMAT(1X,'     SEC.1','     SEC.2','      SILT',
     *   '       SAND','    GRAVEL','   COBBLES','  BOULDERS')
        IT = NGS + 3 + NKNR
        IT2 = IT - NK
        DO 5968 K=2,NR
        DXSSIL = XSSILT(K-1) + TSSILT(K) - XSSILT(K)
        DXSSAN = XSSAND(K-1) + TSSAND(K) - XSSAND(K)
        DXSGRA = XSGRAV(K-1) + TSGRAV(K) - XSGRAV(K)
        DXSCOB = XSCOBB(K-1) + TSCOBB(K) - XSCOBB(K)
        DXSBOU = XSBOUL(K-1) + TSBOUL(K) - XSBOUL(K)
        WRITE(LP,5969)GD(IT),GD(IT2),DXSSIL,DXSSAN,DXSGRA,DXSCOB,DXSBOU
 5969   FORMAT(1X,2F10.3,5F10.2)
        IT = IT - NK
        IT2 = IT - NK
 5968   CONTINUE
C....   WRITE OUT BED MATERIAL COMPOSITION BY SIZE GROUPS.
        WRITE(LP,8009)
 8009   FORMAT(//1X,'ACTIVE PLUS INACTIVE COMPOSITION IN PERCENT',
     *   ' BY SIZE GROUP.')
        WRITE(LP,8010)
 8010   FORMAT(1X,'      SEC.','      SILT',
     *   '       SAND','    GRAVEL','   COBBLES','  BOULDERS')
        IT = NGS + 3 + NKNR
        DO 8011 K=1,NR
        WRITE(LP,8012)GD(IT),BMSILT(K),BMSAND(K),BMGRAV(K),BMCOBB(K),
     *   BMBOUL(K)
 8012   FORMAT(1X,F10.3,5F10.2)
        IT = IT - NK
 8011   CONTINUE
```

```
B1980     C....     WRITE OUT ARMOR LAYER COMPOSITION BY SIZE GROUPS.
B1981               WRITE(LP,8029)
B1982      8029     FORMAT(//1X,'ACTIVE LAYER COMPOSITION IN PERCENT BY SIZE',
B1983          *     ' GROUP.')
B1984               WRITE(LP,8030)
B1985      8030     FORMAT(1X,'      SEC.','      SILT',
B1986          *     '        SAND','    GRAVEL','   COBBLES','  BOULDERS')
B1987               IT = NGS + 3 + NKNR
B1988               DO 8031 K=1,NR
B1989               WRITE(LP,8032)GD(IT),ALSILT(K),ALSAND(K),ALGRAV(K),ALCOBB(K),
B1990          *     ALBOUL(K)
B1991      8032     FORMAT(1X,F10.3,5F10.2)
B1992               IT = IT - NK
B1993      8031     CONTINUE
B1994            END IF
INSERTED BEFORE
A1347     C

COMPARISON FINISHED.
34 DISCREPANCIES FOUND.
```

```
OK, CMPF STMOD2.ORG STMOD2.F77
[CMPF 19.4.11]

A39             COMMON /FALLVE/  CL,   H(10),ACGR                                5863
CHANGED TO
B39       C.... INCREASE THE DIMENSION OF H FROM 10 TO 24.
B40             COMMON /FALLVE/  CL,   H(-7:16),ACGR


A50             DIMENSION SAND(10),SILT(4)                                       5867
CHANGED TO
B51       C.... INCREASE THE NUMBER OF SAND CLASSES FROM 10 TO 24.
B52             DIMENSION SAND(-7:16),SILT(4)


B154      C.... ADD "SAND" SIZES TO SIMULATE SILT AND CLAY TRANSPORT, BECAUSE
B155      C.... SILT AND CLAY WILL NOT SCOUR AND RESUSPEND.
B156            SAND(-7)=.00000113
B157            SAND(-6)=.00000227
B158            SAND(-5)=.00000453
B159            SAND(-4)=.00000906
B160            SAND(-3)=.0000181
B161            SAND(-2)=.0000362
B162            SAND(-1)=.0000725
B163      C     SAND(0) =.0001450
B164      C.... LUMP SILT AND CLAY SIZES INTO ONE CLASS, FOR NOW.
B165            SAND(0)=.000013
INSERTED BEFORE
A152            SAND(1)=.000288                                                  5967
```

```
B176       C.... ADD 6 "SAND" SIZES.
B177             SAND(11) = .296948
B178             SAND(12) = .593895
B179             SAND(13) = 1.187791
B180             SAND(14) = 2.375582
B181             SAND(15) = 4.751164
B182             SAND(16) = 9.502327
INSERTED BEFORE
A162             LBCL=0                                              5977


A442        6260 SD(LGS)=SAND(I)                                     6257
CHANGED TO
B463             SD(LGS)=SAND(I)
B464       C.... INSURE THERE ARE NO MORE THAN 15 CLASSES TOTAL.
B465             IF(LGS.GE.15)GO TO 6261
B466        6260 CONTINUE
B467        6261 CONTINUE

COMPARISON FINISHED.
5 DISCREPANCIES FOUND.
```

```
OK, CMPF TFMOD6.ORG TFMOD6.F77
[CMPF 19.4.4]

A26              COMMON /FALLVE/  CL,   H(10),ACGR                   7020
CHANGED TO
B26        C.... INCREASE THE DIMENSION OF H FROM 10 TO 24.
B27              COMMON /FALLVE/  CL,   H(-7:16),ACGR


A31              DIMENSION D(10),GP(15),PI(15)                       7024
A32              DIMENSION K(20)                                     7025
A33              DIMENSION CL(4),G(10),GF(10),GSUM(12),ZI(10)        7026
A34              DIMENSION PY(10,8)                                  7027
CHANGED TO
B32        C.... INCREASE THE DIMENSION OF D FROM 10 TO 24.
B33              DIMENSION D(-7:16),GP(15),PI(15)
B34              DIMENSION K(20)                                     7025
B35        C.... INCREASE THE DIMENSION OF G,GF, AND ZI FROM 10 TO 24.
B36              DIMENSION CL(4),G(-7:16),GF(-7:16),GSUM(12),ZI(-7:16)
B37        C.... INCREASE THE DIMENSION OF PY FROM (10,8) TO (-7:16,8).
B38              DIMENSION PY(-7:16,8)

COMPARISON FINISHED.
2 DISCREPANCIES FOUND.
```

```
OK, CMPF USTAR.ORG USTAR.F77
 [CMPF 19.4.4]

 A6             COMMON /FALLVE/  CL,   H(10),ACGR                                       7823
 CHANGED TO
 B6       C.... INCREASE THE DIMENSION OF H FROM 10 TO 24.
 B7             COMMON /FALLVE/  CL,   H(-7:16),ACGR

 COMPARISON FINISHED.
 1 DISCREPANCY FOUND.
```

APPENDIX D: MODELING EXTENDED TO JULY 31, 1987

This appendix presents results for modeling extended to July 31, 1987. The modeling period discussed in the main body of the report was a subset of this extended period. In particular, starting times were identical. The period from August 16, 1984 to July 31, 1987, which is applicable to the Puyallup and Carbon Rivers, is 2.959 years long; and the period from July 27, 1984, to July 31, 1987, is 3.014 years long. The information is included here, rather than in the main report, for two reasons. First, no field checks of sediment discharges or bed-elevation changes were available during the extension. The model was used purely in predictive mode and this extended period thus represents an extrapolation from field observations. Secondly, the tables and figures from the extended period would likely have caused confusion with those from the modeling period discussed in the main body of the report. Separation of the extended period into this appendix will hopefully provide the needed distinction.

To aid in comparison with the shorter modeling period, the tables and figures in this appendix are numbered as D--, where the dashes indicate the number of the corresponding table or figure from the main body of the report. The primary purposes of presenting this extended period is that it included a large storm event of November 22 to 26, 1986. Thus, the figures and tables show what changes in average sediment discharge, deposition patterns, and bed-elevation changes would be produced by the inclusion of such a storm. In general, the results are quite similar to those produced by the moderately high storm events of the shorter modeling period. Careful comparison of the figures and tables does show a few modifications in the patterns. For example, the higher flow of the November 22-26, 1986, storm seems to have cleaned the sand and finer deposits from the lower White River (fig. D22 compared with 22). However, the rate of deposition for sand and finer material on the lower Puyallup River is larger (fig. D20 compared with 20). The upstream reaches in which sediment traps affected gravel transport reached somewhat further upstream (table D17 compared with 17). On the Puyallup River, the upstream boundary of the affected local reach was 8,900 feet above the trap, instead of the result in the shorter modeling period of no upstream affected reach. On the White River, the upstream boundary of the affected reach was 4,800 feet upstream of the trap instead of 1,000 feet as it was for the shorter modeling period. An additional reach with substantial deposition of gravel and coarser material showed up on the Carbon River between 5,600 and 7,500 feet from the river's mouth (table D12 compared with 12).

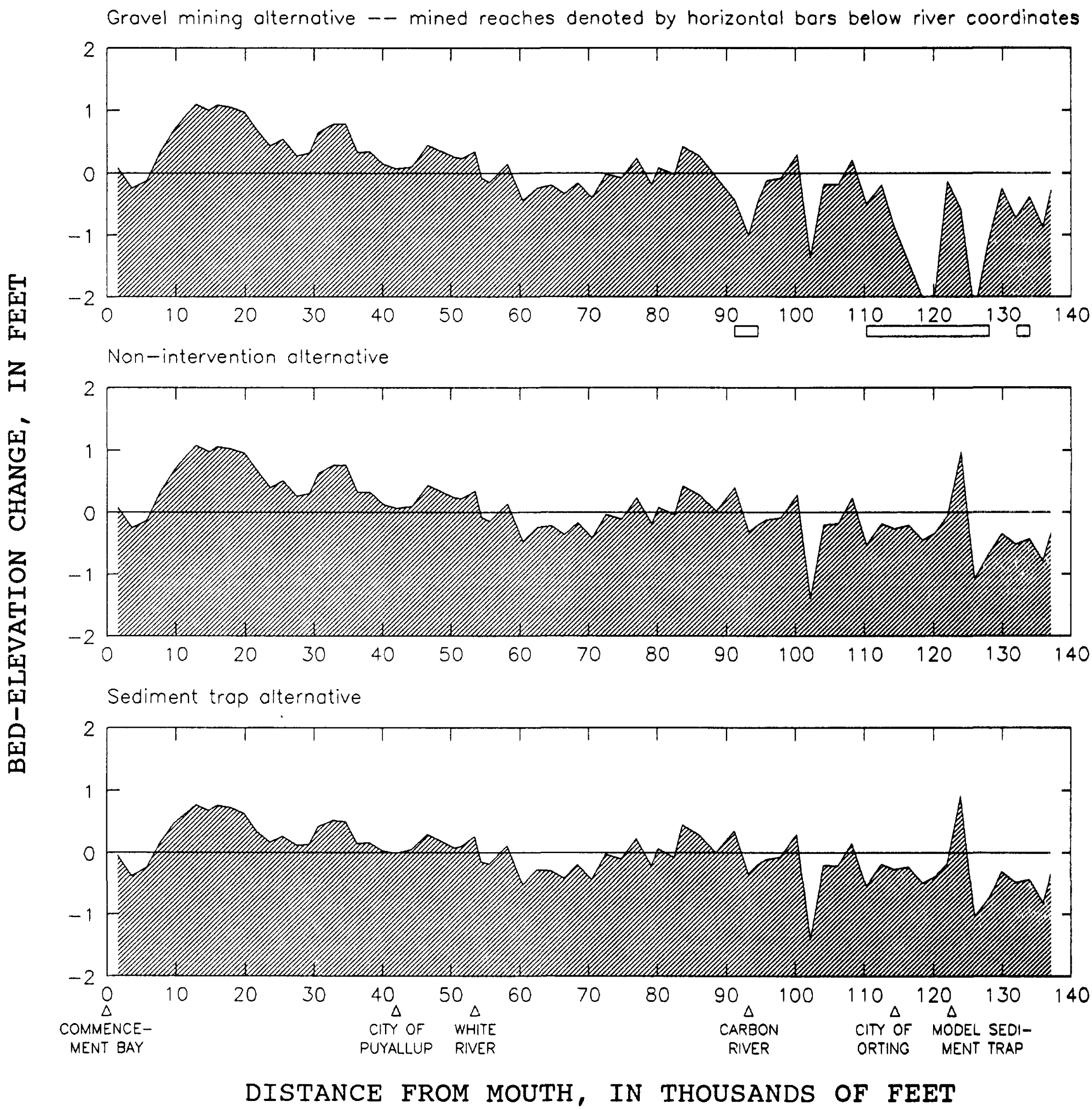

FIGURE D11.--Modeled bed-elevation change on the Puyallup River from August 16, 1984, to July 31, 1987.

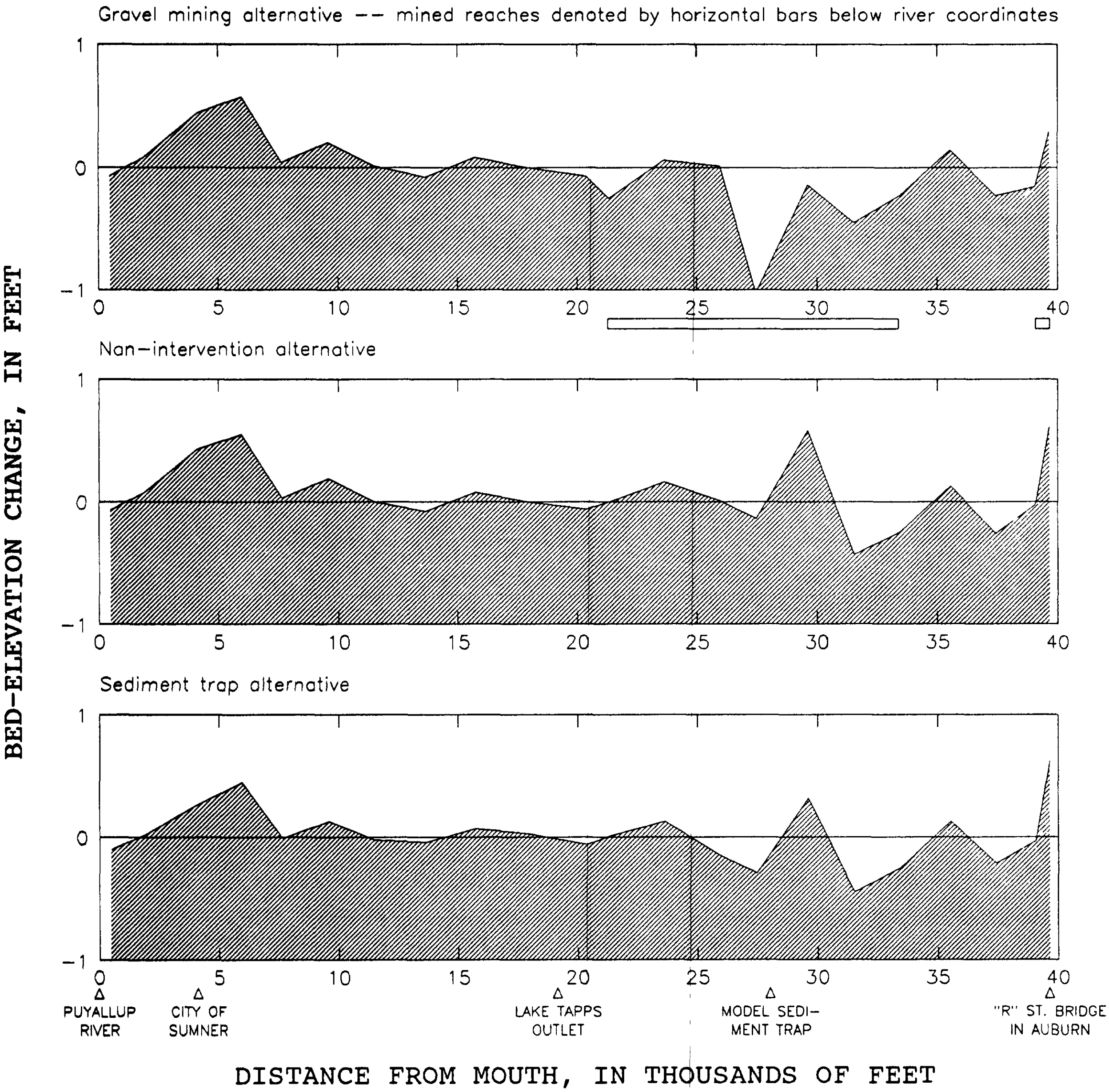

FIGURE D12.--Modeled bed-elevation change on the White River from July 27, 1984, to July 31, 1987.

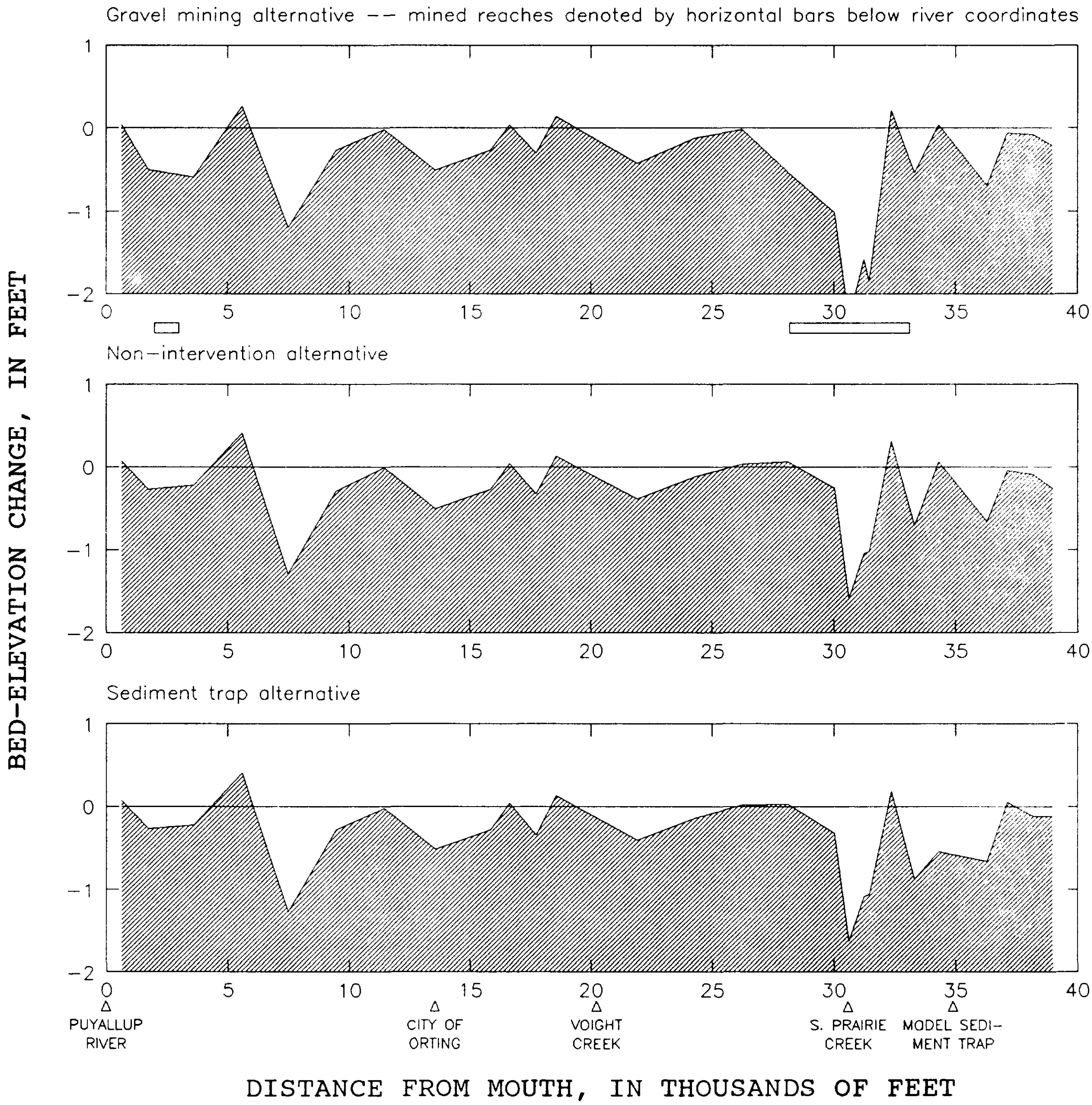

FIGURE D13.--Modeled bed-elevation change on the Carbon River from August 16, 1984, to July 31, 1987.

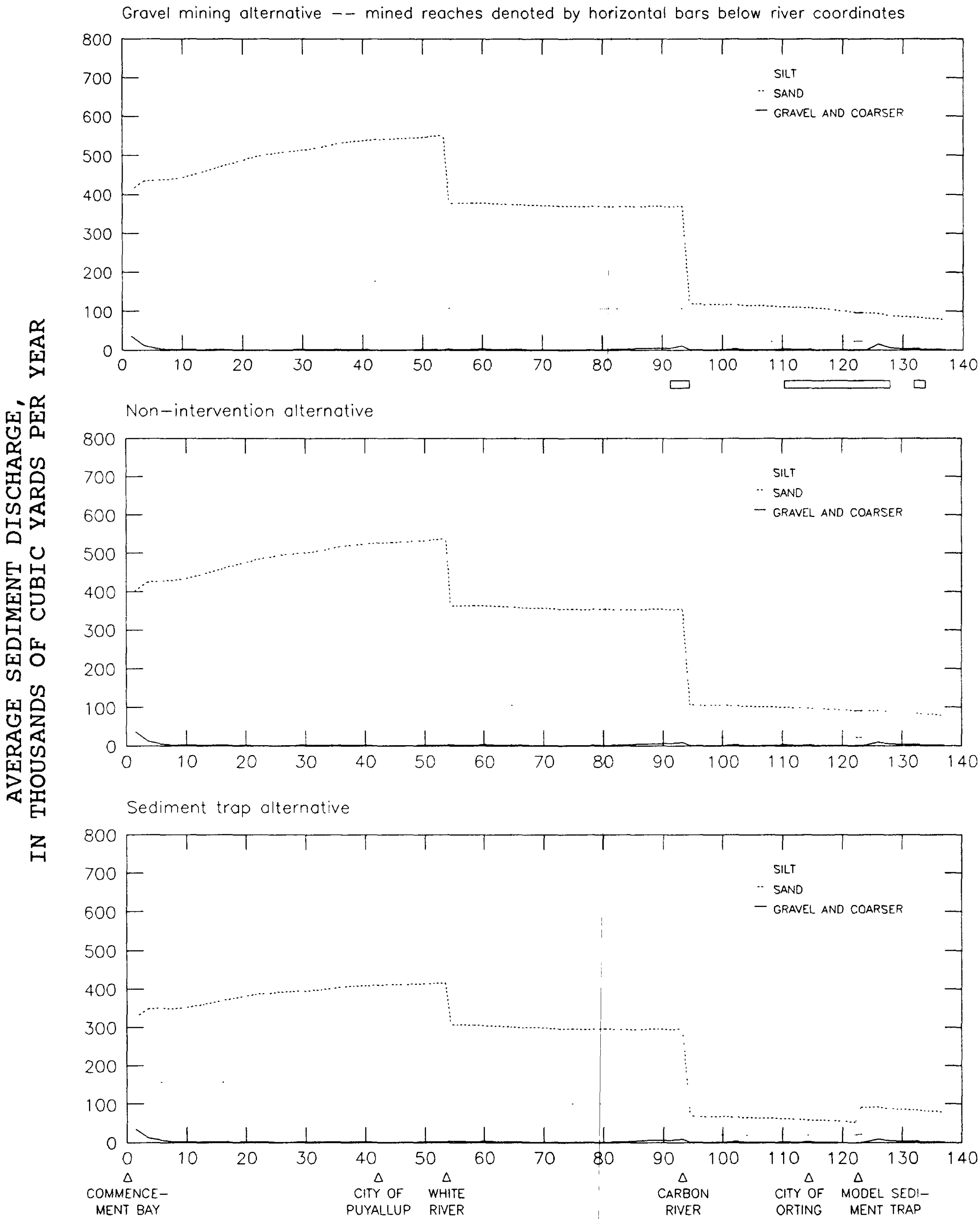

FIGURE D14.--Modeled average sediment discharge on the Puyallup River during August 16, 1984, to July 31, 1987.

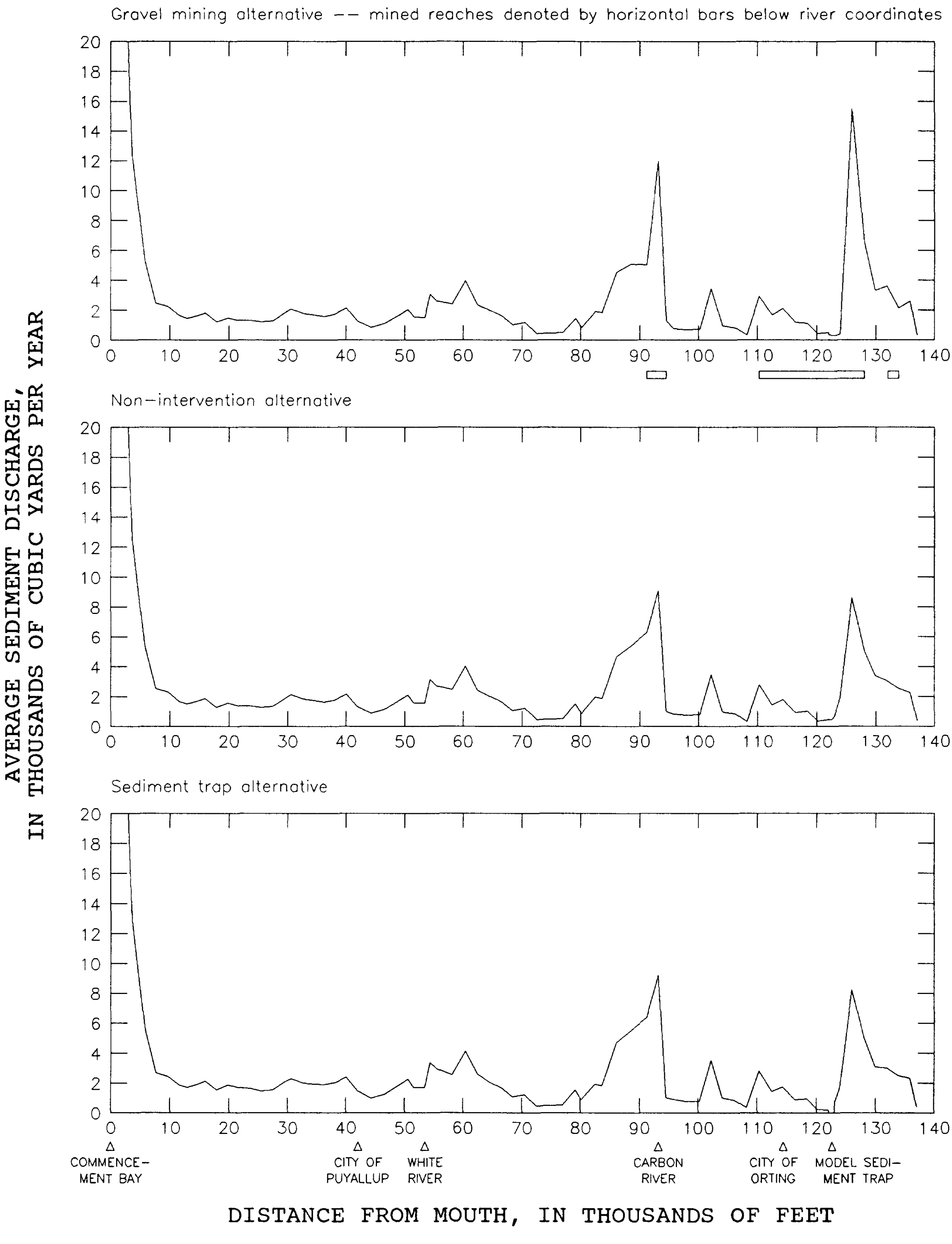

FIGURE D15.--Modeled average discharge of gravel and coarser material on the Puyallup River during August 16, 1984, to July 31, 1987.

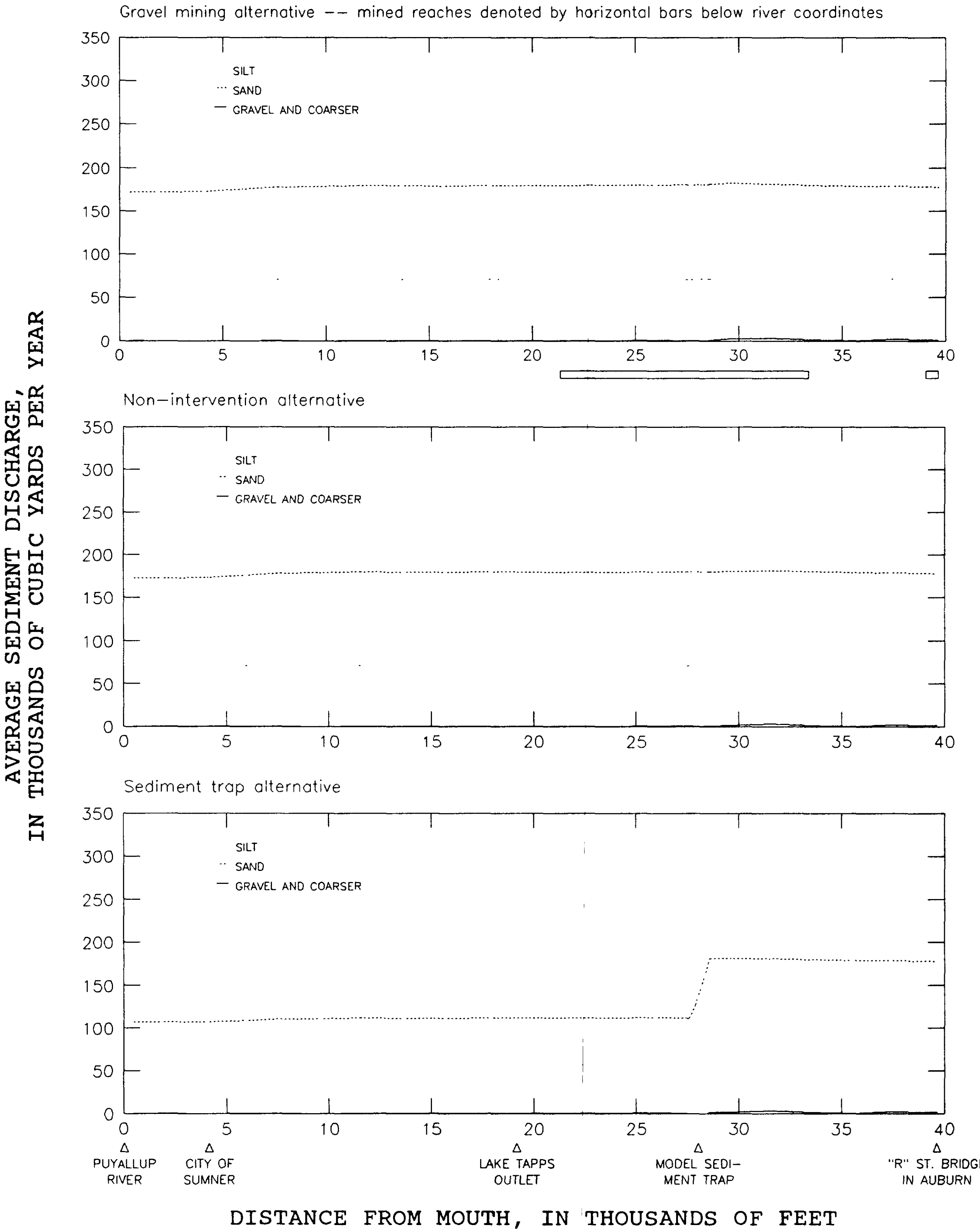

FIGURE D16.--Modeled average sediment discharge on the White River during July 27, 1984, to July 31, 1987.

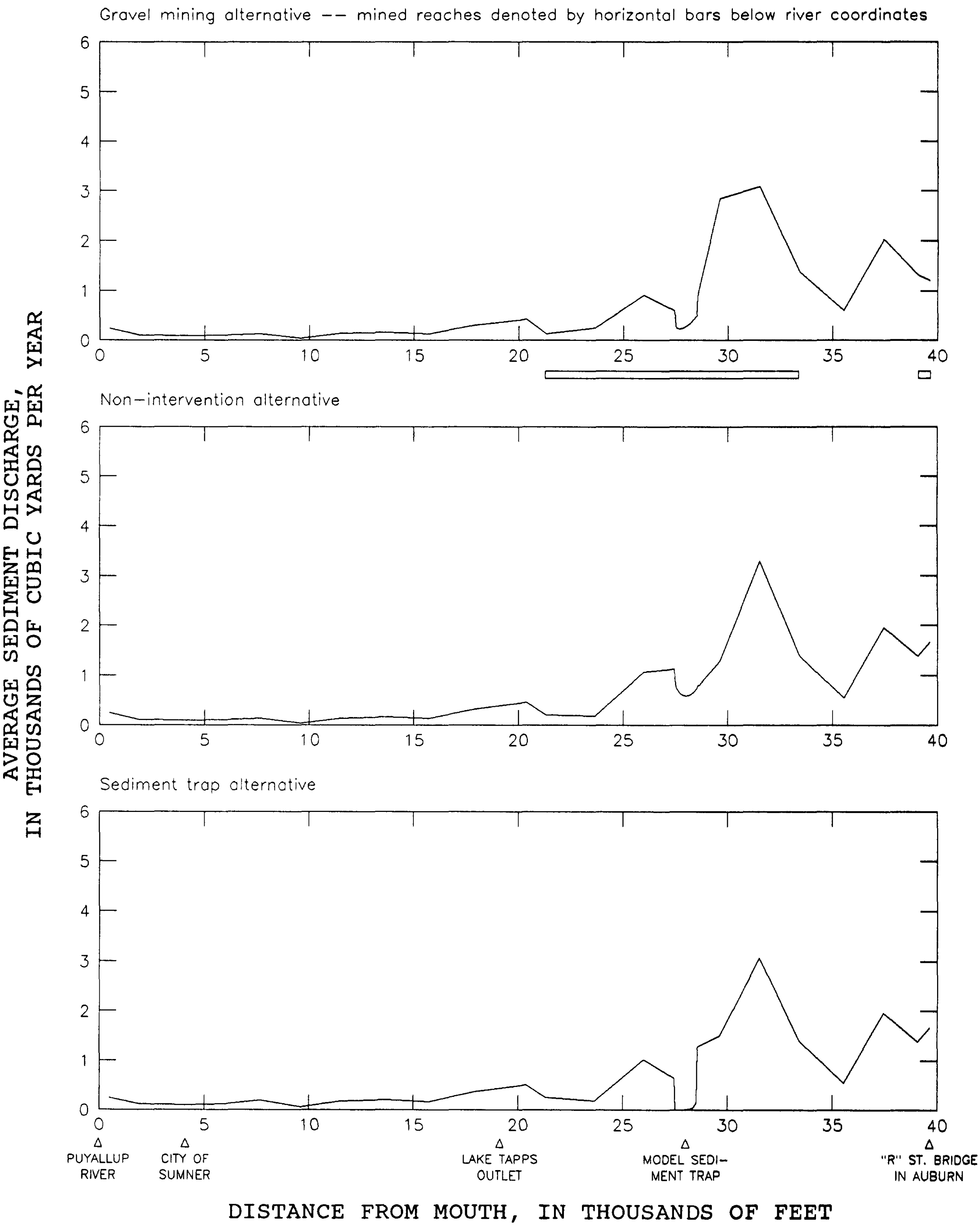

FIGURE D17.--Modeled average discharge of gravel and coarser material on the White River during July 27, 1984, to July 31, 1987.

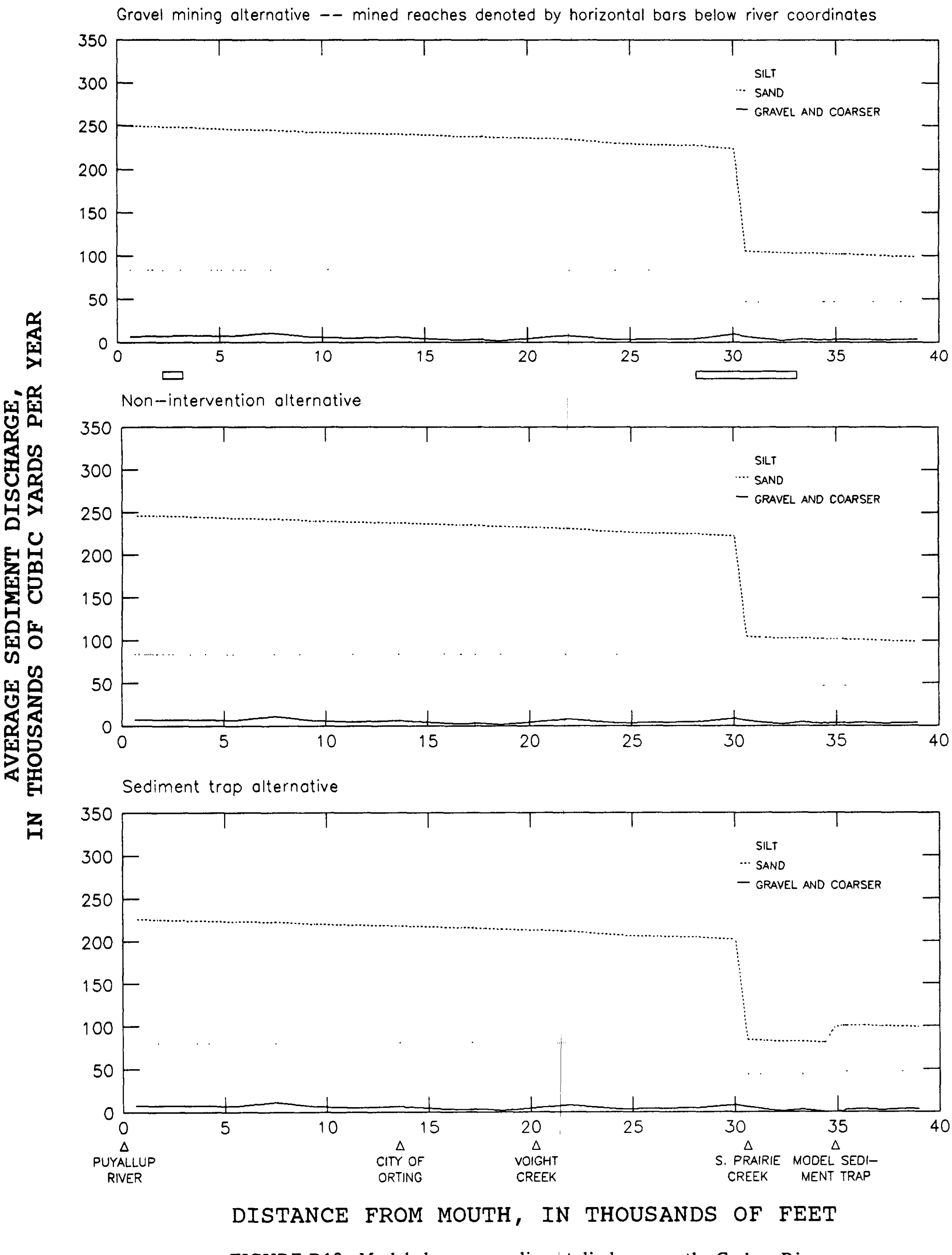

FIGURE D18.--Modeled average sediment discharge on the Carbon River during August 16, 1984, to July 31, 1987.

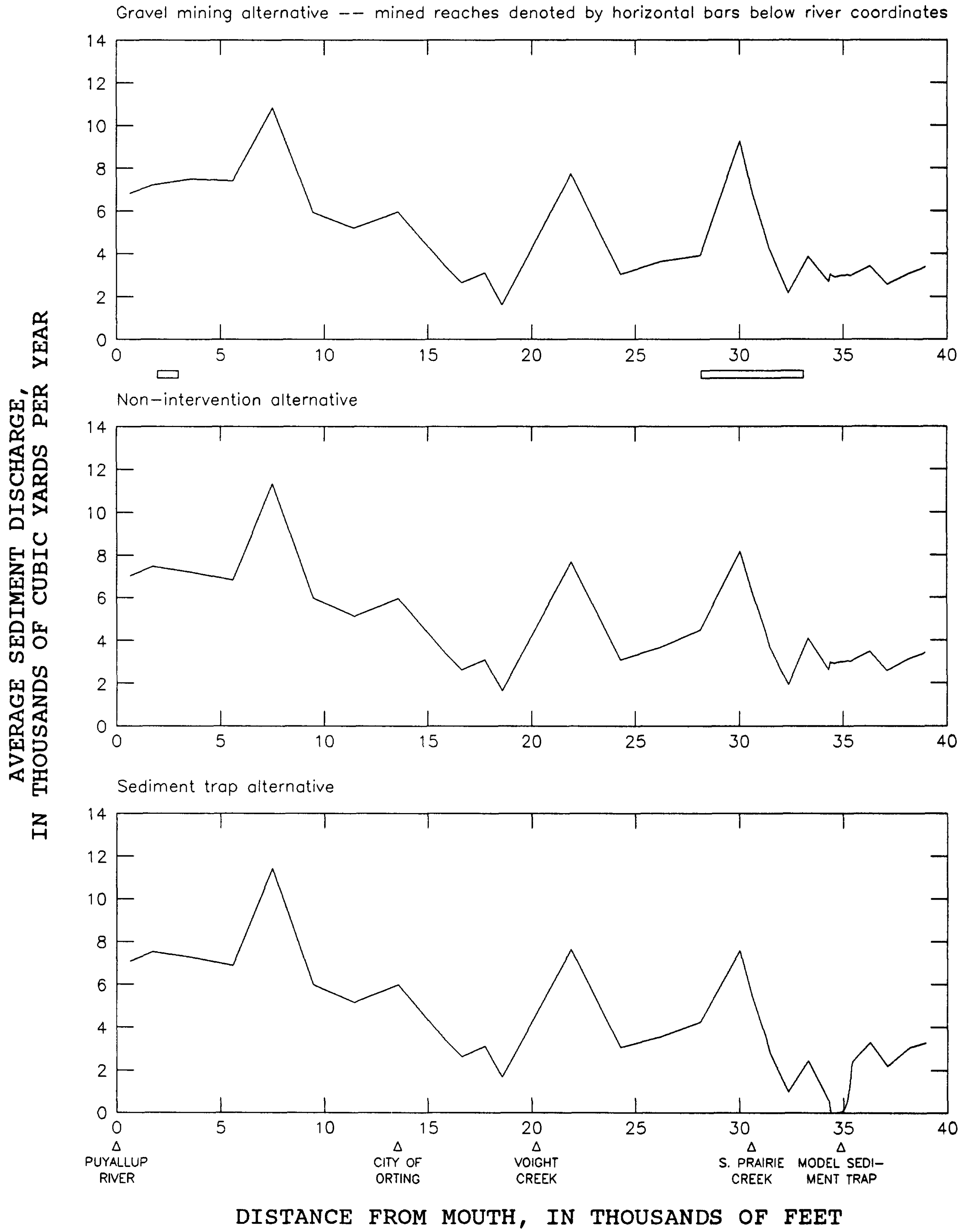

FIGURE D19.--Modeled average discharge of gravel and coarser material on the Carbon River during August 16, 1984, to July 31, 1987.

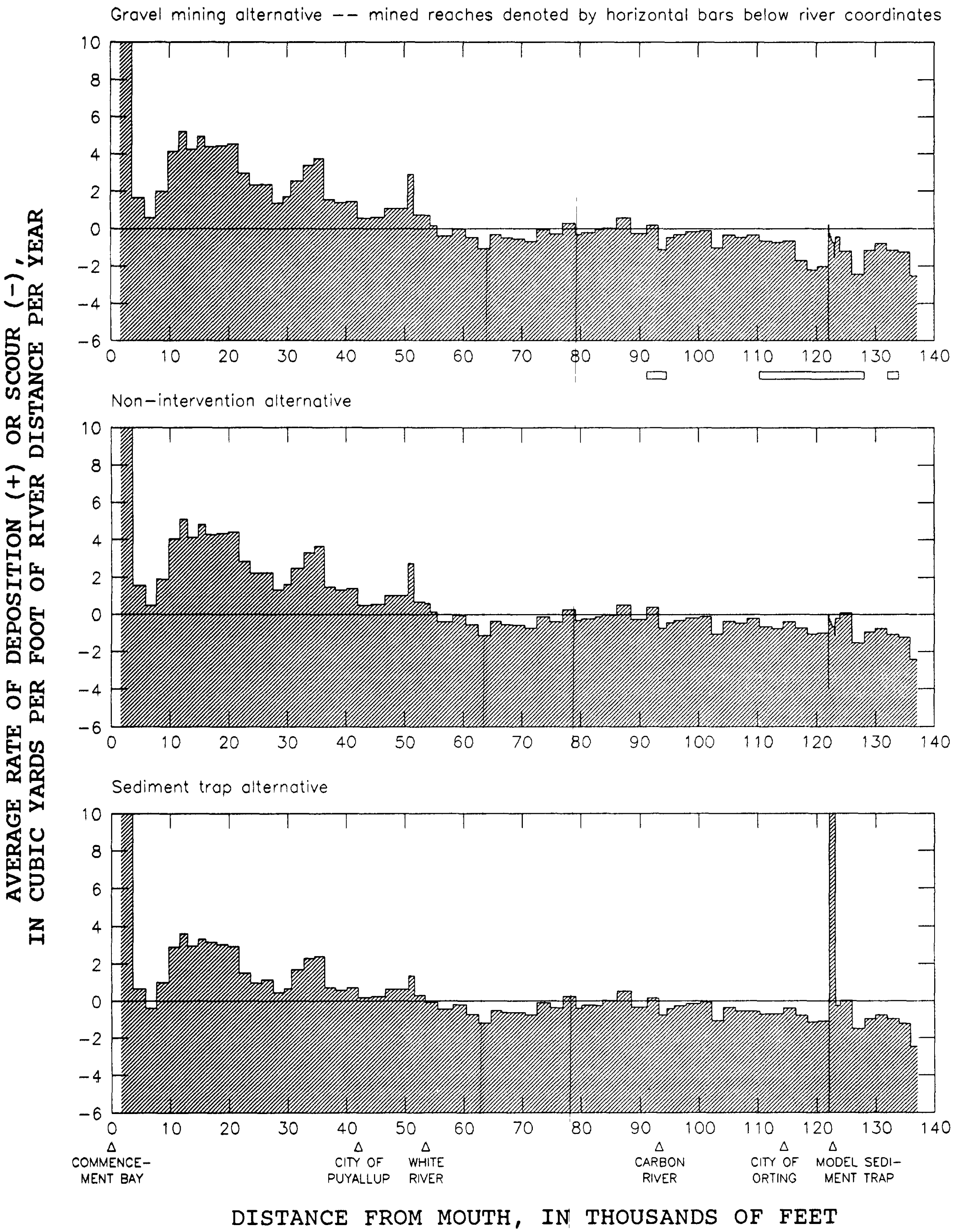

FIGURE D20.--Modeled deposition or scour of sand and finer material on the Puyallup River during August 16, 1984, to July 31, 1987.

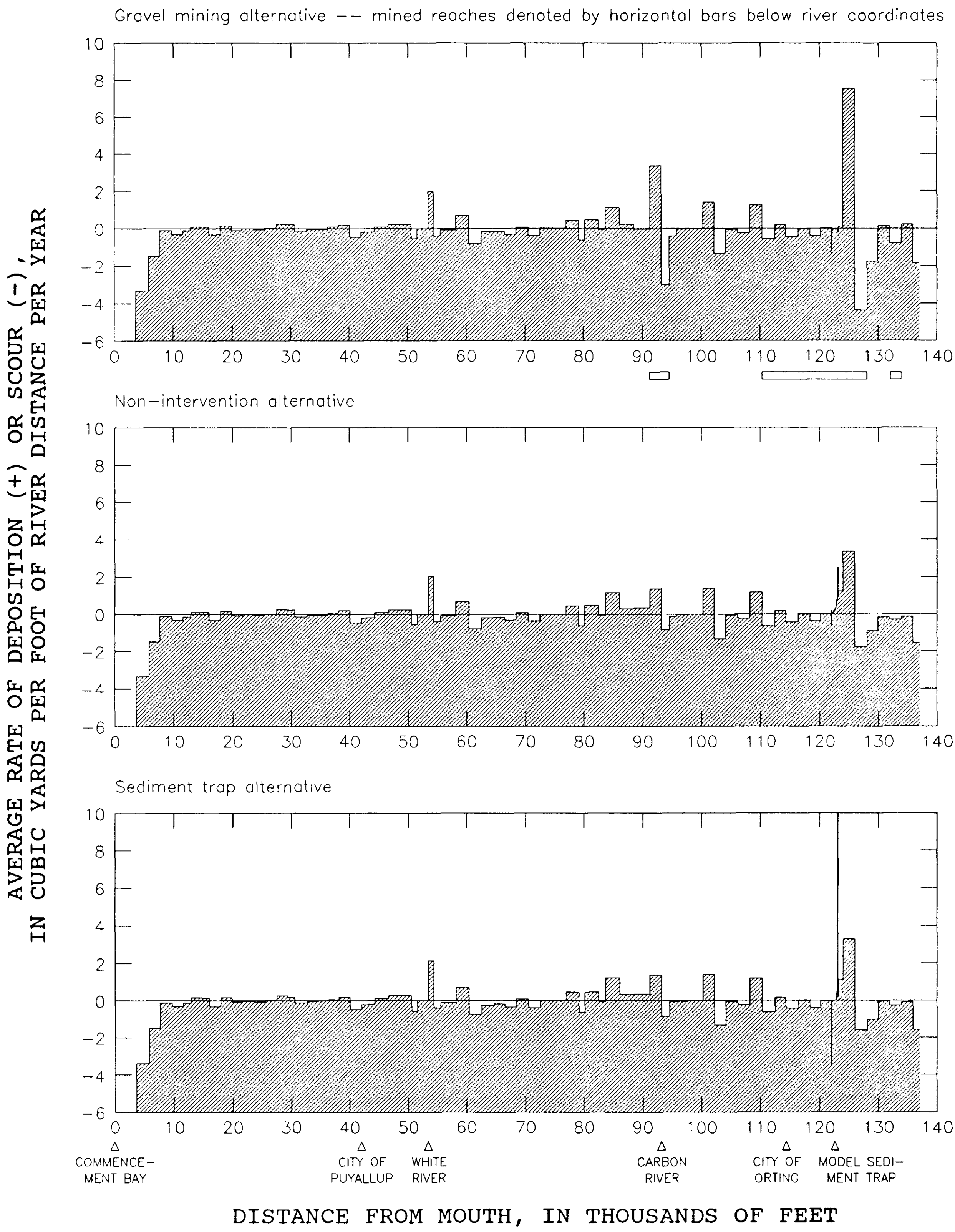

FIGURE D21.--Modeled deposition or scour of gravel and coarser material on the Puyallup River during August 16, 1984, to July 31, 1987.

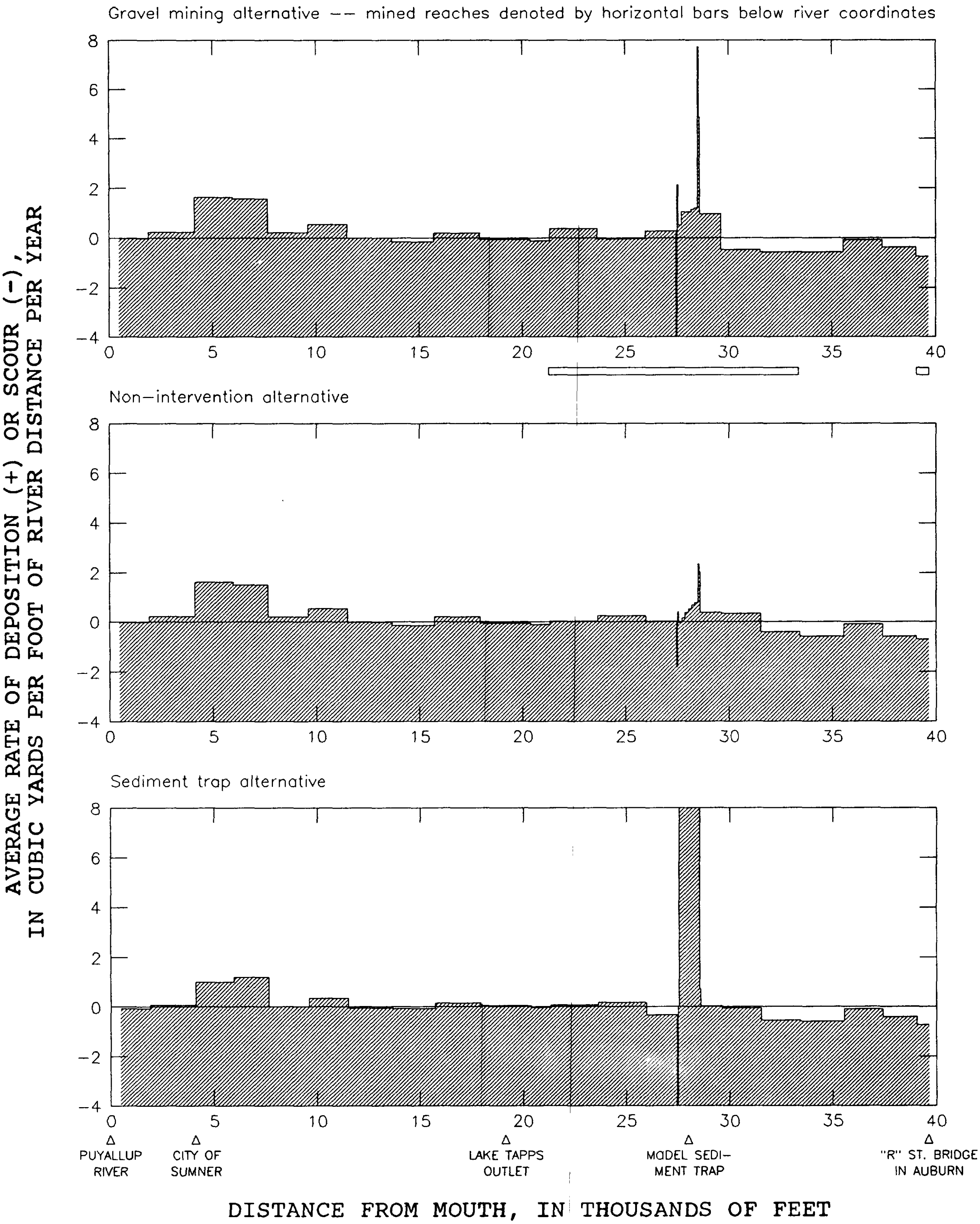

FIGURE D22.--Modeled deposition or scour of sand and finer material on the White River during July 27, 1984, to July 31, 1987.

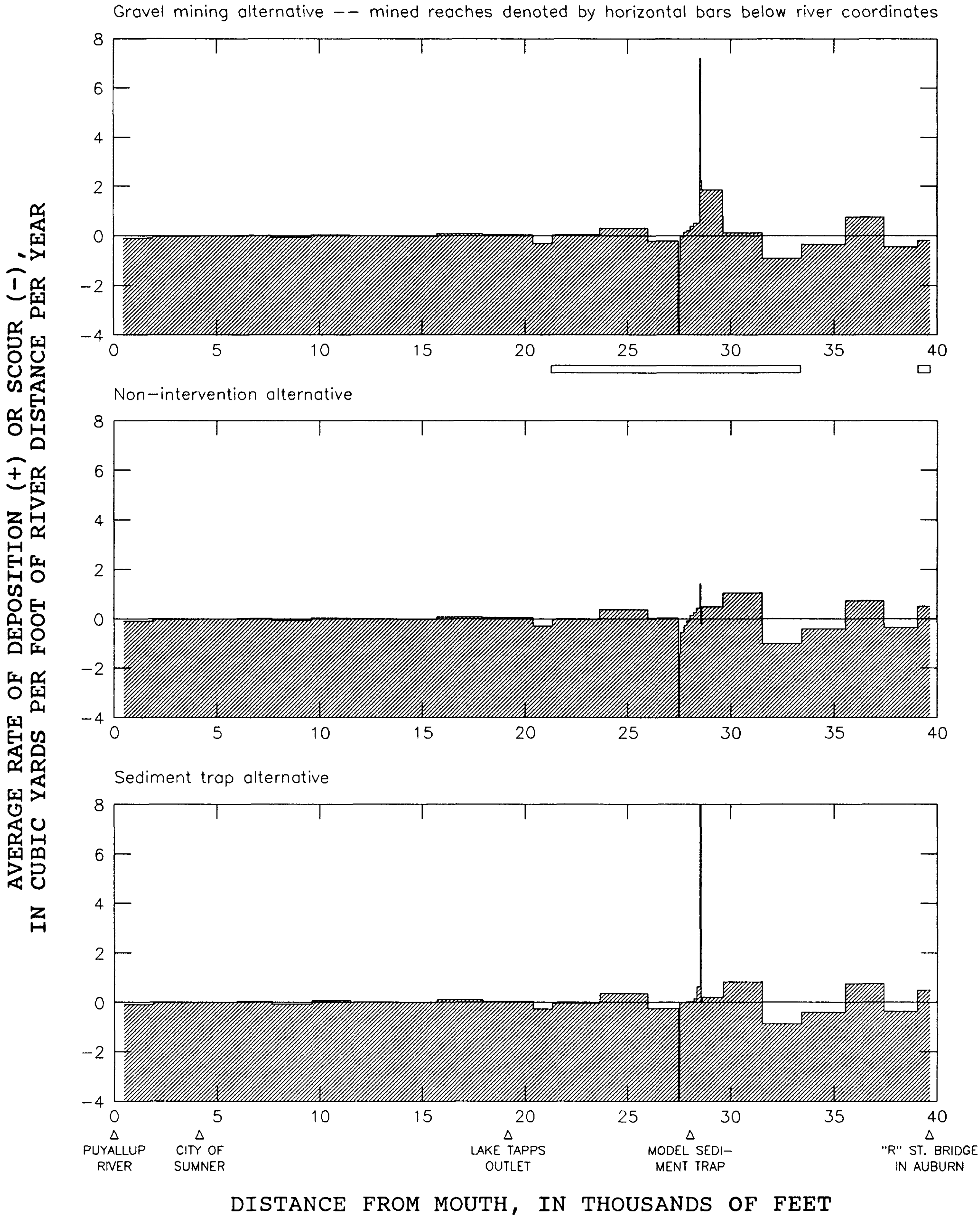

FIGURE D23.--Modeled deposition or scour of gravel and coarser material on the White River during July 27, 1984, to July 31, 1987.

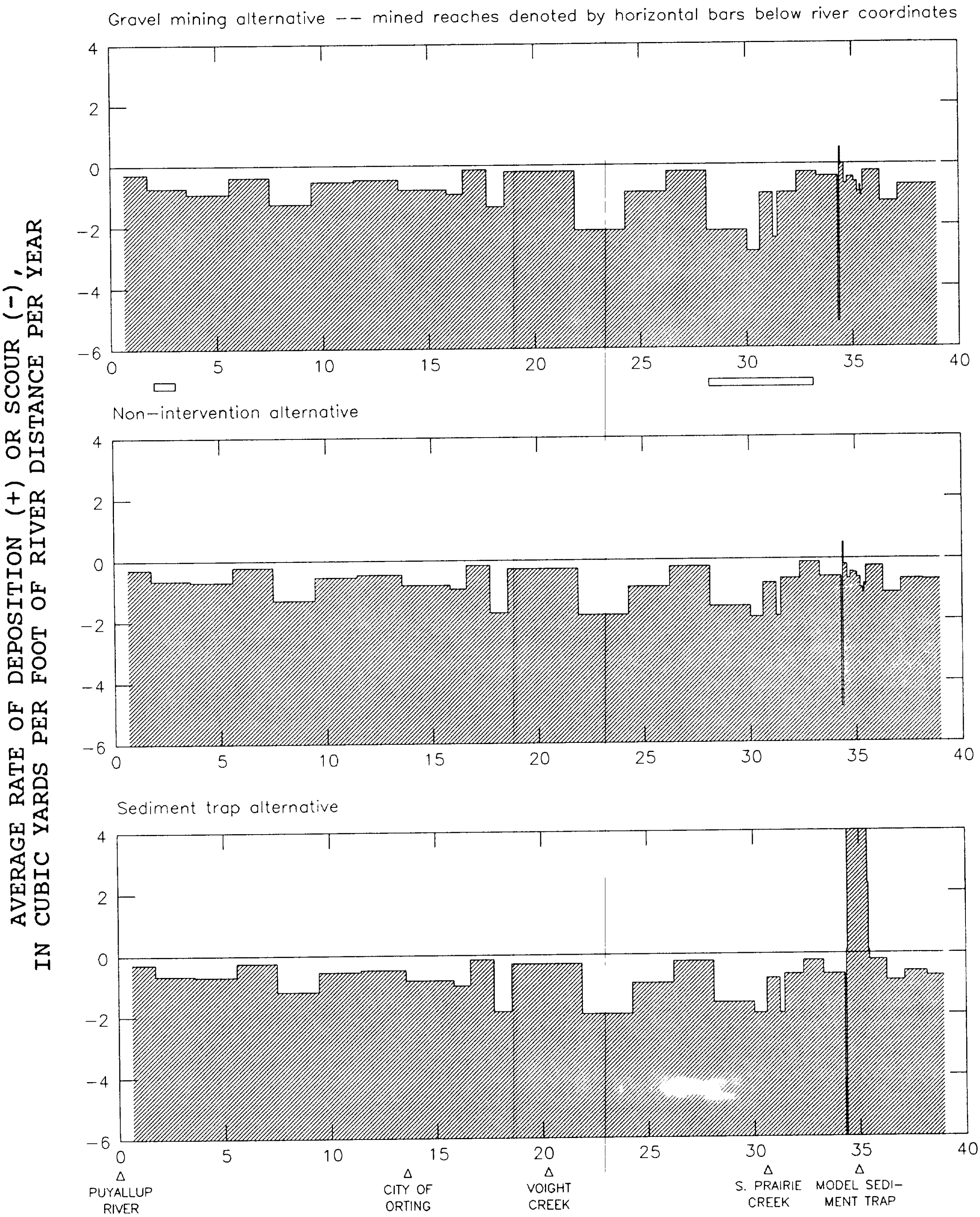

FIGURE D24.--Modeled deposition or scour of sand and finer material on the Carbon River during August 16, 1984, to July 31, 1987.

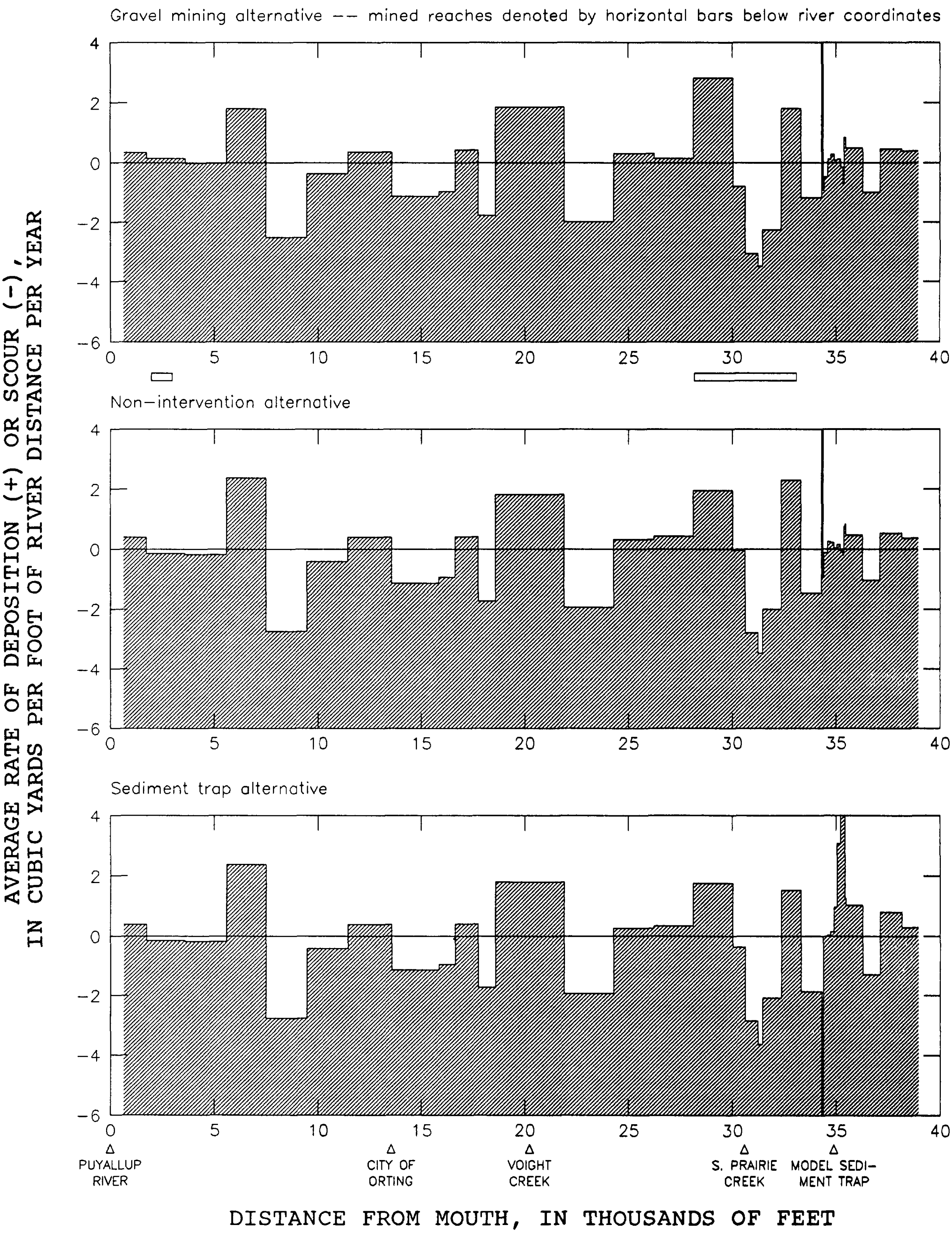

FIGURE D25.–Modeled deposition or scour of gravel and coarser material on the Carbon River during August 16, 1984, to July 31, 1987.

Table D12.--River reaches with substantial deposition of gravel and coarser material[1]

[g, deposition of gravel and coarser material; s, sand and finer material; t, all size classes]

River	Limit of reach, in feet from river mouth		Average rate of deposition (+) or scour (-), in cubic yards per foot of river length per year			Reach description[2]
	Downstream	Upstream	g	s	t	
Puyallup	124,000	126,000	3.4	0.1	3.5	In sediment control site /a/ near Orting, Washington (panel G)
Do.	123,200	124,000	1.2	-0.2	0.9	In sediment control site /a/ near Orting, Washington (panel G)
Do.	108,200	110,300	1.2	-0.2	1.0	Between mouth of Carbon River and Orting, Washington (panel F)
Do.	100,200	102,200	1.4	-0.1	1.3	Between mouth of Carbon River and Orting, Washington (panel F)
Do.	91,200	93,200	1.4	0.4	1.8	Near mouth of Carbon River (panel E)
Do.	83,700	86,100	1.2	0.0	1.2	Near McMillan, Washington (panel E)
Do.	53,500	54,400	2.0	0.6	2.6	Near mouth of White River (panel C)
White	29,600	31,500	1.1	0.3	1.4	Near Auburn, Washington (panel I)
Carbon	32,400	33,300	2.3	-0.1	2.2	Near Crocker, Washington (panel L)
Do.	28,200	30,000	1.9	-1.6	0.3	Near Crocker, Washington (panel K)
Do.	18,600	21,900	1.8	-0.3	1.5	Near Orting, Washington (panel K)
Do.	5,600	7,500	2.4	-0.2	2.2	Near Orting, Washington (panel F)

[1] Deposition rates were averaged during the time interval from July and August 1984 to July 31, 1987. The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

[2] The reference after each reach description is to a panel area shown in figure 6 (gravel deposition areas) or figure 8 (control sites); the same panel of figure A2, Appendix A, shows the area in more detail.

Table D13.--Effect of sediment traps on deposition of sand and finer material, showing average annual deposition in the indicated reaches from July and August 1984 to July 31, 1987[1]

River	Limits of sediment trap, in feet from river mouth: Downstream	Limits of sediment trap, in feet from river mouth: Upstream	Limits of deposition reach, in feet from river mouth: Downstream	Limits of deposition reach, in feet from river mouth: Upstream	Annual volume of sand and finer material, in cubic yards per year[2]: Deposition in reach without trap	Deposition in reach with trap	Reduction in deposition due to trap	Required maintenance removal from trap
Puyallup[3]	122,070	123,130	7,700	58,200	113,000	[4]69,000	[4]44,000	69,000
White[5]	27,510	28,560	500	27,500	8,000	5,000	3,000	84,000
White[3]	27,510	28,560	500	27,500	9,000	5,000	4,000	86,000
Carbon[3]	34,370	35,430	no significant deposition of sand and finer material					24,000

[1] The starting date was August 16, 1984, for the Carbon and Puyallup Rivers. The starting date for the White River was July 27, 1984, but the slightly shorter period starting August 16, 1984, is also given because of the influence of the White River trap on the Puyallup River.

[2] All four columns refer only to sand and finer material, and exclude annual volumes of gravel and coarser material.

[3] August 16, 1984, to July 31, 1987.

[4] Includes reduction of sand and finer load due to traps on the White and Carbon Rivers, as well as on the Puyallup River.

[5] July 27, 1984, to July 31, 1987.

Table D16.--Downstream effect of sediment traps on deposition of gravel and coarser material, showing average annual deposition in the indicated reaches from July and August 1984 to July 31, 1987[1]

	Limits of sediment trap, in feet from river mouth		Limits of deposition reach, in feet from river mouth		Annual volume of gravel and coarser material, in cubic yards per year[2]			
River	Downstream	Upstream	Downstream	Upstream	Deposition (+) or scour (-) in reach without trap	Deposition (+) or scour (-) in reach with trap	Reduction in deposition and (or) increase in scour due to trap	Required maintenance removal from trap[3]
Puyallup	122,100	123,100	120,200	122,100	100	-200	300	800
White	27,500	28,600	26,000	27,500	-300	-1,000	700	1,300
Carbon	34,400	35,400	28,100	34,400	-1,500	-4,200	2,700	2,400

[1] The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

[2] All four columns refer only to gravel and coarser material, and exclude annual volumes of sand and finer material.

[3] The column refers to the total required maintenance removal of gravel and coarser material from the trap; this quantity is duplicated in table D17, and the values from the two tables should not be added.

Table D17.--Upstream effect of sediment traps on deposition of gravel and coarser material, showing average annual deposition in the indicated reaches from July and August 1984 to July 31, 1987[1]

	Limits of sediment trap, in feet from river mouth		Limits of deposition reach, in feet from river mouth		Annual volume of gravel and coarser material, in cubic yards per year[2]			
River	Downstream	Upstream	Downstream	Upstream	Deposition (+) or scour (-) in reach without trap	Deposition (+) or scour (-) in reach with trap	Reduction in deposition and (or) increase in scour due to trap[3]	Required maintenance removal from trap[4]
Puyallup	122,100	123,100	123,100	132,000	2,200	2,200	0	800
White	27,500	28,600	28,600	33,400	600	100	500	1,300
Carbon	34,400	35,400	35,400	39,000	400	900	-500	2,400

[1] The starting date was July 27, 1984, for the White River, and August 16, 1984, for the Carbon and Puyallup Rivers.

[2] All four columns refer only to gravel and coarser material, and exclude annual volumes of sand and finer material.

[3] The negative value for the Carbon River indicates an increase in deposition.

[4] The column refers to the total required removal of gravel and coarser material from the trap; this quantity is duplicated in table D16, and the values from the two tables should not be added.