Scour at Bridge Piers

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Final Report

Research Project GC8287, Task 4
Scour at Bridge Piers

SCOUR AT BRIDGE PIERS

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16. Abstract

Field measurements of riverbed scour at bridge piers were pursued during this research. This would provide additional information to determine applicability of an empirical estimating procedure for estimating such scour. Two field sites on the Okanagon River, and one on the Yakima River were established; these were added to five sites already in existence.

Because direct measurement of scour depth during the highest stream flows cannot be made with accuracy, an indirect method of determining scour occurrences was established. In general, clear water scour occurs during high flows, some scour hole refill would occur during flow recession. Otherwise, no refill could exist. Field measurement of clear water scour quality was planned to define the possibility of scour hole refill.

Snowpacks in the State of Washington during the winter of 1987-88 were unusually low. Thus, flowrates from snowmelt were insufficiently high to create riverbed scour. Consequently, conclusive evidence about scour at bridge piers didn't materialize.

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SUMMARY

Research upon which this report is based was a continued investigation of earlier (1985-87) research on riverbed scour at bridge piers. The current research identified new field measurement sites which, together with original ones, could be used to study actual and continuing streambed scour originating from high runoff flows in Washington state. Field measurements were to confirm or contradict a University of Auckland procedure for estimating streambed scour at bridge piers where streambeds were made up of uniformly-graded gravels.

More than twenty bridge sites were examined across Washington but only three new sites were selected for field measurements. Riverbed characteristics were not adequate at most other locations, bridge piers were not situated sufficiently well within the stream at others, and access was extremely difficult at some. Field observations and measurements were made at the new and old sites (eight in total) before and following 1988 spring high flows.

At all field sites, snowmelt runoff was far less than normal because winter snowpack was much smaller than usual. High flows were insufficient to create any scour either generally at the sites or at bridge piers. Therefore, the study produced no definitive conclusions regarding the validity of the University of Auckland estimating procedure.

However, the study did identify and establish field sites at which further measurements can be made. Also, a hypothesis was developed that uses general riverbed erosion measurements, live bed scour knowledge and deductive reasoning to verify pier scour measurements.

INTRODUCTION

During 1985, 1986 and 1987, Washington State University studied several methods available to estimate the depth of riverbed scour that might occur at intermediate bridge piers. The results of that study are embodied in a report entitled "Riverbed Scour at Bridge Piers[1]." Those results suggested 1) a method labelled as the University of Auckland (New Zealand) method should be considered for use in Washington State whenever bridge crossings were located in uniformly graded, gravel riverbeds, and 2) methods currently in use by the Washington State Department of Transportation to estimate scour depths were appropriate for alluvial, sand-bed streams.

The New Zealand method estimates scour depths given mean streambed particle size and a geometric deviation of particle size. Its use was developed from research results at the University of Auckland. Field measurements of scour at bridge piers was included in the WSU 1985-87 study which attempted to verify this empirically-based method at the several study sites.

Questions arose concerning the accuracy of the estimations based on arguments that scour depth would be universally impacted by the onset of live-bed scour. Thus, additional field measurements were made late in 1987 and in 1988 to augment earlier measurements and more fully address this scour issue. The issue would be clarified if maximum scour depths could be measured during peak flows.

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[1]"Riverbed Scour at Bridge Piers," Copp, H. D. and J. P. Johnson, Washington State Department of Transportation Final Report WA-RD 118-1, June, 1987.

Field measurements of maximum depths are not easy to make because high stream flows are quite destructive to conventional measuring equipment. Recognizing this, measurements of general riverbed erosion upstream from bridge piers were planned. Deductive reasoning then could formulate a hypothesis about the live bed scour phenomenon and maximum scour depth.

SCOUR DEPTH ESTIMATION

Research at the University of Auckland since about 1979 suggests that Fig. 1 is suitable for estimating scour in streambeds made up of rather uniform particle-sized materials that can be represented by a mean particle size, d_{50}. The scour depth, d_s, represents an equilibrium depth at a pier of width b placed in a stream more or less parallel with the stream flow. Coefficients K then modified the d_s value for plan shape of piers, orientation with the streamflow, and streambed size gradation. Figure 2 illustrates the adjustment for streambed size gradation. Here, the gradation of the bed materials, represented by σ_g, is used to adjust d_s by a multiplier K_σ.

Field measurements were made during research in 1985-87 at six different existing bridges to compare actual local scour with the estimated scour depth using the University of Auckland procedure described above. In all cases, that procedure estimated scour depths much closer to measured depths than those estimated by procedures for uniform, alluvial streambeds. On this basis, the Univ. of Auckland procedure was recommended for use where graded materials are encountered.

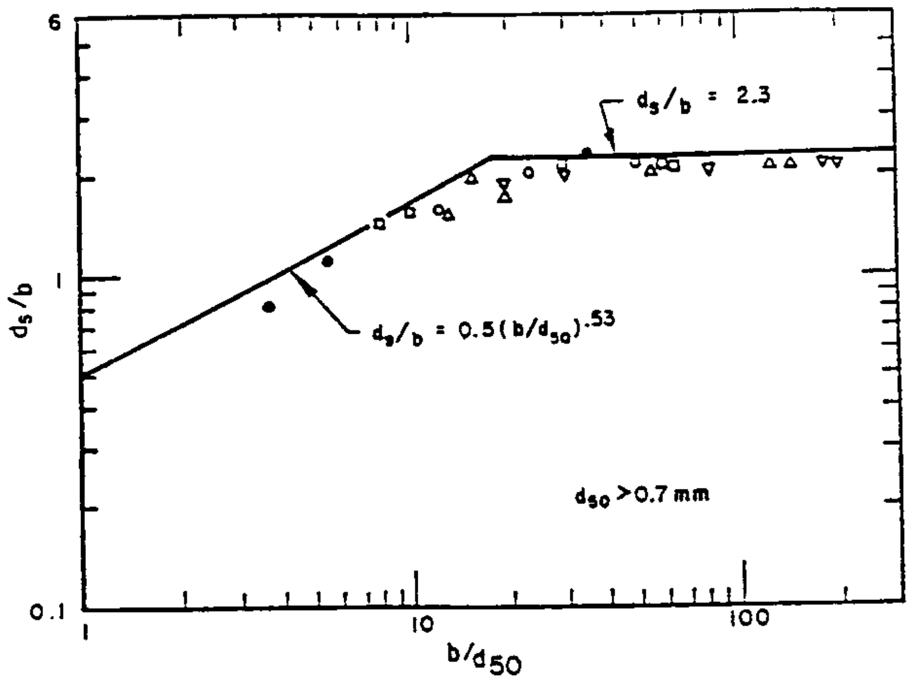


Figure 1. Local Scour Depth (d_s) in Uniform Streambeds as Functions of Pier Width (b) and Particle Size (d_{50}) (From Copp and Johnson, cf, p. 1).

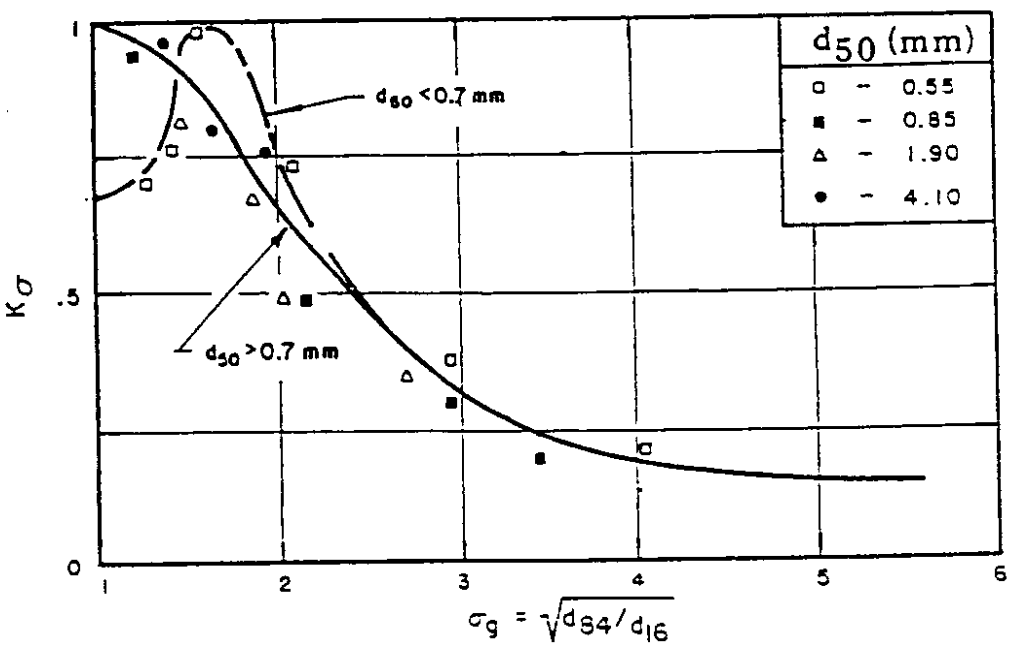


Figure 2. Particle Size Coefficient, K_σ, vs Geometric Deviation, σ_g (From Copp and Johnson, cf, p. 1).

A set of six measurements alone can not form an unquestionable basis for that recommendation even though existing estimating procedures, based on sand bed streams, were even more unreliable when applied to graded-sized streambeds. Also, field measurements of scour depth were made after recession of high flow events in streams. A scour hole at a pier may become partially refilled during this recession. The purposes of this 1987-88 research were to augment a meager data base on local scour on graded streambeds and to examine scour hole refill.

MEASUREMENT HYPOTHESES

Scour depth measurement right at a pier is not an easy task. Measurements during a high flow event are difficult because high flows tend to destroy measurement instruments, it is dangerous at high flows to approach the scour hole with temporary equipment, and measurement from bridge decks is difficult and unreliable because outside edges of decks generally extend some distance out from supporting piers.

Measurements were planned here to determine if general riverbed scour would occur upstream from a pier(s) and then to determine the depth of scour holes at the pier(s) after high flows receded. If significant general scour occurred, one can conclude logically that live-bed scour existed during high flows and this would have partially refilled the scour during flow recession. If insignificant general scour occurred, nothing would be available to refill the local scour hole. Field measurement sites were sought and established with these hypotheses in mind.

SITE SELECTION

One of the six sites utilized in the 1985-87 research was abandoned as a measurement site for this project because the bridge at the site was replaced with a new structure. Visits to the remaining five locations suggested that measurements at those sites should be made in this 1987-88 study. Twenty four other bridge crossings in Washington State were investigated. All but three were discarded as useful because access was extremely difficult, streambeds had other than desirable characteristics, man-made pier protection had been placed, or other like situations were found.

Measurement sites used in this research were:

1. Bridge No 507/102 over Skookumchuck River near Centralia, WA
2. Bridge No. 5/216E over Newaukum River near Chehalis, WA
3. Bridge 90/82S over the South Fork, Snoqualmie River near North Bend, WA
4. Bridge 12/706 over the Touchet River near Dayton, WA
5. Bridge 12/725 over the Tucannon River near Dayton, WA
6. U.S. Highway 97 bridge over the Okanogan River near the north city limits of Omak, WA
7. U.S. Highway 97 bridge over the Okanogan River approximately 4 miles south of Tonasket, WA
8. Interstate 90 bridge (eastbound lanes) over the Yakima River immediately west of Easton, WA

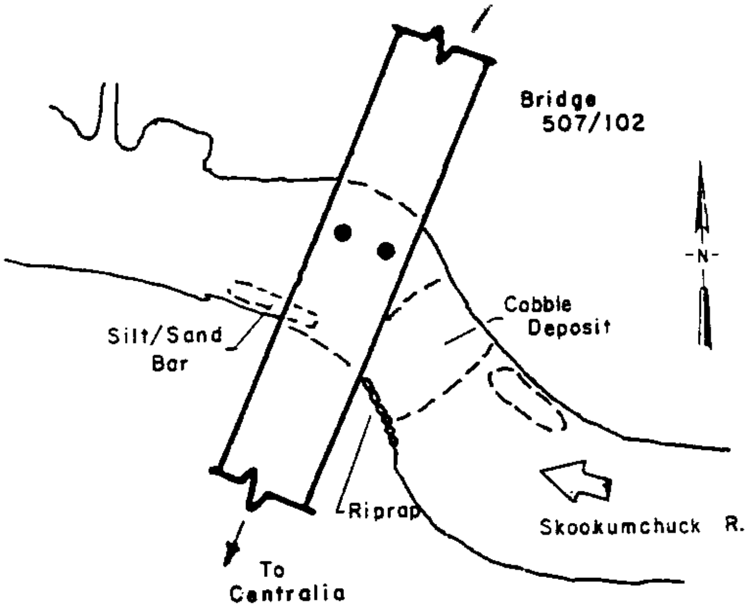
This list was somewhat smaller than originally planned; additional sites were not found for reasons already set forth. Measurement sites had to be identified and established prior to inclement winter weather so any scour that would be measured would result from the first occurrence of high flow. Additionally, any debris accumulation at piers had to be removed so that it would not influence local erosion.

Each of the first five sites in the above list is described in Copp and Johnson (cf, p. 1) and each is illustrated here in Fig. 3. Site 7 is illustrated in Fig. 4; the stream consists of two channels separated by a large sand bar. Bridge piers are round; four are situated in the stream channels. The streamflow is regulated upstream by lakes; controlled outflow from each affects the measurement site. The streambed consists of graded gravels and small boulders varying in size from about one inch to as large as four to six inches

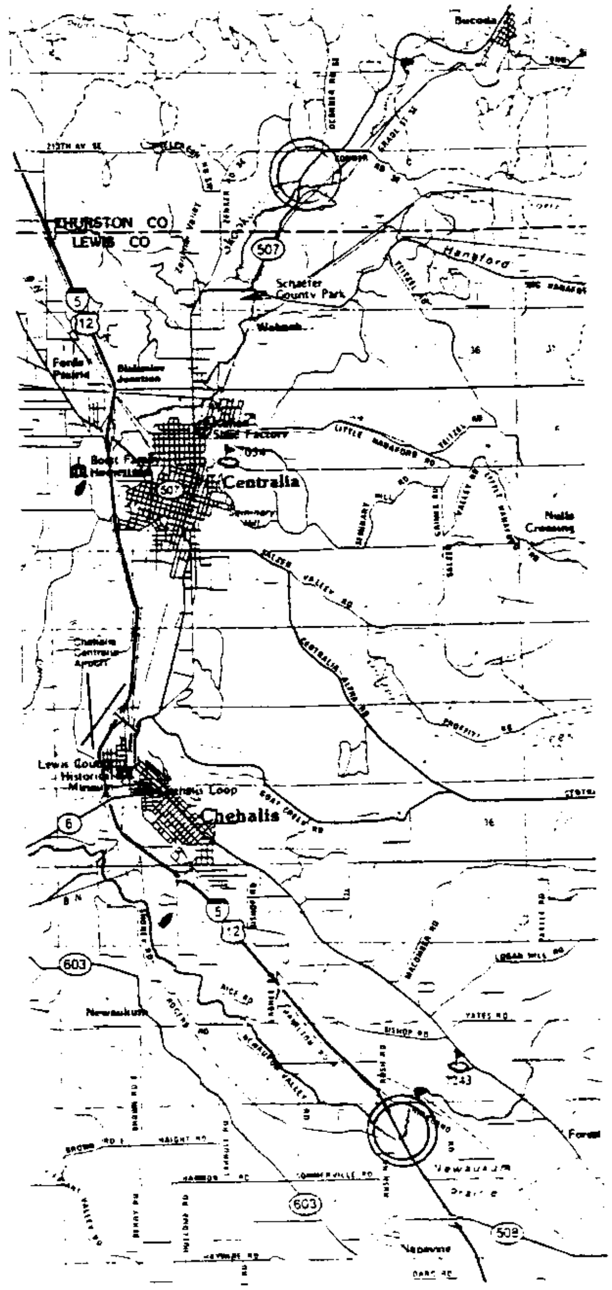
Site 6 is within the same water runoff province as Site 7. The stream at this site has a single, broad, shallow channel which is shown in Fig. 5. The streambed is coarse, graded gravels slightly smaller than at Site 6. The bridge is supported by three elongated piers; one is situated at the south bank. The bank itself is riprapped extensively with extremely large boulders which also forms protection at the base of that pier.

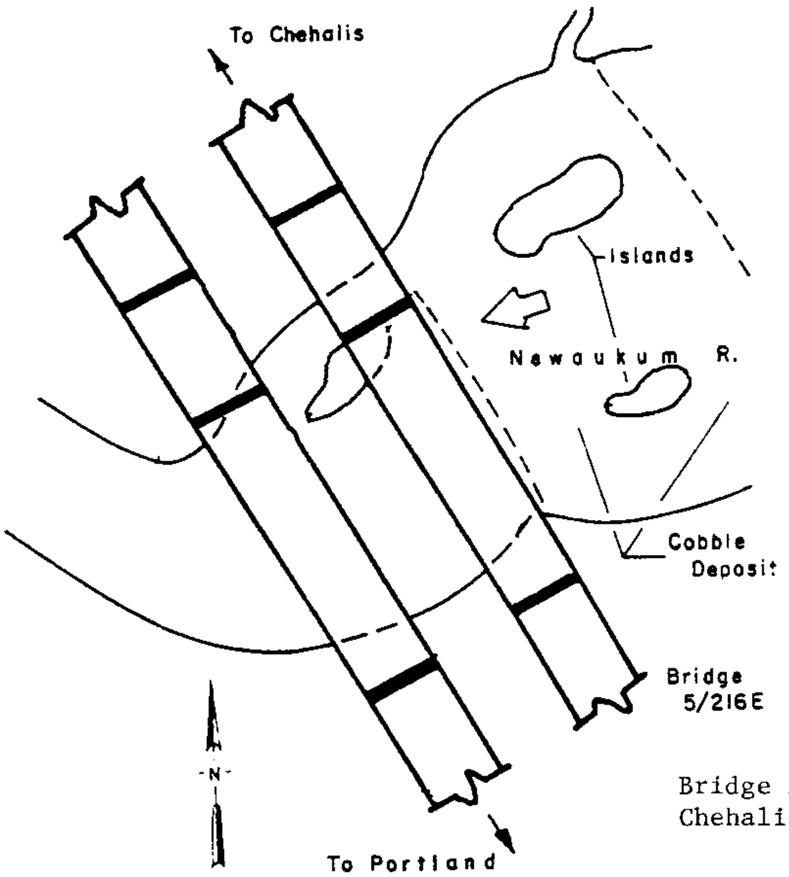
The Yakima River site is illustrated in Fig. 6. Two parallel bridges exist here; measurement was near the southern-most one which support the highway's eastbound lanes. Piers are cylindrical; some scour had occurred at one pier prior to the initial inspection at the site. This may have been due in part to debris that had been lodged adjacent to the pier.

The Yakima River streambed here consists largely of gravel and cobble bed material varying from sand size (a very small percentage by volume) up to course gravels as large as four inches in diameter. The streamflow is regulated upstream by Keechelus, Kachess, and Easton



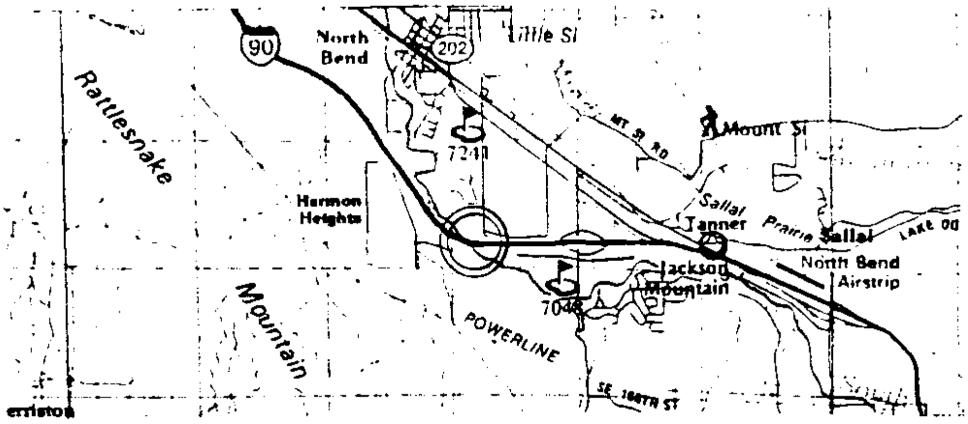
Bridge 501/102 over Skookumchuck River near Centralia, WA.

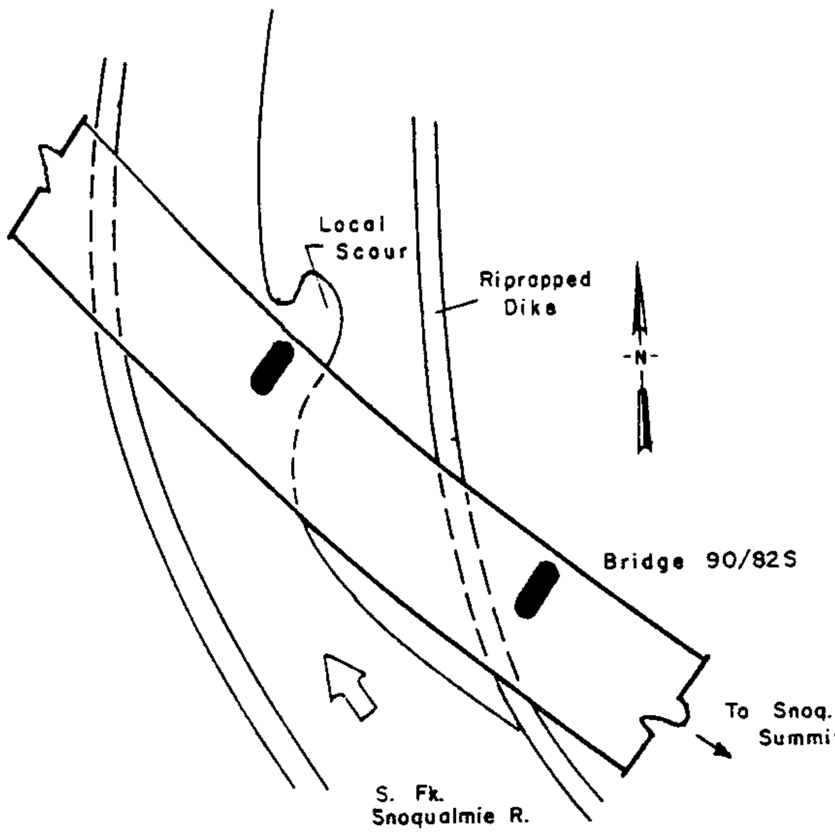




Bridge 5/216E over Newaukum River near Chehalis, WA.

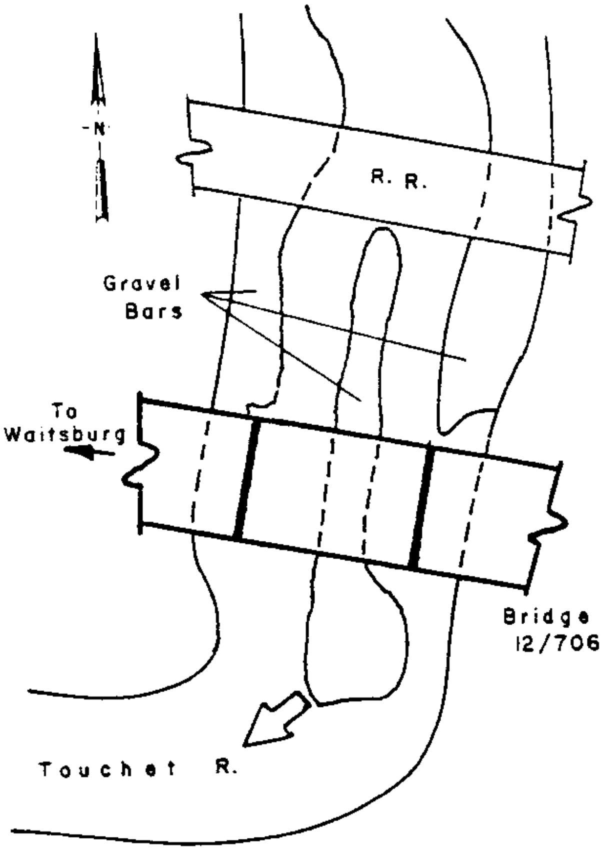
Figure 3. Location and details of earlier field sites.

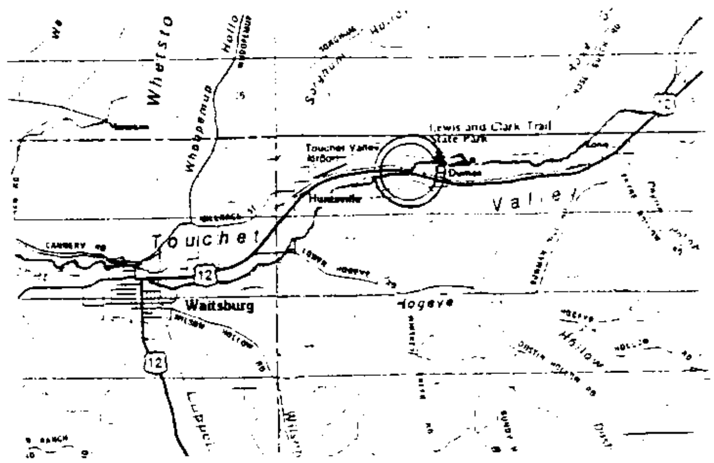




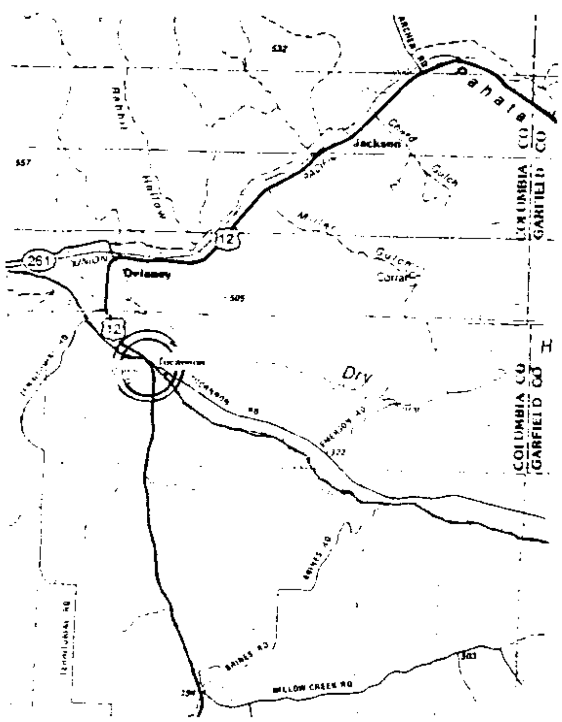
Bridge 90/82S over S. Fk. Snoqualmie River near North Bend, WA.

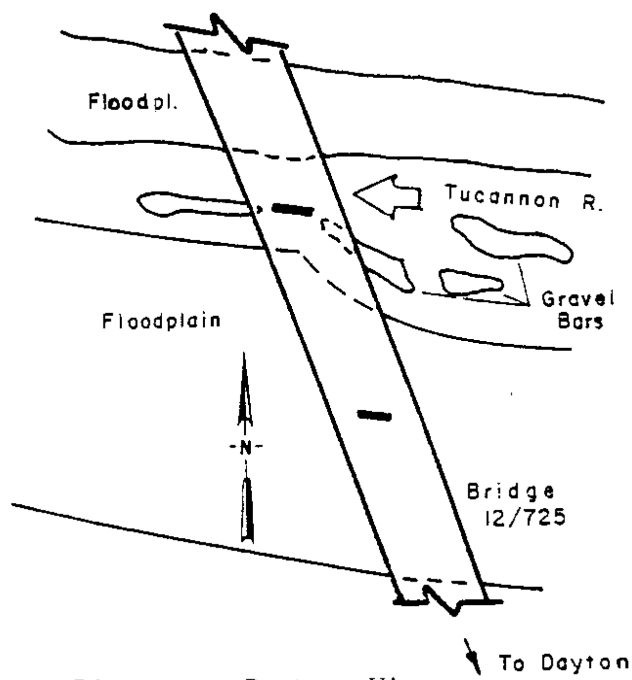
Figure 3. (continued)





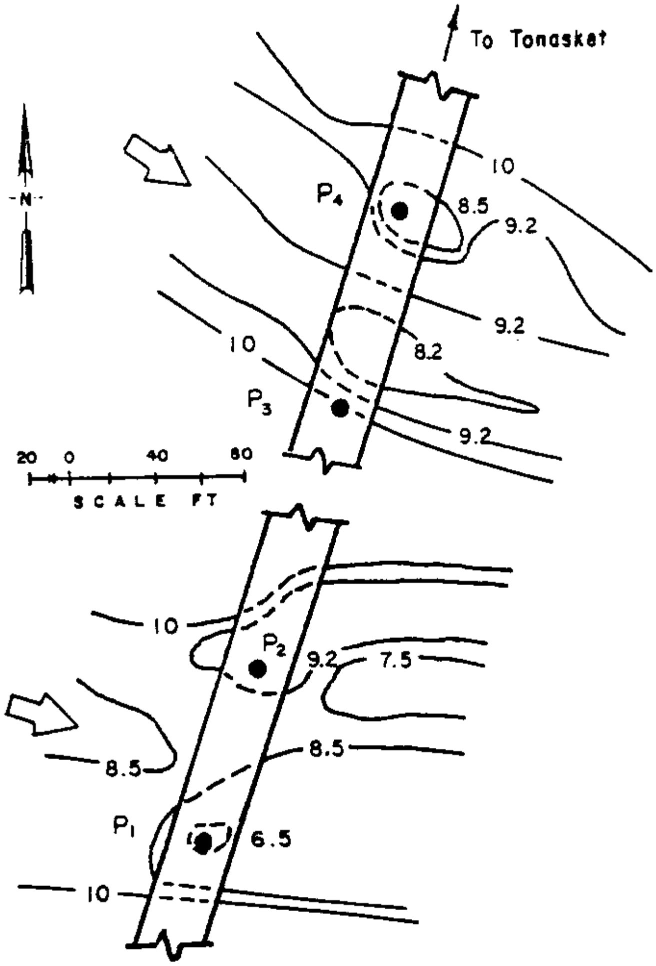
Bridge 12/706 over Touchet River near Dayton, WA.





Bridge 12/725 over Tucannon River near Dayton, WA.

Figure 3. (continued)



Contour elevations are in feet;
10 is water surface level at
time of measurement.

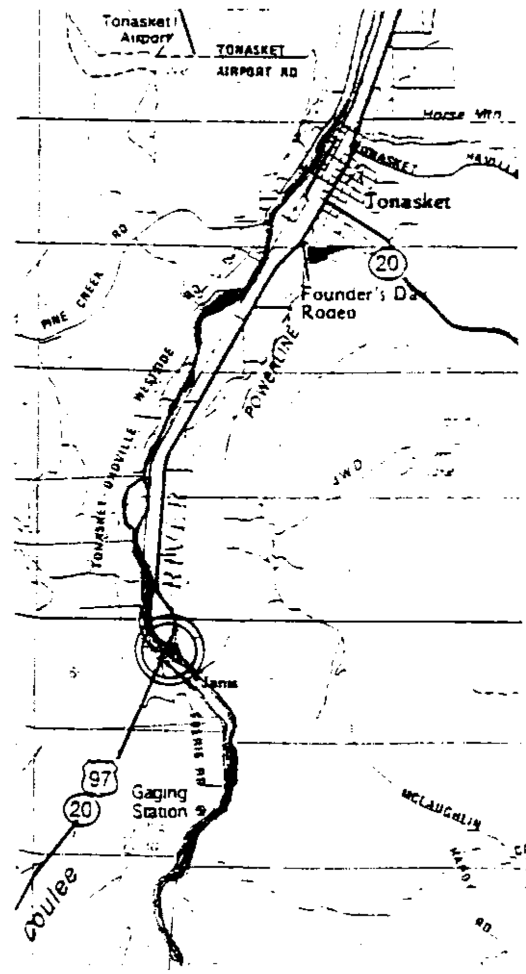


Figure 4. Field site of U.S. Highway 97 bridge near Tonasket, WA.

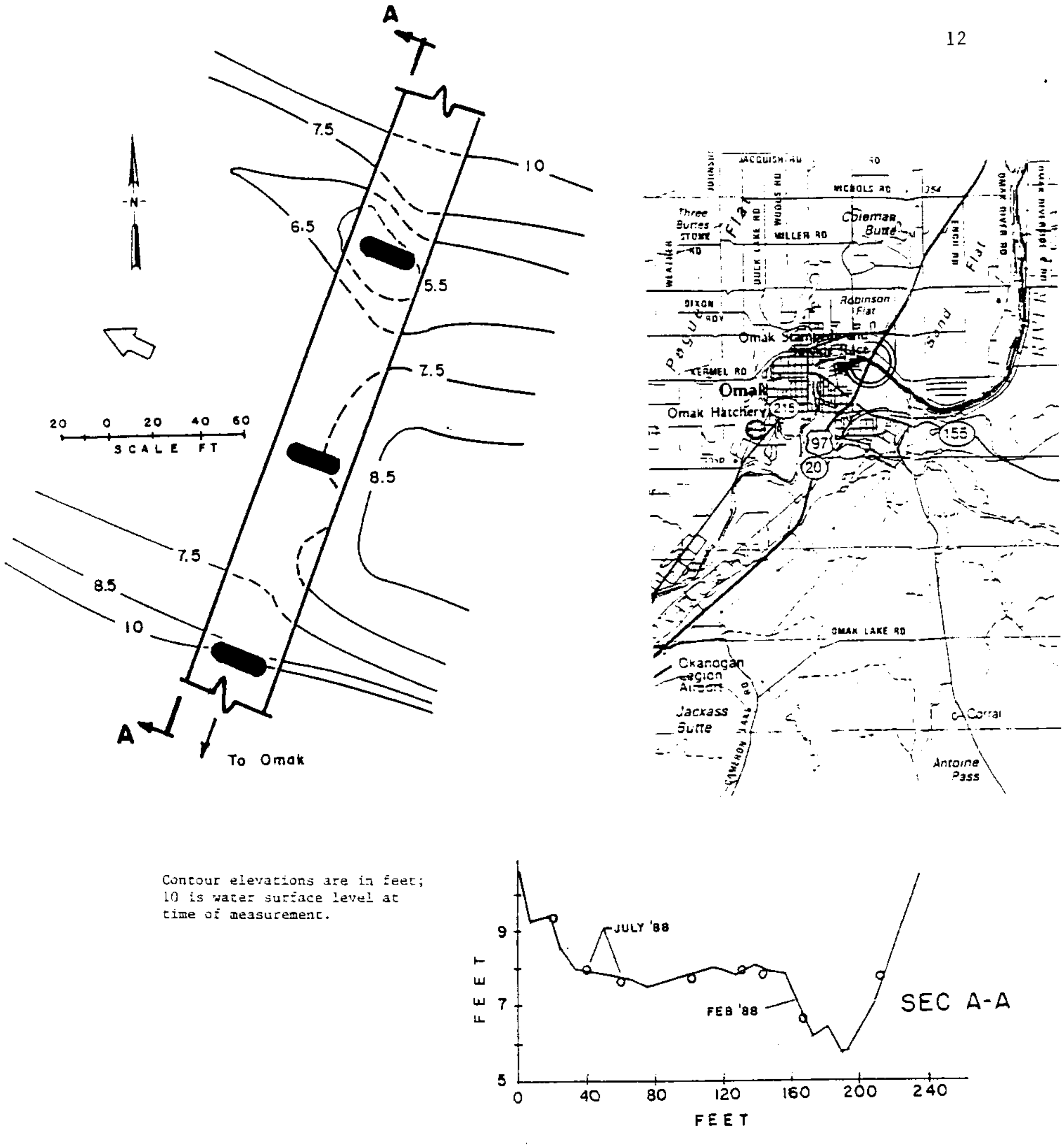


Figure 5. Field site of U.S. Highway 97 bridge over Okanogan River at Omak, WA.

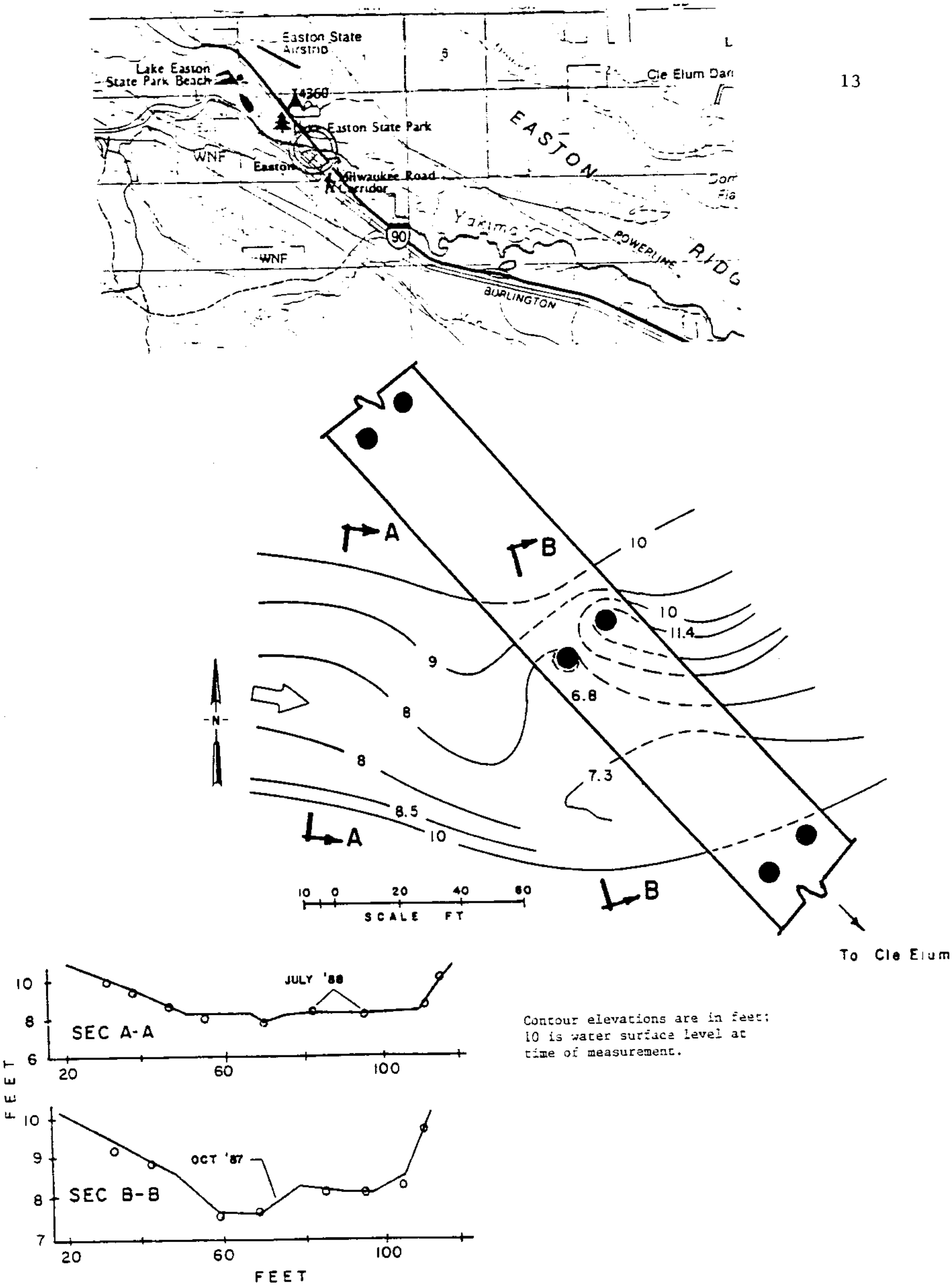


Figure 6. Field site of Interstate 90 bridge over Yakima River near Easton, WA.

Lakes. The latter is a diversion feature in the Yakima River irrigation project developed by the U.S. Bureau of Reclamation and the first two are storage reservoirs in that project.

MEASUREMENTS AND OBSERVATIONS

Visits were made in October, 1987 to Sites 1, 2, 4, and 5. Observations at the Skookumchuk River site revealed the same streambed topography and local scour documented in 1986. The same was true at the Newaukum River site. Flowrates during the winter of 1986-87 apparently were not high enough to create additional scour at these locations that could be measured. Observations at the Snoqualmie site near North Bend in May and again in September, 1988, suggested that measurable local scour did not occur during the preceding two years.

The Touchet River site, in October, 1987, was found to be influenced by considerable silt and clay sedimentation. The hole at the south pier, which in Fig. 3D is shown as a debris collector, was completely filled with mud mixed with the debris still in place. As a result, this site was discarded as a measurement site but was left in the project as an observation location.

Neither riverbed nor local scour occurred at the Tucannon site during the interim between late spring 1986 and October, 1987. Additional stream bed measurements were made here in November, 1987 to augment previously collected data. The highest stream flowrate recorded during the 1988 runoff season was 242 cfs which is approximately one third as large as the baseflow that is used to identify flood flows. A visit to the site in May, 1988 indeed revealed no topography changes or local scour anywhere.

The Highway 97 bridge crossing the Okanogan River just south of Tonasket passes over two channels in the stream which are separated by a rather large sand/gravel bar that rises perhaps 20-22 feet above the water level at moderately low flows. These two channels have existed at least since the late 1950s. Figure 4 shows the crossing area and its location.

While the dividing bar consists largely of sand and small gravel sized material, much clay-sized material is in the northern-most bank of the north channel. Furthermore, both stream channels have armored streambeds with materials fairly uniformly graded from about 15 mm to some 75 mm. The initial measurements at the site were made in February, 1988 and showed little scour at the piers. A hole around Pier P_1 was about three feet deep and appeared to have existed for some time.

A visit to and measurements at the site in July, 1988 revealed that shape of both channels remained almost exactly as measured earlier. The gravel (not sand) bar in the north-central portion of the south channel appeared to have moved closer to Pier P_2 during the February to July interim. However, the transect along which measurements were made in February was located such that the full extent of this bar, shown in Fig. 4, probably was not identified.

Streamflow at this site reached a high value during the spring snowmelt season of approximately 13,000 cubic feet per second. This is significantly lower than in most years and less than 25 percent of the largest recorded flood flow. The flow exceeded 10,000 cfs for less than 48 hours. Information available suggests that flows were insufficiently high to create significant scour in the study reach. There is evidence that some riverbed material was brought into the reach from upriver but the extent of the movement is unknown.

The other site on the Okanogan River is at Omak, Fig 5. The streambed is of graded gravels with little or no sand particles either in the bed or banks. Significant scour had existed near the northern-most pier prior to the first site visit. A depth of 4.5 feet is indicated on Fig. 5 but this is below the water surface. Depth below the surrounding bed level is less than two feet.

The high flow during snowmelt in 1988 was only slightly higher than at the Tonasket site, i.e., about 14,000 cfs. As with that earlier site, this is not very large and probably insufficient to create significant scour to the riverbed. Figure 5 shows a cross sectional profile measured in February, 1988 and data obtained also the following July. No difference occurs along this transect nor along a transect some 40 feet upstream from the piers.

The Yakima River site, Fig. 6, is below two storage reservoirs as mentioned earlier. Both reservoirs were nearly empty entering the winter months of 1987-88. The snowpack in the cascade mountain range was considerably less during this winter. At the beginning of spring snowmelt season those reservoirs would have been able to absorb most runoff. This occurred and the streamflow at this measurement site reached a peak magnitude that would not scour the streambed here. Both of the transects illustrated in Fig. 6 were unchanged after the spring flows. Further, the scour hole around the one pier did not change perceptibly.

CONCLUSIONS

The 1988 water year (Oct 1, 1987-Sept 30, 1988) witnessed one of the lowest runoff events on record in Washington state. This was reflected in the measurements and observations at eight field sites that were established to measure general riverbed erosion and local scour at bridge piers. As a result, no new data contributed to the verification of the University of Aukland scour estimation procedure. However, new field sites were established at which further measurements of the scour process can be made.

A measurement process was identified that would permit evaluating the maximum scour depth at piers in absence of being able to make direct measurement of this depth. This is based on a hypothesis that if live bed scour does not occur during high flows (something that can be determined), scour at the piers measured following a high flow event would be nearly the same as maximum depth.