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Hydraulic and Habitat Analysis of Nataga Creek Bridges

Final Report
Project No. 51-005

Prepared for:

Alaska Department of Natural Resources,
Division of Forestry

Prepared by:

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November 23, 1995

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HYDRAULIC AND HABITAT ANALYSIS OF NATAGA CREEK BRIDGES

OBJECTIVE

The Alaska Department of Natural Resources, Division of Forestry, (DNR) maintains two logging road bridges over a wide, braided, gravel/cobble deposition area of Nataga Creek several hundred feet above the confluence with the Kelsall River. Pentec Environmental, Inc. (Pentec), has conducted a study of the effects of the Nataga bridges on channel characteristics and fish habitat conditions. The objective of this analysis has been to answer the following questions raised by personnel from the Alaska Department of Fish and Game:

1. Do the Nataga bridges form velocity barriers to upstream passage of chinook salmon?

2. Do the Nataga bridges increase channel scour and therefore redd excavation?

3. Are the Nataga bridges causing massive sediment deposition upstream and creating the potential for a large sediment blowout?

4. Should the isolated steel span on the Kelsall River be removed because it creates a potential hazard to downstream fish habitat?

A previous qualitative assessment of these questions has been conducted by hydrologists employed by the US Forest Service (USFS), Richard Smith and Adelaide Johnson (Smith and Johnson, June 23, 1992). Pentec's study is more comprehensive than the USFS evaluation and includes an assessment of channel history from aerial photographs and quantitative hydraulic evaluations. This report provides a brief description of Nataga Creek, documents our methodology for assessing channel conditions, presents our findings and discusses previous findings, and makes suggestions for future management alternatives.

DESCRIPTION OF NATAGA CREEK

Nataga Creek drains a 31-square-mile basin straddling the United States/Canada border northwest of Haines, Alaska. The basin drains the northern flank of Mount Princep (approximately 6,100 ft in elevation) and the southwestern flank of Mount Seltat (6,525 ft in elevation). The summit of Mount Seltat is the high point of the watershed. Nataga Creek flows into the Kelsall River at an elevation of approximately 260 ft (USGS 1963). The Kelsall River subsequently flows into the Chilkat River and the Lynn Canal. The Nataga Creek basin within the United States is illustrated in Figure 1.

Average annual precipitation in the Nataga Creek basin is estimated to be 80 to 100 inches (Jones and Fahl 1994). Most peak annual flows in this area of Alaska are caused by fall and early winter rainfall events. October and November are the months in which peak annual flows are most likely to occur (Jones and Fahl 1994). The period of lowest streamflows coincides with the period of lowest precipitation, from May through July. Streamflows increase in response to spring snowmelt, but spring snowmelt rarely produces the peak annual flow in Southeast Alaska (Martin et al. 1995). The following peak flow rates have been estimated for Nataga Creek using the USGS regional regression equation (Jones and Fahl 1994):

Average return interval of exceedance flows	Flow (cfs)
2-year	1,420
5-year	1,970
10-year	2,360
25-year	2,890
50-year	3,320
100-year	3,740

Nataga Creek carries a very large sediment load relative to its flow regime; therefore, it features an active channel that is much larger than necessary to convey typical flood flows. Typically, the devegetated channel cross section in a mountain stream can only convey flows on the order of the 2-year flow or less, but the devegetated channel cross section of Nataga Creek can convey approximately the 25-year flow.

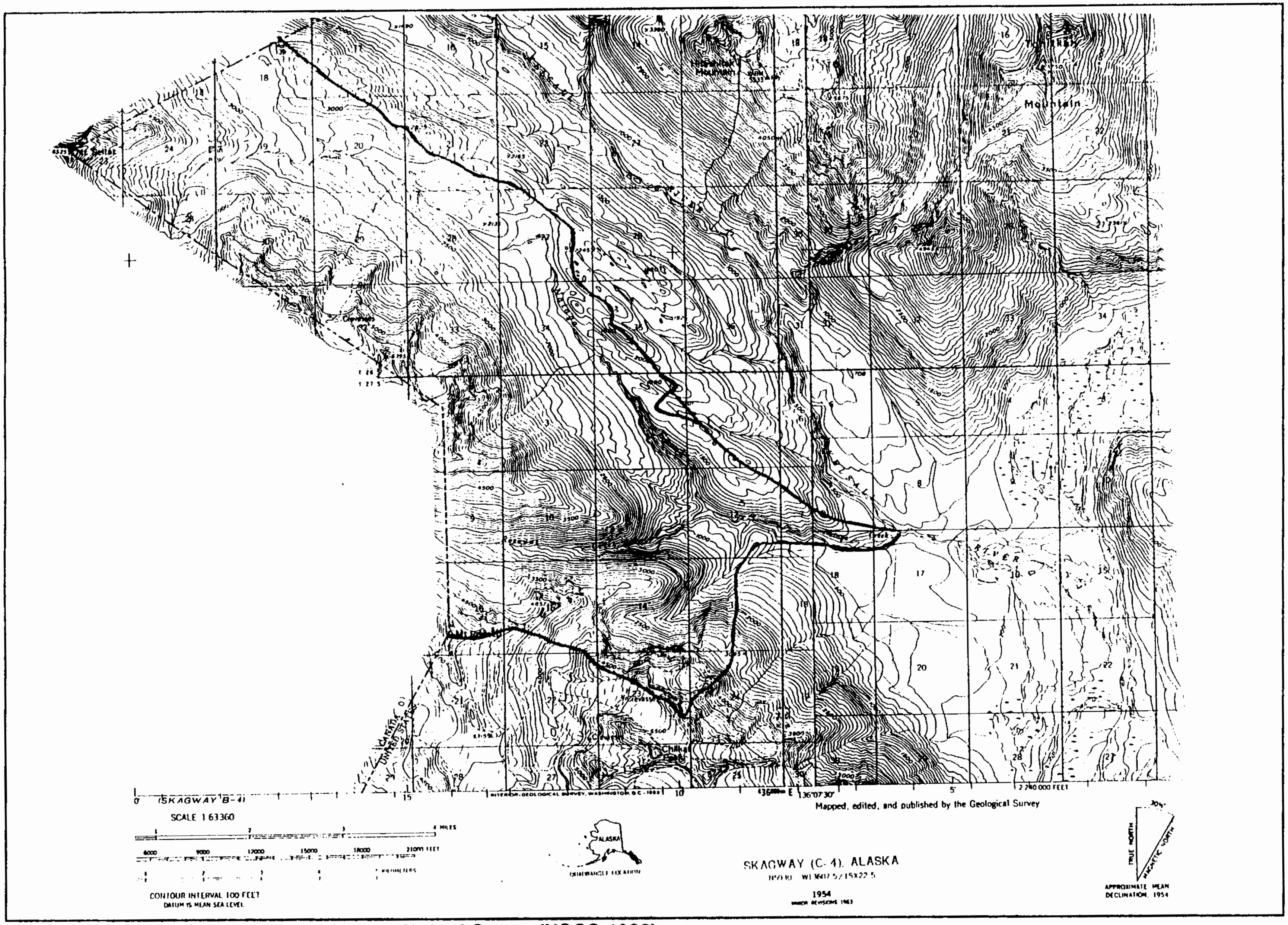

Figure 1 Nataga Creek basin within the United States (USGS 1963).

For most of its length, Nataga Creek drops steeply from the mountains; typical channel gradients are 6 to 7 percent, with some sections exceeding 20 percent and other sections averaging only about 3 percent. A longitudinal profile of the stream is shown in Figure 2. Just above the bridges, Nataga Creek's channel gradient drops from about 7 percent to as little as 2 percent as it approaches the valley floor of the Kelsall River. On August 16, 1995, the slope of the water surface at the southern bridge was less than 1 percent, and at the northern bridge it was about 2 percent. Water surface profiles at each bridge are shown in Figures 3 and 4. Massive sediment deposition occurs naturally in the reach above the bridges. The stream is highly braided in this reach, and the primary channels are active, changing location frequently. The creek's flow regime relative to its sediment load is not strong enough to scour and maintain a consistent channel. A photocopy of a 1961 aerial photograph, prior to installation of any bridge crossings, showing the natural braiding of the channel is provided in Figure 5.

Because the Nataga bridges are only 250 to 300 ft upstream of the confluence with the Kelsall River, movement of the main channel of the Kelsall River can significantly impact the channel gradient and sediment routing of lower Nataga Creek. Nataga Creek has formed a deltaic deposit at its mouth, and the channel of Nataga Creek must drop from its perch upon this deposit to reach the Kelsall. If the Kelsall moves to its right bank and cuts 50 ft of the delta deposit at the base of Nataga Creek, the average gradient of the lower Nataga would be doubled. When the primary channel of the Kelsall moves to its left bank, the Nataga delta can elongate and reduce the channel gradient below the bridges. Thus the channel behavior of the Kelsall is an important determinant of channel form and sediment routing of the lower Nataga below the bridges.

One of the reasons for the high sediment load is that the Nataga Creek basin is located near an active plate boundary. The Denali fault, which runs north-south through the Nataga/Kelsall valley, is a transform fault very similar to the San Andreas fault in California. The west side of the Nataga/Kelsall valley is moving north relative to the east side of the valley (Gehrels and Berg 1992). The northward movement along the Denali fault has sheared and fractured the relatively weak Triassic sedimentary rocks of the Nataga basin. Another reason for the high sediment load is that alpine glaciers in the headwaters of Nataga Creek are carving the tectonically weakened and sheared bedrock.

Nataga Creek provides spawning and rearing habitat for chinook salmon. The chinook enter Nataga Creek in July and August and spawn shortly thereafter. Two mating pairs of chinook salmon were observed spawning above the bridges during our stream survey conducted on August 15, 1995. The eggs of the chinook salmon incubate in the gravel before hatching, and

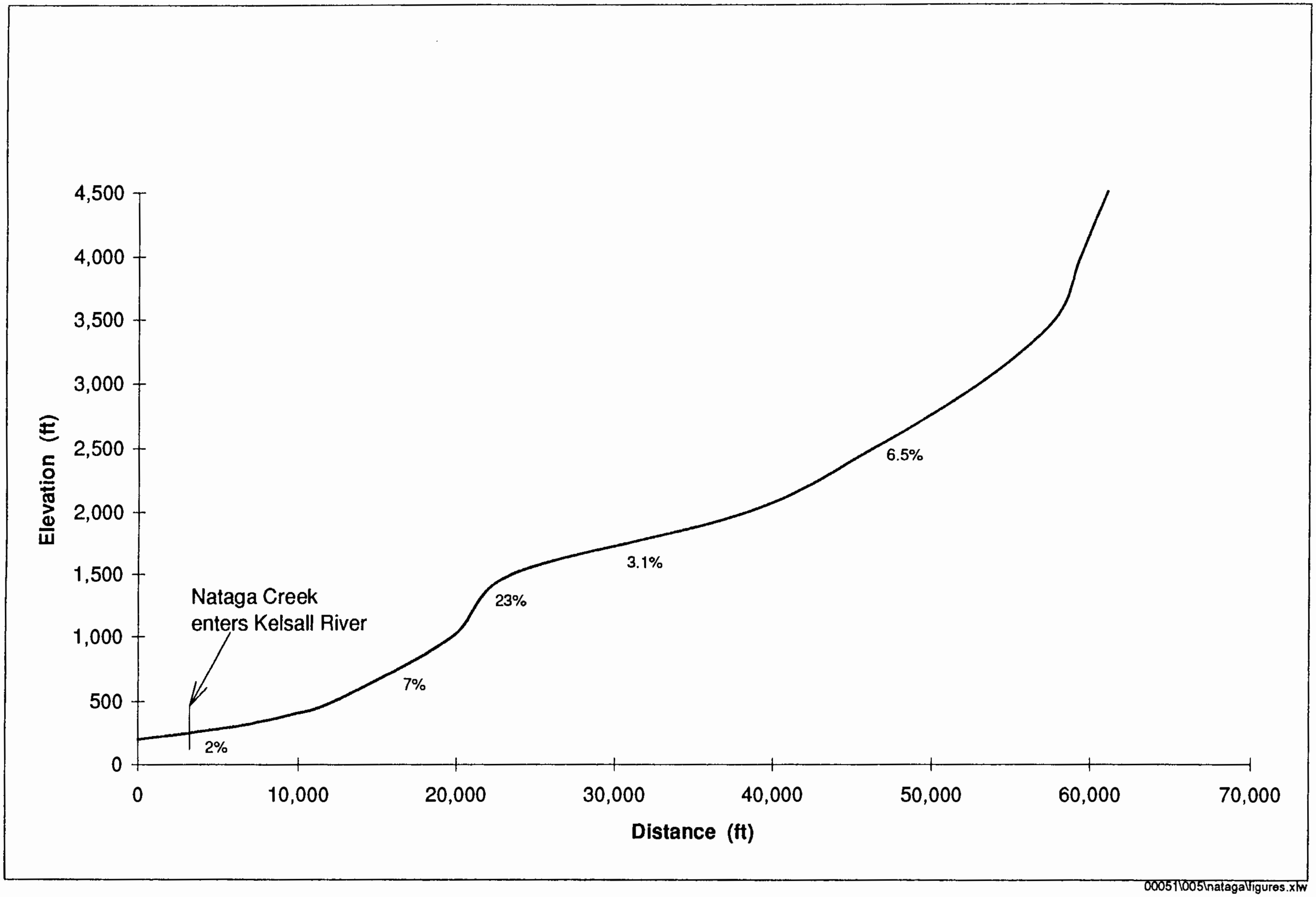

Figure 2 Nataga Creek longitudinal profile.

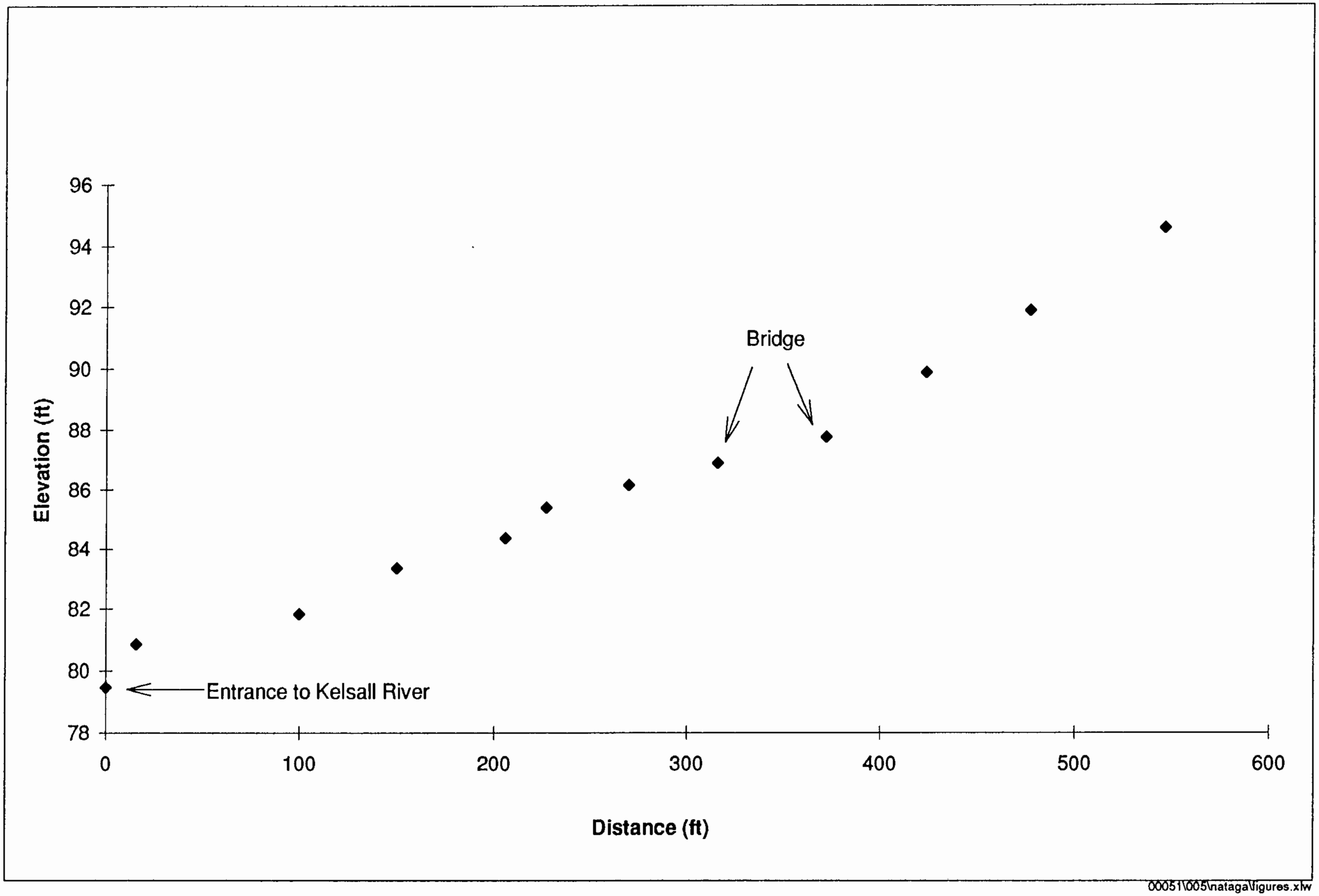

Figure 3 Left channel longitudinal profile.

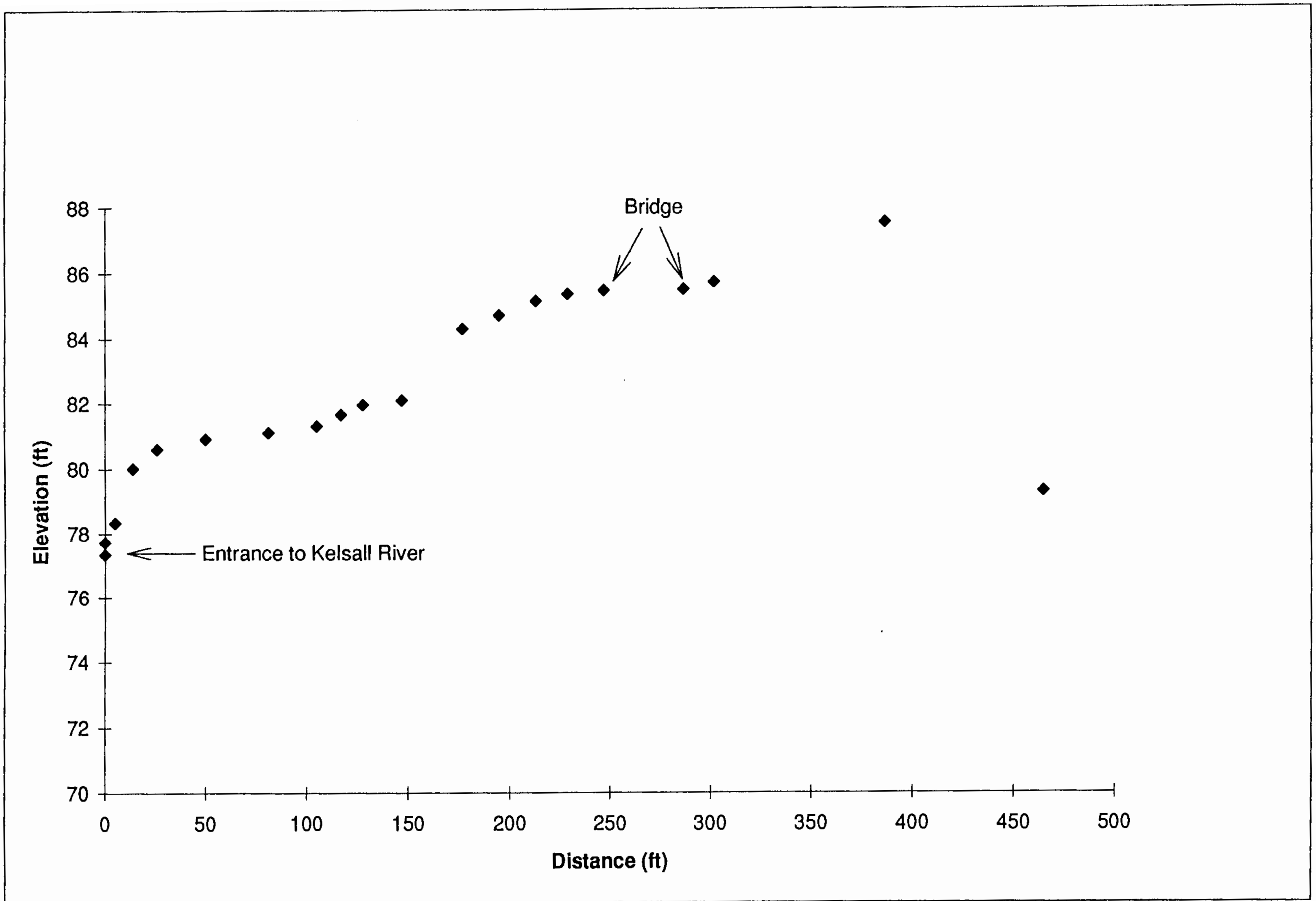

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Figure 4 Right channel longitudinal profile.

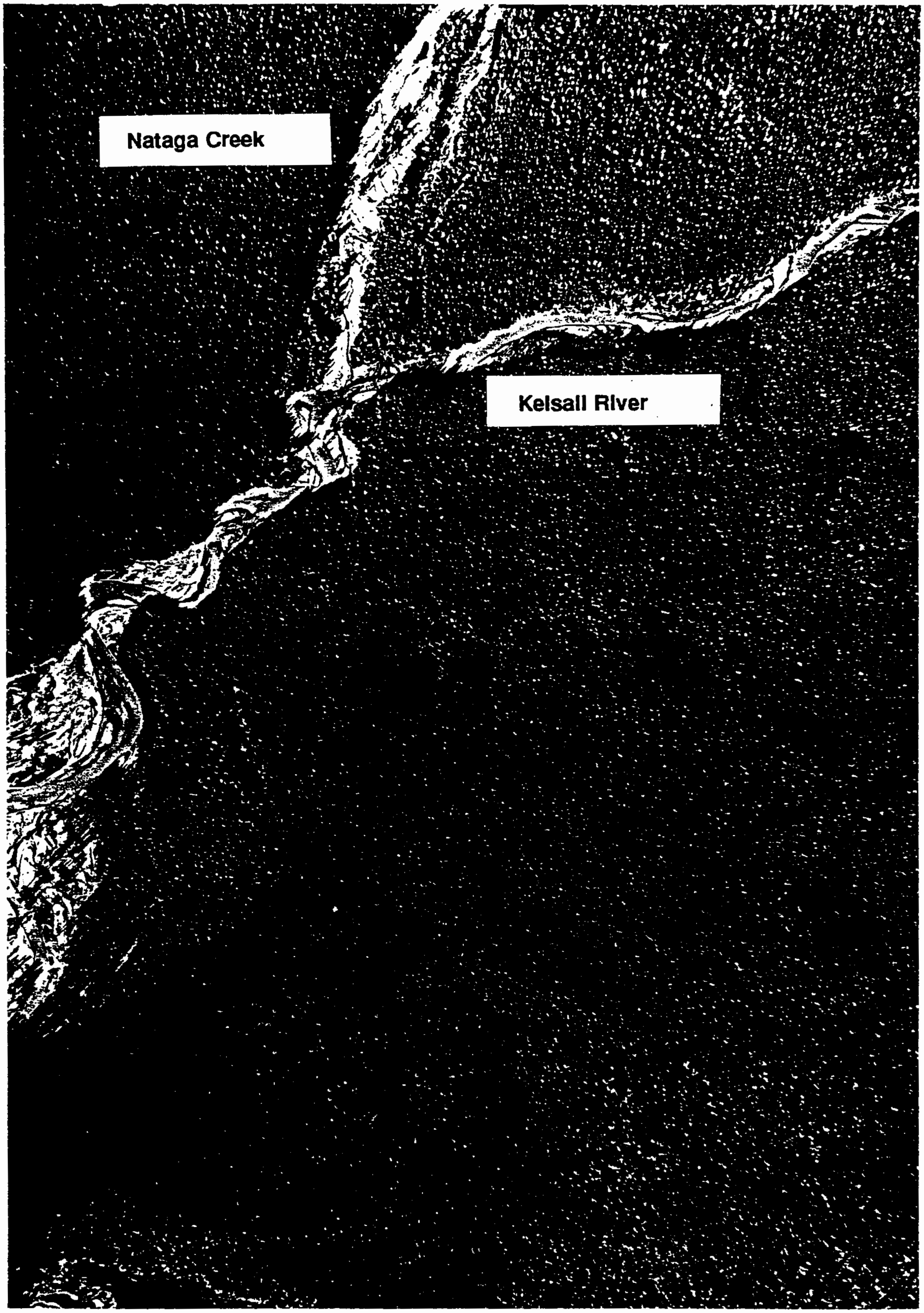

Figure 5 Copy of 1961 aerial photograph showing braiding in lower Nataga Creek.

the alevins remain in the gravel until they have absorbed their yolk sacs. The total period of egg incubation and alevin development in Southeast Alaska can be as long as 6 months (Scott and Crossman 1973). During the period of incubation and alevin development, substantial mortality may be incurred due to various factors including redd scour by high flows or dewatering of the gravel as a result of channel abandonment. In Nataga Creek, the incubation and alevin development period continues through September and October, the months during which high flows and channel scour are likely.

METHODS

AERIAL PHOTOGRAPH ANALYSIS

DNR supplied Pentec with stereo aerial photographs of lower Nataga Creek. Photographs from the following years were analyzed with respect to channel width and configuration:

1961 - Prior to installation of bridges
1970
1976
1978 - Single photograph without stereo pair
1981
1993 - Infra-red photographs

LONGITUDINAL PROFILE

On August 16, 1995, Jeff Kirtland of Pentec and DNR personnel surveyed the profiles of the northern and southern channels of lower Nataga Creek. Because the depths and velocities of flow in the thalwegs of the channels were often too great to allow them to be safely surveyed, a water surface profile was surveyed rather than a profile of the channel bottom. Surveys of each channel were begun at the Kelsall River and continued to a point approximately 200 ft upstream of each bridge. The water surface profiles were used to gage the gradients of the channels and to determine whether changes in the channel profile were associated with the bridges.

HEC2 ANALYSIS

The HEC2 model, the United States Army Corps of Engineers' standard flood plain analysis computer program, is currently the standard accepted program for analyzing hydraulics of rivers and streams. The HEC2 model was used here to estimate average channel velocities, flow depths, and average channel shear stresses at several locations in the northern and southern channels of Nataga Creek. This hydraulic model allowed us to estimate the effect of the bridges on flow cross sections, flow velocities, and channel scour.

The HEC2 model assumes one-directional, steady flow, and it calculates flow characteristics based on input data regarding channel cross sections, channel slopes, and channel roughness. HEC2 provides output regarding flow cross sections, water surface profiles, the energy grade line, velocities, shear stresses, and other flow characteristics. Backwater hydraulic models like HEC2, however, are not well suited for the analysis of braided streams. In a braided stream such as Nataga Creek, flow can spread out of the primary channel into multiple channels as flow increases, so the relevant channel cross section depends on the flow level. A complete analysis of such a system requires many channel cross section surveys so that each potential side channel is characterized and referenced to a base elevation. Such a detailed investigation was beyond the scope and need of this analysis. Instead, the upper channel cross sections were simplified for higher flow scenarios to allow water to spread out over a relatively uniform flood plain rather than to cascade into separate side channels. This simplification will tend to overestimate the hydraulic effects of the bridge while not distorting the results significantly.

Flows were split between the northern and southern channel on a 90 percent/10 percent basis. This is the approximate flow apportionment observed by Smith and Johnson in 1992 and by Pentec in 1995. It is not known how this apportionment changes at higher flows.

CHANNEL CROSS SECTIONS

Six cross sections of each channel were surveyed to define the hydraulic characteristics of the channel for the HEC2 model. For each channel, the set of cross sections included two below the bridge, two above the bridge, and one each on the upstream and downstream sides of the bridge. The locations of the cross sections are shown in Figure 6. About 325 ft of channel were covered by the cross sections. The elevations of the channel cross sections were tied to temporary benchmarks placed near the channel. Elevation differences and channel distances

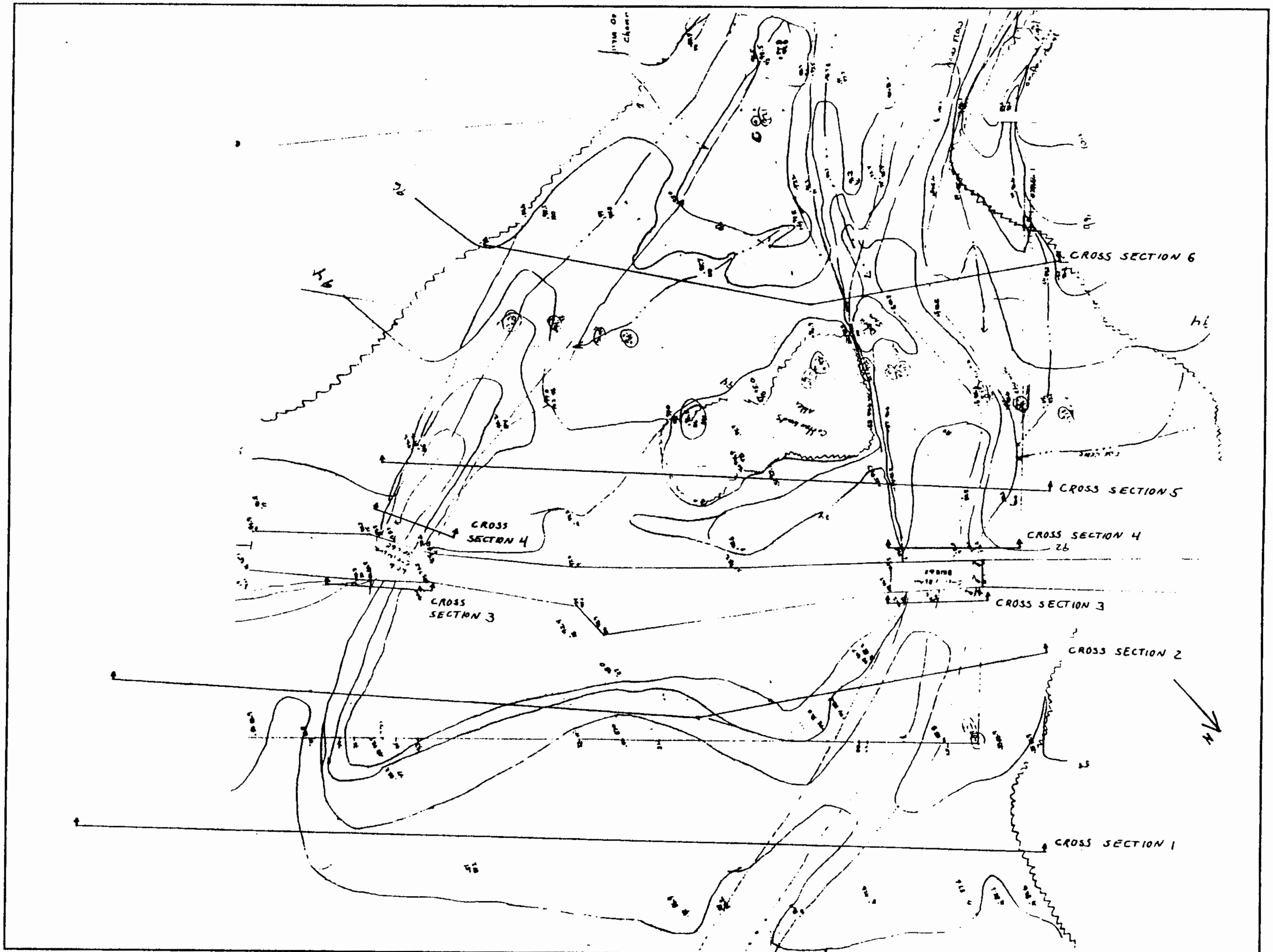

Figure 6 Cross section locations.

between cross-sections were measured to define channel gradients. Flow measurements were also taken to calculate a Manning's roughness coefficient of 0.035 for the channel.

RESULTS

CHANNEL HISTORY

The following channel history has been constructed from six sets of aerial photographs dating from 1961. Only the 1961 photographs show the channel before roads and bridges were constructed.

- 1961—No bridges or roads had been constructed. The principal channel flowed through the forested bar on the northern margin of the flood plain. There were many small channels, however, and the lower system was very braided (see Figure 7).

- 1970—A road and bridge system had been constructed across Nataga Creek and Kelsall River (see Figure 8). Lower Nataga Creek flowed into primary channels on opposite sides of the flood plain. The Nataga road crossed a wide gravel bar in the middle of the flood plain between the two channels.

- 1976—A large storm flow had swept over the gravel bar in the center of the flood plain and created multiple braided channels. No obvious primary channels existed. The flow washed out the southern bridge and the road across the flood plain. The northern bridge and the Kelsall bridge were intact.

- 1978—The road system had been replaced. The channel system in lower Nataga Creek had developed the basic configuration that has prevailed until the present (1995). Lower Nataga Creek flowed in two primary channels, one through the southern bridge and one through the northern bridge. In 1978, however, the southern channel appeared to carry the majority of the flow. Also, the Kelsall bridge approach forced the flow in the northern channel farther to the north than it flows currently (in 1995).

- 1981—Channel and road configuration were basically unchanged since 1978.

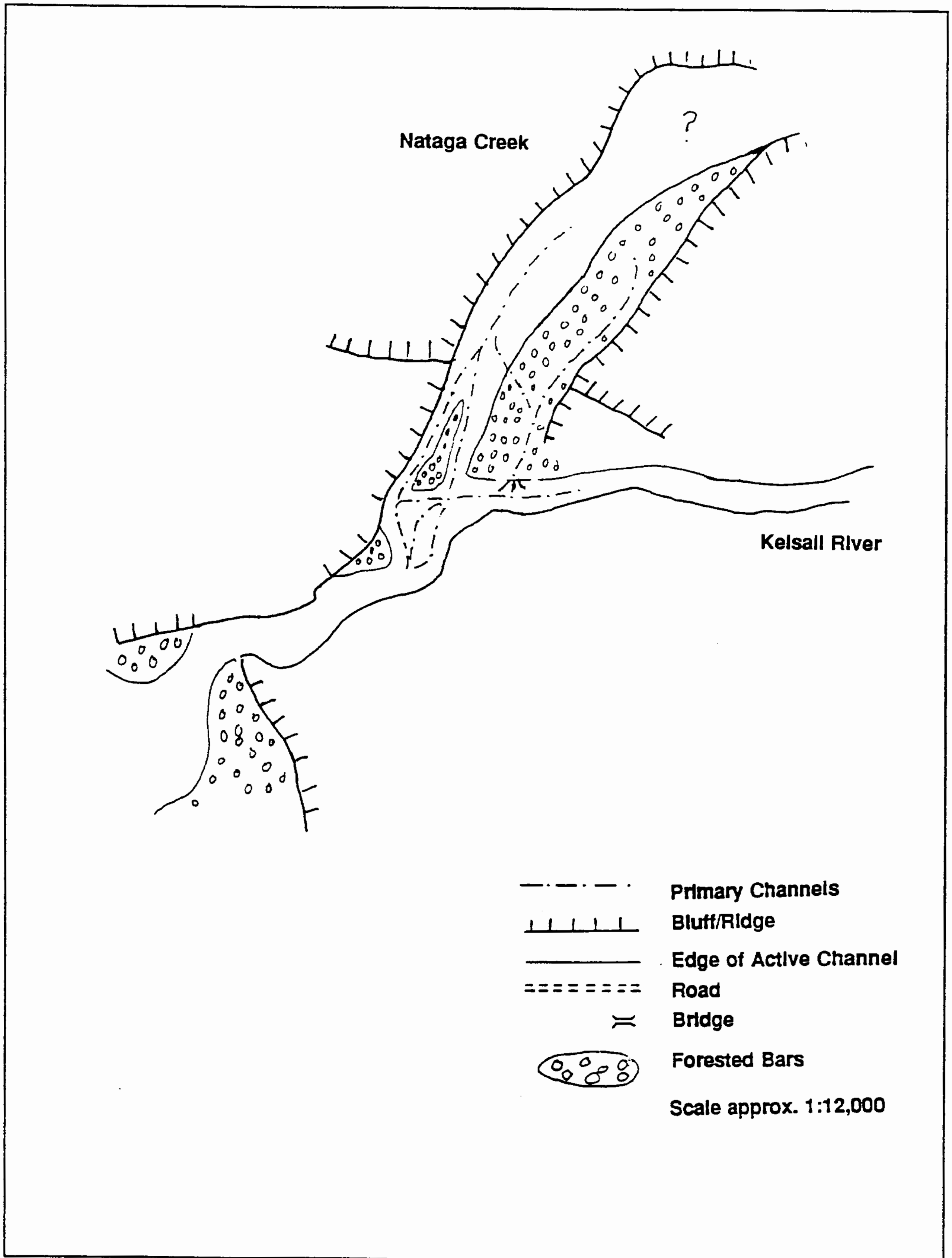

Figure 7 1961 channel configuration.

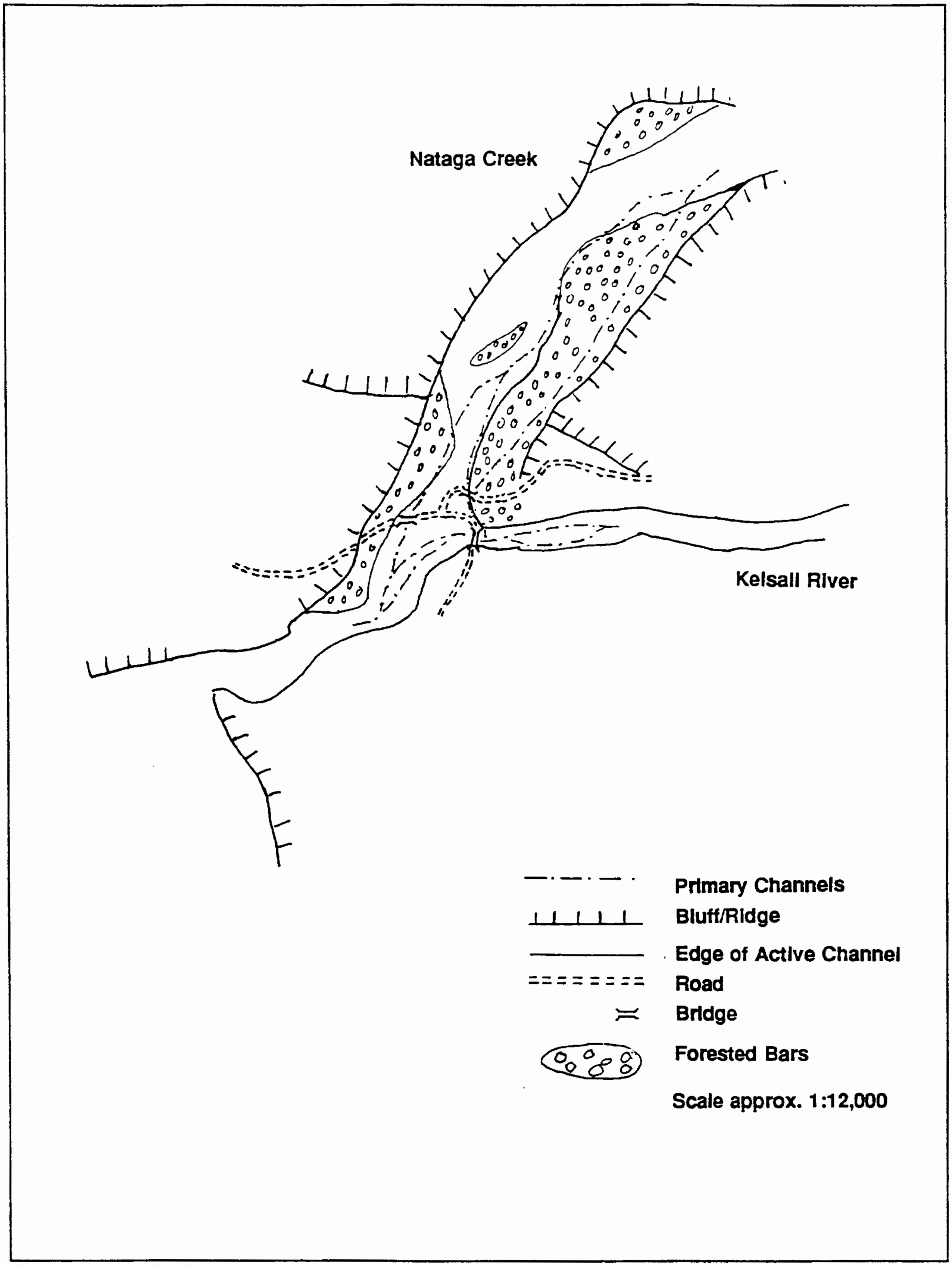

Figure 8 1970 channel configuration.

- 1993—The 1993 photograph shows the effects of the washout of the Kelsall bridge approach in 1986. After flowing through the bridge, the northern channel turned gently to the south, flowing across the former location of the Kelsall approach. As opposed to flow conditions in 1978 and 1981, the large majority of flow was in the northern channel in the 1993 photograph. This is the same channel configuration and flow apportionment observed by Smith and Johnson in 1992, mapped by DNR in 1986, and observed in August 1995 (see Figure 9). With the exception of the slight migration of the northern channel below the bridge, this channel configuration is very similar to that of 1978 and 1981. The Nataga road still crossed the Nataga flood plain on a wide gravel bar. The long-term stability of the bar (at least 17 years as of 1995) was manifesting itself in the growth of dense vegetation on the bar.

In every photograph year, the reach of Nataga Creek above the location of the road and bridges was highly braided. None of the photographs show any significant widening or narrowing of the active channel area or flood plain or any significant bank destabilization. Also in every photograph year, Nataga Creek flowed into the Kelsall River in multiple channels. The photograph series demonstrates that the bridges and roads help stabilize the channel configuration at the mouth of Nataga Creek. While the flow has reapportioned itself on occasion, the present configuration of the northern and southern channels has been stable for the past 17 years. The present road and bridge configuration has reduced channel abandonment and migration in the lowest 600 ft of Nataga Creek.

CHANNEL PROFILE/CROSS SECTIONS

The longitudinal profiles of the water surface of each channel do not show significant impacts to the channel profile as a result of the bridges. The profile for the left (northern) channel does indicate a potential area of scour extending about 50 ft upstream of the bridge. This correlates with scour predictions from the hydraulic model discussed later. There is no evidence of significant sediment deposition caused by the bridges. The channel cross sections do demonstrate that the bridges constrict the flow area of the channel during high flows.

FLOW VELOCITIES

During migration flows, the bridges do not constrict the flow area enough to increase flow velocities. The results of the hydraulic model show that average channel velocities are mostly a function of local channel slope during normal migration flows. Flows of 110 and 10 cfs were

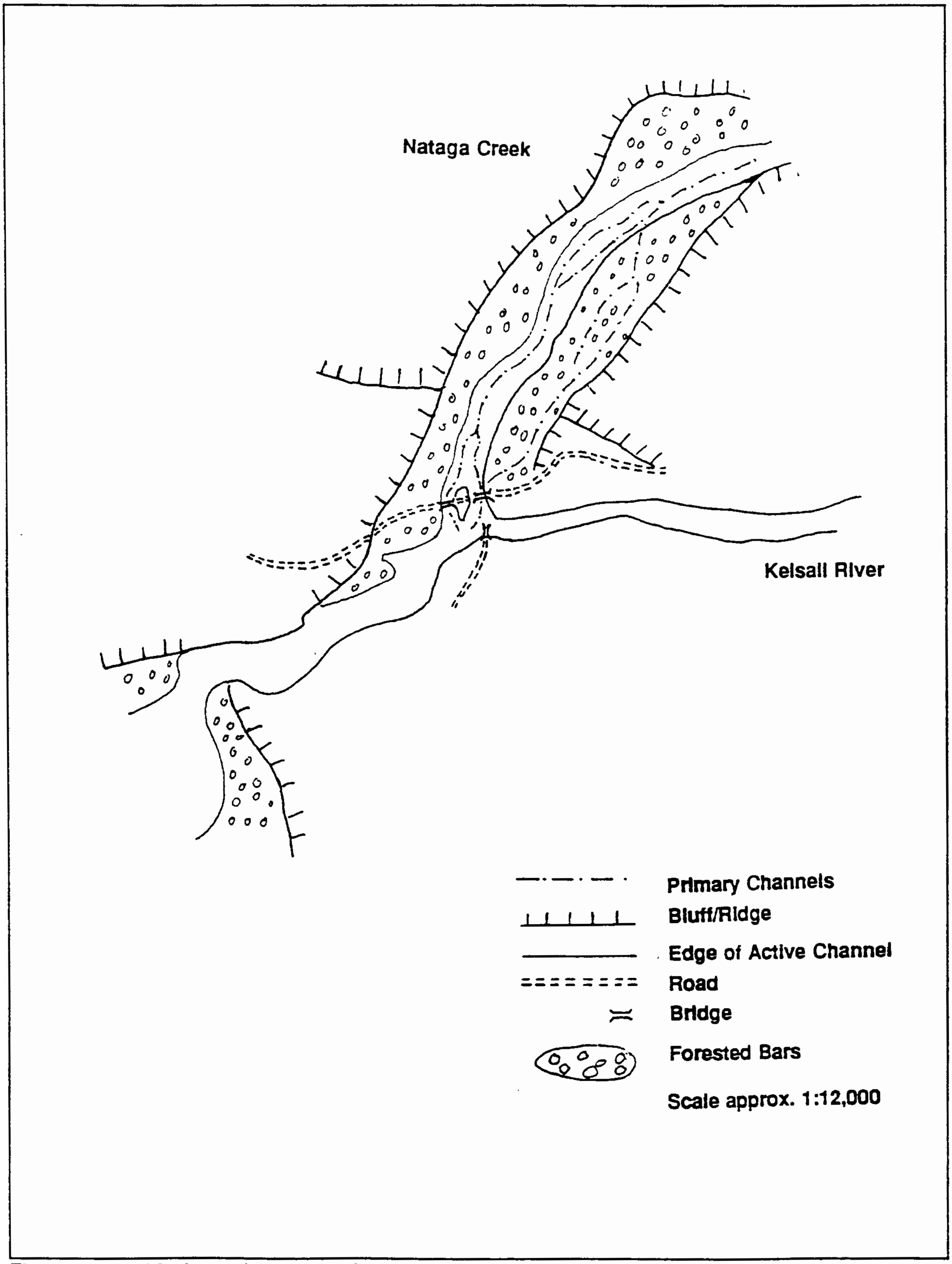

Figure 9 1993 channel configuration.

used to represent normal migration flows in the northern and southern channels, respectively. These flows are roughly equivalent to flows observed on August 15 and 16, 1995. The average velocities for each cross section for various flow levels are shown in Table 1. The average velocities through the northern bridge are in the range of 3.2 to 3.7 ft/second during migration flows. As shown in Figure 10 (from Powers and Orsborn 1985), this is within the velocity tolerances of chinook, coho, and chum salmon. Because chinook were observed spawning upstream of the bridge during the survey, it is obvious that these velocities do not pose a barrier to migration.

As shown in Figure 11 (from Raleigh et al. 1986), chinook are only likely to spawn in velocities ranging from 0.8 to 3.2 ft/second. During flows equal to or greater than the 2-year flow, the hydraulic model shows that velocities are too high everywhere in the stream for chinook to be spawning.

The hydraulic model does show that the northern bridge causes increased local velocities during peak flows in excess of the 10-year flow. For these high flows the bridges definitely constrict the flow cross section, locally increasing velocity and scour.

The hydraulic analyses were conducted assuming that 90 percent of the flow moves down the northern channel, and only 10 percent moves down the southern channel. Under this assumption, the flows in the southern channel are not large enough to be constricted by the bridge opening. These analyses show no significant velocity effects of the southern bridge. This can, however, change if and when a higher percentage of flow moves down the southern channel. In this case, one can assume that the southern bridge would locally constrict flows, increase velocities, and increase shear stresses as the northern bridge does now during high flows.

CHANNEL SHEAR STRESSES AND CHANNEL SCOUR

The hydraulic model indicates that the bridges significantly increase channel shear stresses and scour only for flows in excess of the 10-year flow (see Table 1). Because of the gradient of the stream, shear stresses are high enough during any flow in excess of the 2-year flow to move sediment particles with diameters of 100 mm or more, meaning that almost the entire bed of Nataga Creek will be in motion (see Figure 12 from Federal Highway Administration 1988).

Together with the channel profile, the hydraulic model results indicate that the northern bridge has caused additional scour (up to about 1 ft) just upstream of the bridge and additional

Table 1 Predicted average flow velocities and shear stresses at each cross section.

Left Channel

Flow: 110 cfs (observed August flow)

Cross section	Velocity (ft/s)	Shear stress (lb/ft^2)
1	2.22	0.13
2	4.80	0.77
3	3.22	0.30
4	3.71	0.40
5	5.22	0.85
6	3.70	0.41

Flow: 1,400 cfs (approx. 2-year flow)

Cross section	Velocity (ft/s)	Shear stress (lb/ft^2)
1	9.60	1.79
2	9.96	1.95
3	8.33	1.33
4	9.95	1.94
5	10.31	1.99
6	5.86	0.77

Flow: 2,200 cfs (approx. 10-year flow)

Cross section	Velocity (ft/s)	Shear stress (lb/ft^2)
1	10.52	1.97
2	10.82	2.07
3	11.37	2.38
4	11.81	2.50
5	11.85	2.42
6	5.39	0.55

Flow: 3,500 cfs (approx. 100-year flow)

Cross section	Velocity (ft/s)	Shear stress (lb/ft^2)
1	11.00	1.95
2	12.50	2.55
3	13.50	3.09
4	13.80	3.11
5	13.80	2.76
6	5.30	0.47

Right Channel

Flow: 10 cfs (approx. August flow)

Cross section	Velocity (ft/s)	Shear stress (lb/ft^2)
1	1.96	0.15
2	2.97	0.35
3	1.90	0.15
4	1.69	0.11
5	3.46	0.50
6	2.70	0.35

Flow: 140 cfs (approx. 2-year flow)

Cross section	Velocity (ft/s)	Shear stress (lb/ft^2)
1	5.79	0.84
2	6.56	1.11
3	3.02	0.21
4	4.03	0.40
5	6.38	1.01
6	4.33	0.59

Flow: 220 cfs (approx. 10-year flow)

Cross section	Velocity (ft/s)	Shear stress (lb/ft^2)
1	6.40	0.96
2	6.59	1.01
3	3.74	0.31
4	4.86	0.54
5	7.41	1.28
6	4.78	0.67

Flow: 350 cfs (approx. 100-year flow)

Cross section	Velocity (ft/s)	Shear stress (lb/ft^2)
1	6.70	0.99
2	6.63	0.95
3	5.42	0.63
4	6.86	1.04
5	7.23	1.11
6	5.53	0.85

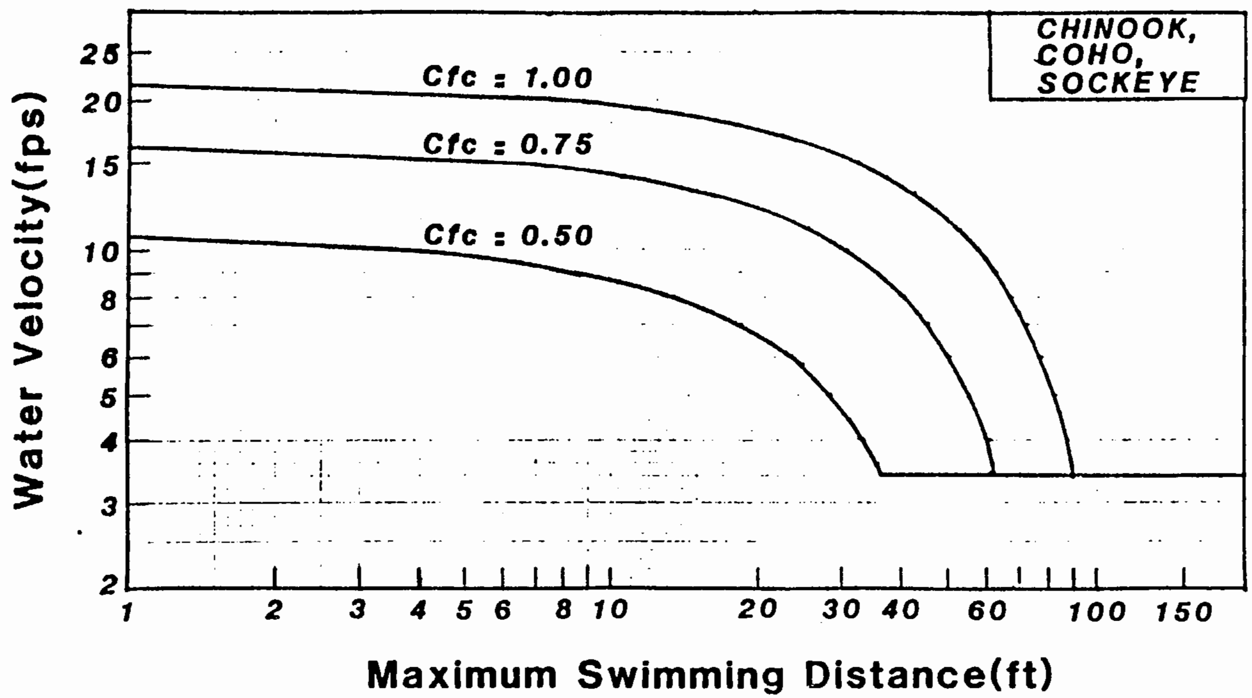

Figure 10 Maximum swimming distance for chinook, coho, and sockeye salmon under three fish conditions (Powers and Orsborn 1985).

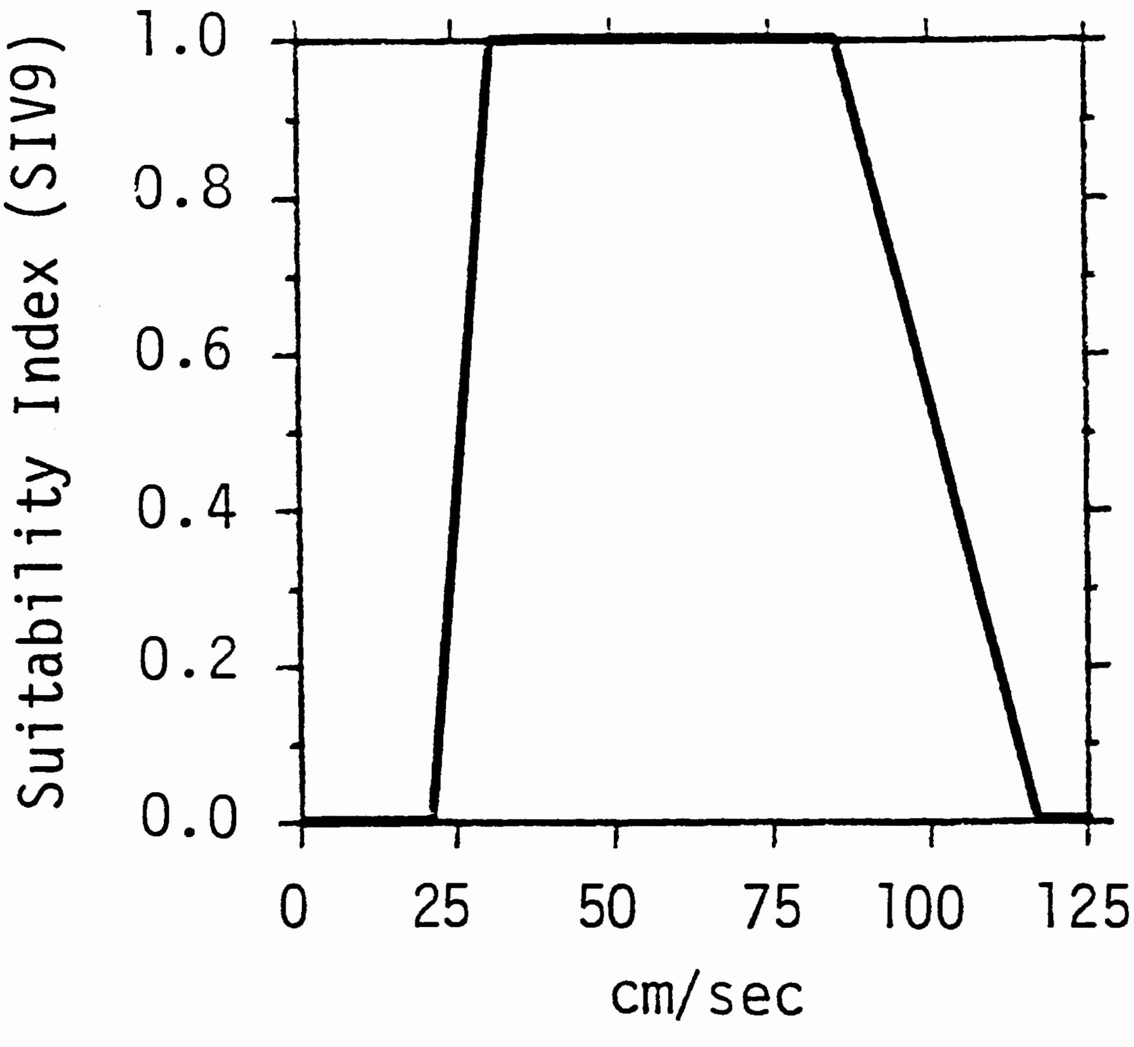

Figure 11 Average water column velocity (cm/s) over areas of spawning gravel used by chinook salmon during period of spawning and embryo development (Raleigh et al. 1986).

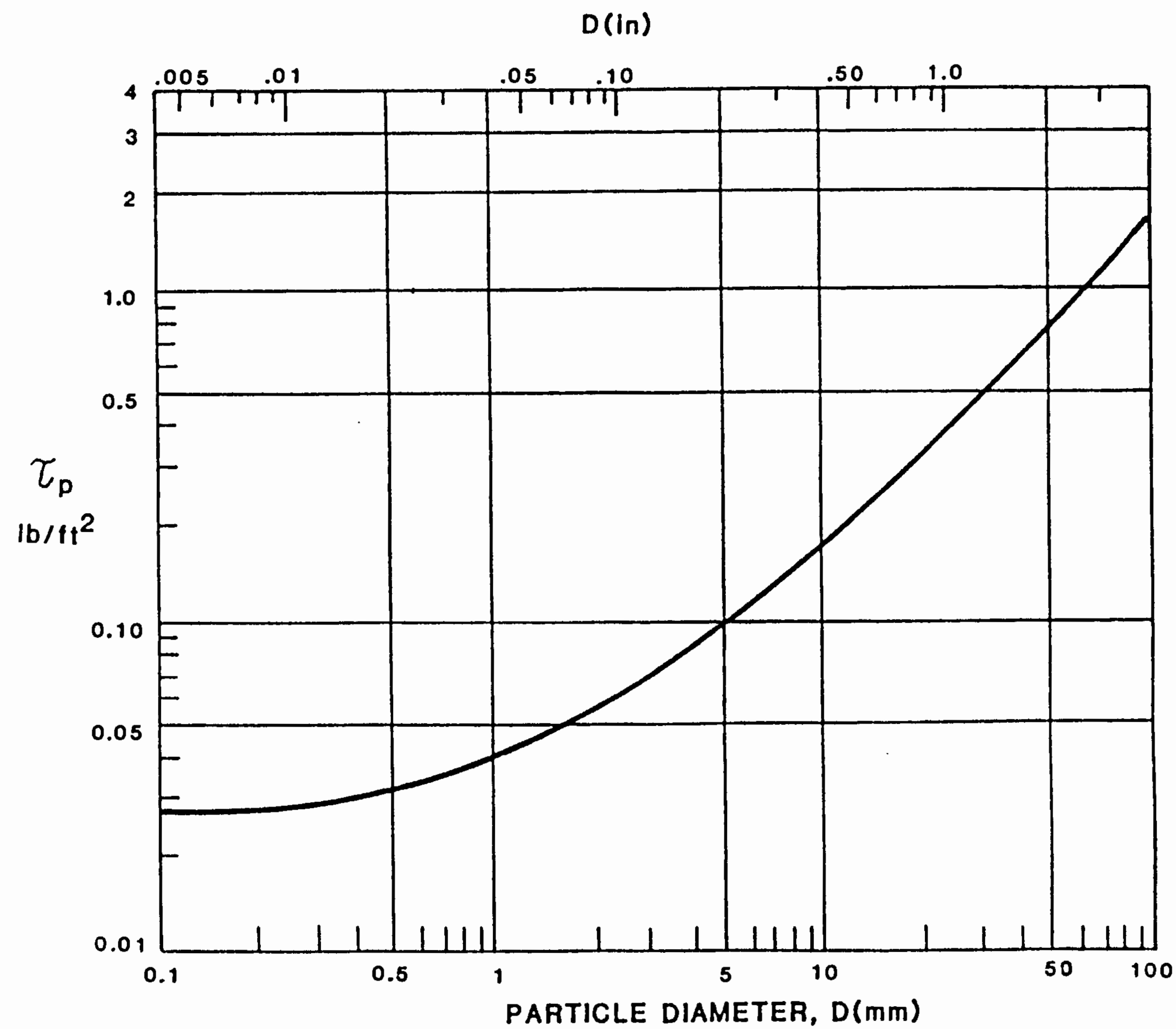

Figure 12 Permissible shear stress for non-cohesive soils (Federal Highway Administration 1988).

deposition (up to about 1 ft) just downstream of the bridge as the flow spreads out again. The total length of affected channel is less than 100 ft. Similar but less pronounced effects are evident at the southern bridge. Again, if the flow apportionment between the two channels reversed, so would the relative results.

The flow model indicates that the Nataga bridges do not affect the sediment mechanics of Nataga Creek beyond an approximately 150-ft-long reach just above and below the bridges. The channel gradient is too steep and the peak flows are too small for the bridges to affect the channel profile more than 100 ft away.

CONCLUSIONS

The Nataga bridges do not threaten habitat conditions or increase redd mortality in Nataga Creek. They do, however, alter the natural sediment dynamics of the creek. A brief answer to each of the questions listed in the Objective section is provided below.

The Nataga bridges do not pose a velocity barrier to upstream chinook passage. They only constrict the flow cross section during large storm flows on the order of the 10-year flow. During normal late-July, August, and September migration flows, the bridges do not constrict the flow cross section of the creek. Hydraulic modeling confirms that flow velocities within the stream reaches above and below the bridges are well within the range of velocities negotiable by chinook. Direct visual observation of chinook migrating and spawning above the northern bridge during our stream survey confirms that the bridge does not pose a barrier to chinook.

Preliminary modeling indicates that the Nataga bridges probably caused the channel to downcut approximately 1 ft immediately upstream and aggrade approximately 1 ft immediately downstream of the bridges some time after construction. The hydraulic analyses and the channel profiles demonstrate that the bridges do not have large scale impacts on shear stresses and sediment mechanics. The length of channel affected by increased scour or deposition is less than 100 ft. As a result of this local scour and aggradation, the bridges could be playing a role in the mortality by excavation of redds in the vicinity of the bridges, but any negative impact of the bridges on redd survival in this creek is minimal, especially in light of the amount of spawning habitat available in this stream and the fact that the bridges stabilize the channel.

By stabilizing the channel configuration, the bridges clearly are reducing the mortality of redds due to channel abandonment. Like many mountain streams in Southeast Alaska, Nataga Creek carries a huge sediment load relative to its flows. The creek's flow regime is not strong enough to scour and maintain a consistent channel; therefore, it is very active and highly braided. In its natural condition, this creek frequently changes course, leaving redds stranded without flow. The stabilizing influence on the streams was discussed in the report by USFS hydrologists Smith and Johnson (June 23, 1992). The channel history constructed from the aerial photographs clearly demonstrates this stabilizing influence. As a result of the road and bridges, the channel configuration at the mouth of Nataga Creek has been stable for 17 years, much longer than would be the case without the road system. Smith and Johnson (June 23, 1992) also identified this effect of the road crossings stabilizing channel locations.

The Nataga bridges do not constrict the high flows enough to significantly alter the sediment deposition patterns of Nataga Creek. Neither are the bridges durable enough to alter the stream's response to an extreme runoff event. There is no reason to believe that the bridges endanger downstream habitat by altering sediment dynamics or increasing the potential for large scale sediment movement. Correspondence from the Alaska Department of Fish and Game repeatedly refers to a "cycle of extreme aggradation and degradation" at the bridges. We have no data from which to determine whether such a cycle exists, nor have we seen such data presented. The channel history constructed from the aerial photographs do not show any significant changes in the width of the active channel or flood plain, nor do they show bank destabilization.

Monitoring of stream cross sections has been suggested as a way to identify whether the bridges are causing bed aggradation or degradation. Such a monitoring effort would have to be conducted in several locations over a long time period, however, because the natural sediment dynamics in Nataga Creek are such that cycles of aggradation and degradation at a point are common as waves or pulses of sediment move downstream.

From a channel hydraulics and habitat structure standpoint, the old steel bridge on the Kelsall River actually stands as a potential benefit to downstream conditions rather than a threat. In the event of failure, the steel elements of the bridge will serve the same function as large woody debris downstream; they will create scour elements around which pools will form. The only foreseeable fish hazard posed by the steel structures is that as they rust away, they might form sharp edges against which salmon may harm themselves. This does not seem likely, however, as the high sediment load of the Kelsall River will destroy the steel when it becomes thin and weak.

ALTERNATIVES FOR FUTURE BRIDGE MANAGEMENT

While the Nataga bridges do not pose a problem for fish habitat conditions or redd survival, they do affect the channel dynamics of Nataga Creek, and they will continue to do so until a large flow event destroys the bridges as such events have destroyed previous bridges. There are several options DNR may consider if it wants to restore natural channel dynamics to Nataga Creek or increase the expected longevity of the bridges.

ALTERNATIVE 1

Add another span to both the northern and southern bridges. This will reduce the constraints on high flows and thus reduce the scour impacts of the bridges during high flows. All of the bridge abutments should then be hardened. Pulling back the northern abutment of the northern bridge has been suggested previously to improve the bridge's stability, but the northern abutment rests on bedrock and is in less danger of failure than are the other abutments. Hardening the abutments and increasing the flow area will increase the life span of the bridges. Channel configuration will continue to be stabilized in its current condition, but scour will be reduced and sediment transport will be enhanced.

ALTERNATIVE 2

Do nothing. As discussed above, the present configuration has little to no net negative impact on habitat conditions. The bridges will continue to alter channel dynamics until they are destroyed by high flows, and then they can be replaced by a system such as one of those proposed in the other alternatives.

ALTERNATIVE 3

Reroute the road system over upper Nataga Creek where the channel is narrower. This will obviously restore natural channel dynamics to lower Nataga Creek and allow construction of a more stable bridge. This option may be expensive, however, and is unlikely to improve habitat.

ALTERNATIVE 4

Replace the current bridges with temporary bridges or quick bridges. Remove the temporary bridges and the bermed road approaches during periods when access to the upper Nataga basin is not required. This will allow high flows to disperse across the floodway, but it will also result in more frequent channel changes.

ALTERNATIVE 5

Leave the current bridges in place but remove the bermed road approaches when the road system is not in use, or simply reduce the length of elevated roadway. Leave short ramps approaching the bridges. This will allow high flows to disperse across the floodway, but it will also reduce the life span of the current bridges.

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