Scour and Fill of Spawning Gravels in a Small Coastal Stream of Northwestern California

Cooperative Research Project
Final Report

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Principal Investigation

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INTRODUCTION

Excessive and inopportune scouring of spawning gravel beds can be detrimental to salmonid eggs and the subsequent alevins. Habitat may also be adversely effected by excessive scour of riffles and filling of pools.

Pointed out less often, however, is that spawning gravel beds must be periodically cleaned by scouring and redeposition. A static state would eventually produce poor spawning conditions by filling the gravel interstices with fine sediments and decreasing intergravel flow and dissolved oxygen delivery. Complete and heavy armouring of spawning gravel beds over a long period of time could also decrease spawning success by inhibiting redd establishment.

Gravel riffles provide the nesting areas for the various salmonids found in the streams of northwestern California. During their evolutionary development, salmonids adapted to their natural channel sediment. Besides needing gravels for spawning, salmonids depend on the stream sediments for rearing their young and providing for their food. However, the proper mix of sediment particle sizes for optimum fish productivity is not clear. Most likely, a complex mixture of sediment sizes is needed in combination with certain hydraulic conditions to provide the ideal channel environment.

One of these hydraulic conditions necessary to produce high spawning success is a riffle sufficiently devoid of fine sediments to insure good subsurface water movement through the riffle sediments. The maintenance of this ideal condition is produced by continual, periodic rejuvenation of the riffles by scouring, replacement, and rearrangement. However, when flows of high enough magnitudes and frequency cause such actions to not occur, riffle sediments become plugged and the surface armour layers can become so cemented as to also be resistant to redd excavation. (This condition is often referred to as "imbricated".)

On the other hand, excessive scouring of spawning gravel beds can be detrimental to salmonid redds (Gangmark and Bakkala 1960; James 1956). Salmonids usually select areas where the hydraulic controls of the stream channel provide a substrate high in gravel, small rubble and some fines that can provide a cover layer that protects the eggs and alevins. This particle size distribution provides an egg cover that will withstand most of the velocities the stream exerts without sediment movement damaging the embryos.

The necessary balance between advantageous spawning gravel movement sufficient for "rejuvenation" and excessive movement, however, has not been documented. An extensive search of the literature indicates that almost no information exists on the extent, timing, and variation of scouring in spawning riffles. The distribution of stream sediments is ordered largely by stream energy, hydraulics, and physical characteristics of a watershed, hence is nonrandom. Streams used by spawning salmonids usually consist of a succession of riffles and pools whose positions remain relatively constant over time despite wide fluctuations in streamflow. Texture in a given reach of stream is a function of stream mechanics governed by climate (quantity and intensity of rainfall) and geology (lithology, structure, and geomorphology). It is not a strictly stochastic phenomenon but usually results from episodic events caused by regional meteorology.

In this study, I have investigated the spatial and temporal variable in gravel movement on three spawning riffles over two winter seasons. This study attempts to provide some answers to the following questions:

1. What is the frequency of spawning gravel bed movement?
2. During which months is movement most likely to occur?
3. Where does gravel movement most likely occur on a riffle?

Study Area

The study was conducted within the watershed of Prairie Creek (figure 1), along a reach containing five riffles, three of which were used in this study. Prairie Creek is a tributary of Redwood Creek which flows into the Pacific Ocean near Orick, California.

The Prairie Creek basin lies within the Coast Redwood type (Sequoia Sempervirens). Red alder (Alnus rubra), Sitka spruce (Picea Sitchensis), and assorted ferns are the other main plant species in the area.

Altitude ranges from sea level to about 300 m (1000 ft) and the rainfall of the area averages about 190 cm (75 in) annually. Most of the rainfall occurs between November and March of the water year with snow being an infrequent, short lived occurrence. The stream is only 14 miles long and drains an area of 7770 hectares (30 mi^2).

The drainage basin of Prairie Creek is underlain by unnamed weakly indurated sedimentary rocks and is characterized by average hillslope and stream gradients that are less steep than elsewhere in the local area (Janda et al 1975). Average channel gradient is about 12 m per km (64 ft/mile). The average gradient of the study reach is about 4 m per km (18 ft/mile).

Prairie Creek has a single clearly defined channel that even during low flow occupies most of a narrow river flood plain and displays a slightly sinuous course. Throughout most of its

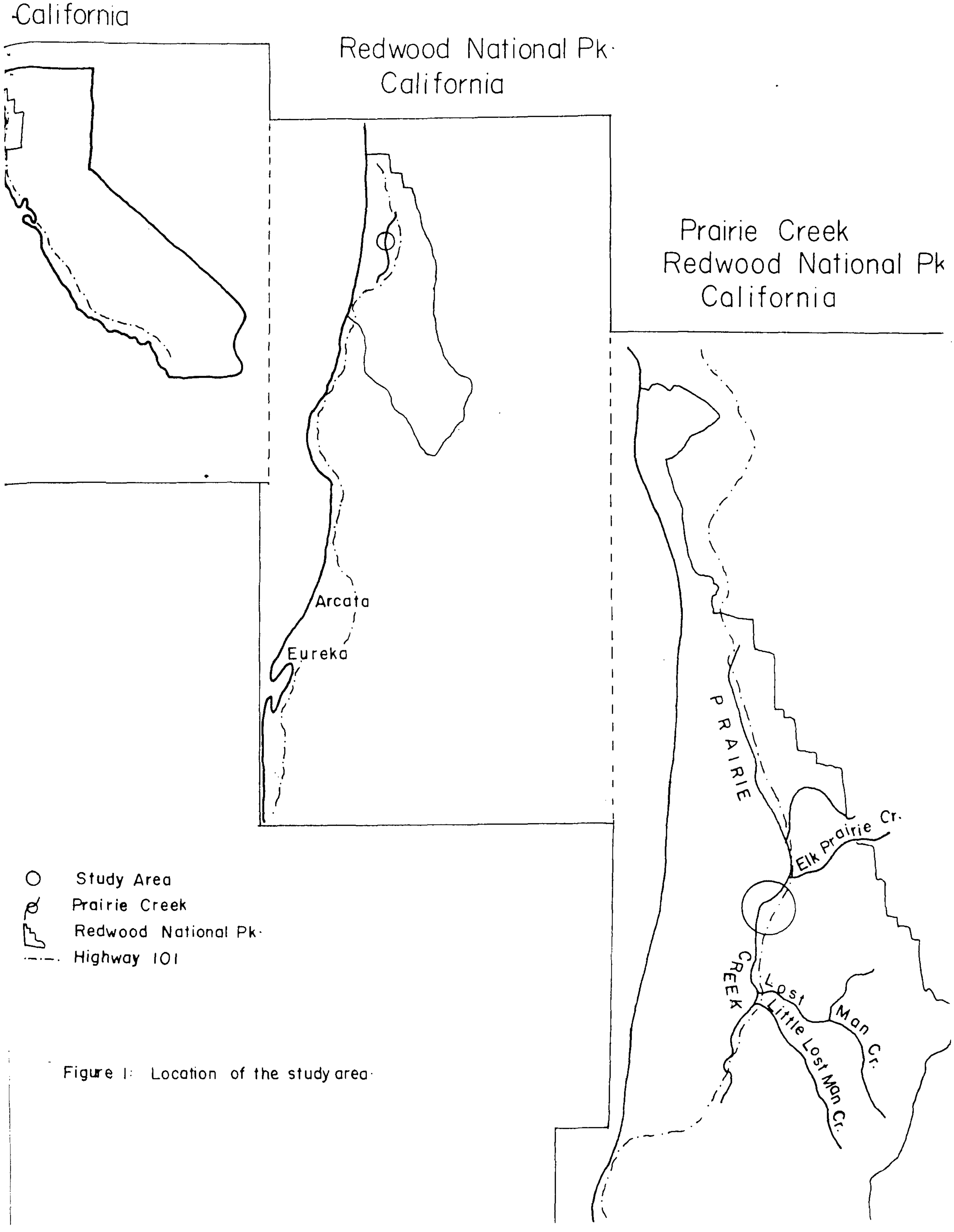
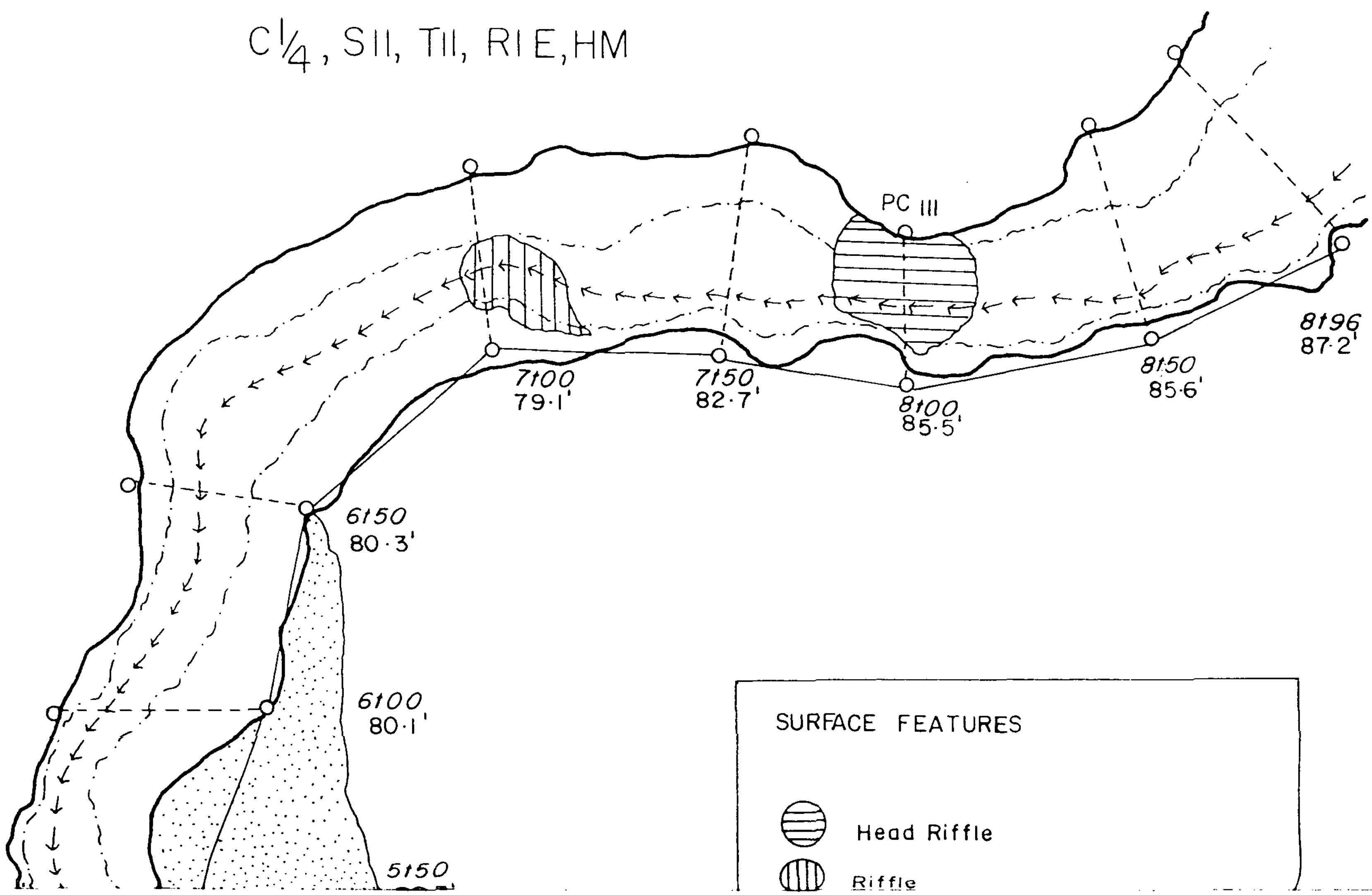


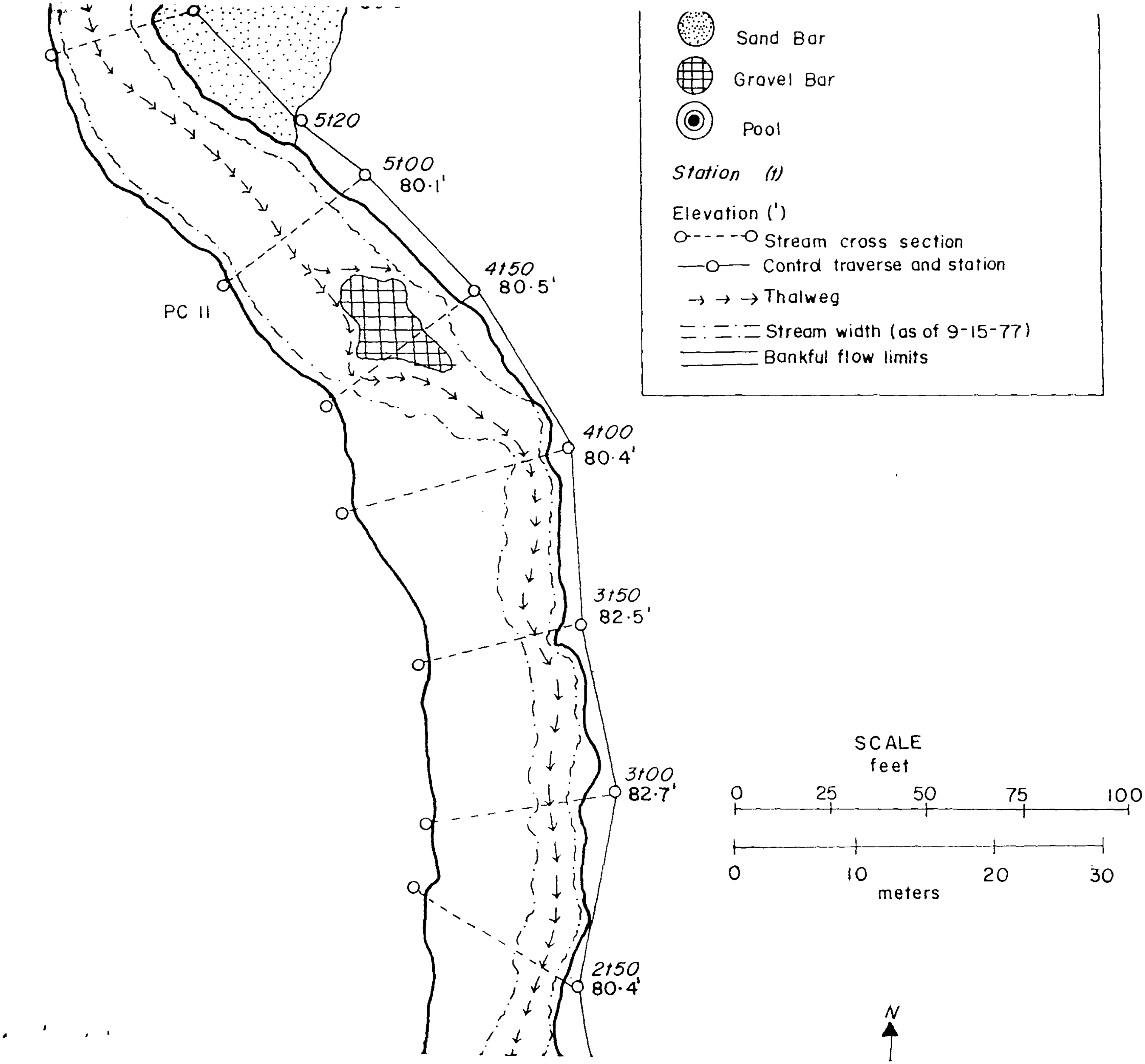
Figure 1: Location of the study area·

PRAIRIE CREEK STUDY REACH

Humboldt County

C1/4, S11, T11, R1E, HM





Sand Bar
Gravel Bar
Pool
Station (t)
Elevation (')
Stream cross section
Control traverse and station
Thalweg
Stream width (as of 9-15-77)
Bankful flow limits
5t20
5t00
80·1'
4t50
80·5'
PC 11
4t00
80·4'
3t50
82·5'
3t00
82·7'
2t50
80·4'
SCALE
feet
0
25
50
75
100
0
10
20
30
meters
N

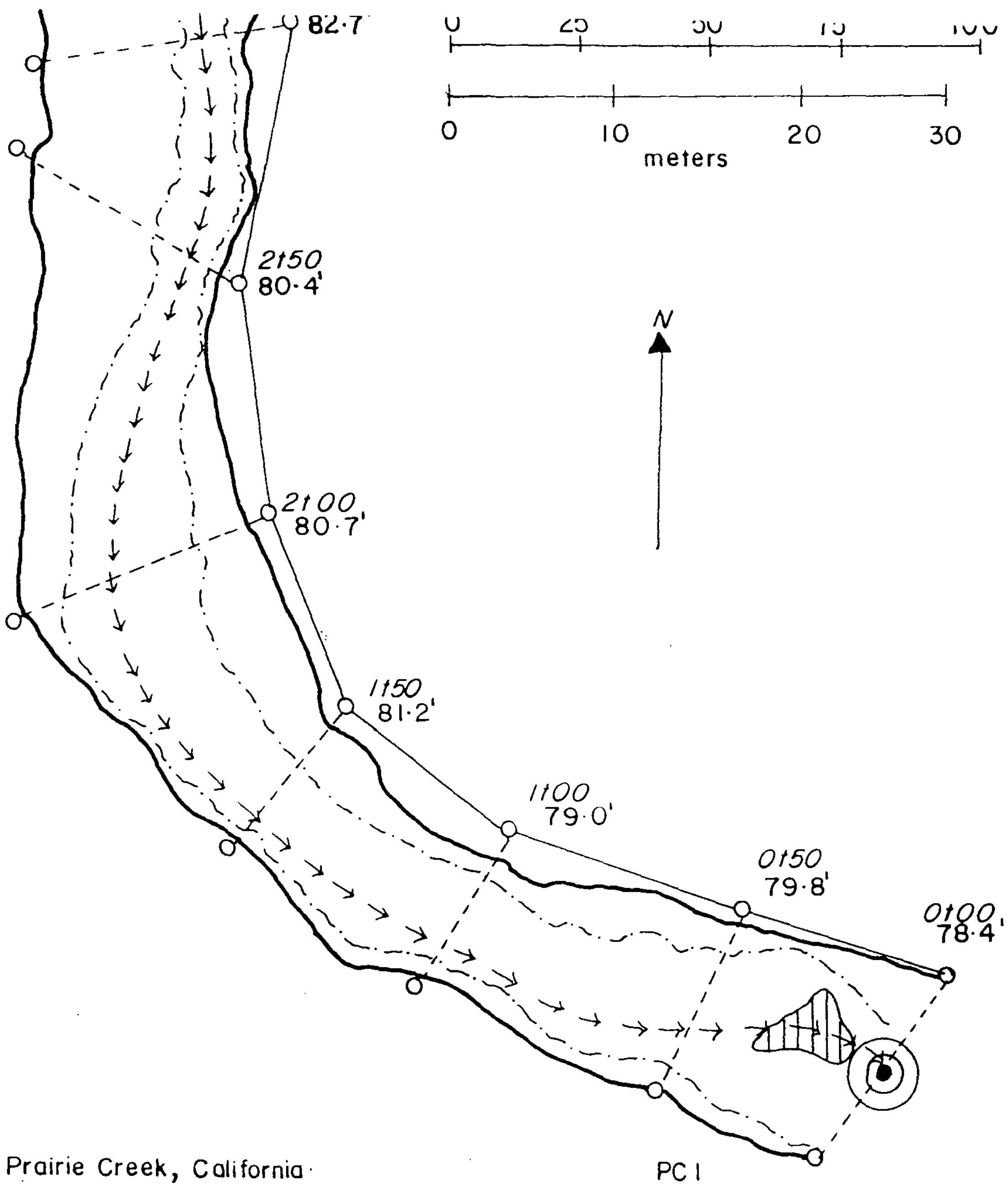


Figure 2: Monitored reach of Prairie Creek, California.

length, this channel is separated from wide upper flood plain areas of overbank deposition by clearly defined banks. Streambed material is predominantly sandy-fine pebble gravel. The lower portions of Prairie Creek travel through reworked alluvial deposits rather than through local parent material and this factor, to a large extent, controls the bed load characteristics in the study reach.

Prairie Creek was selected for this study because of its small size, good access, and because it was evidently subject to less severe winter flooding than many other coastal streams. Also, the riffles were numerous and contained particle-sizes that appeared to be subject to at least some annual rearrangement. In addition, the flow channel cross-section appeared to be adequately well defined for this type of study. Several other streams were investigated as possible study sites, but were not selected for one reason or the other; mainly lack of access, excessive travel time to reach, or lack of riffles.

The study reach selected is just at the southend of the large meadow near the Prairie Creek State Park headquarters. The study reach is approximately 275 m (900 ft) long and contains three monitored riffles. Debris obstructions within the reach were minor and except for two organic ledges did not influence the riffles to any great extent.

METHODS

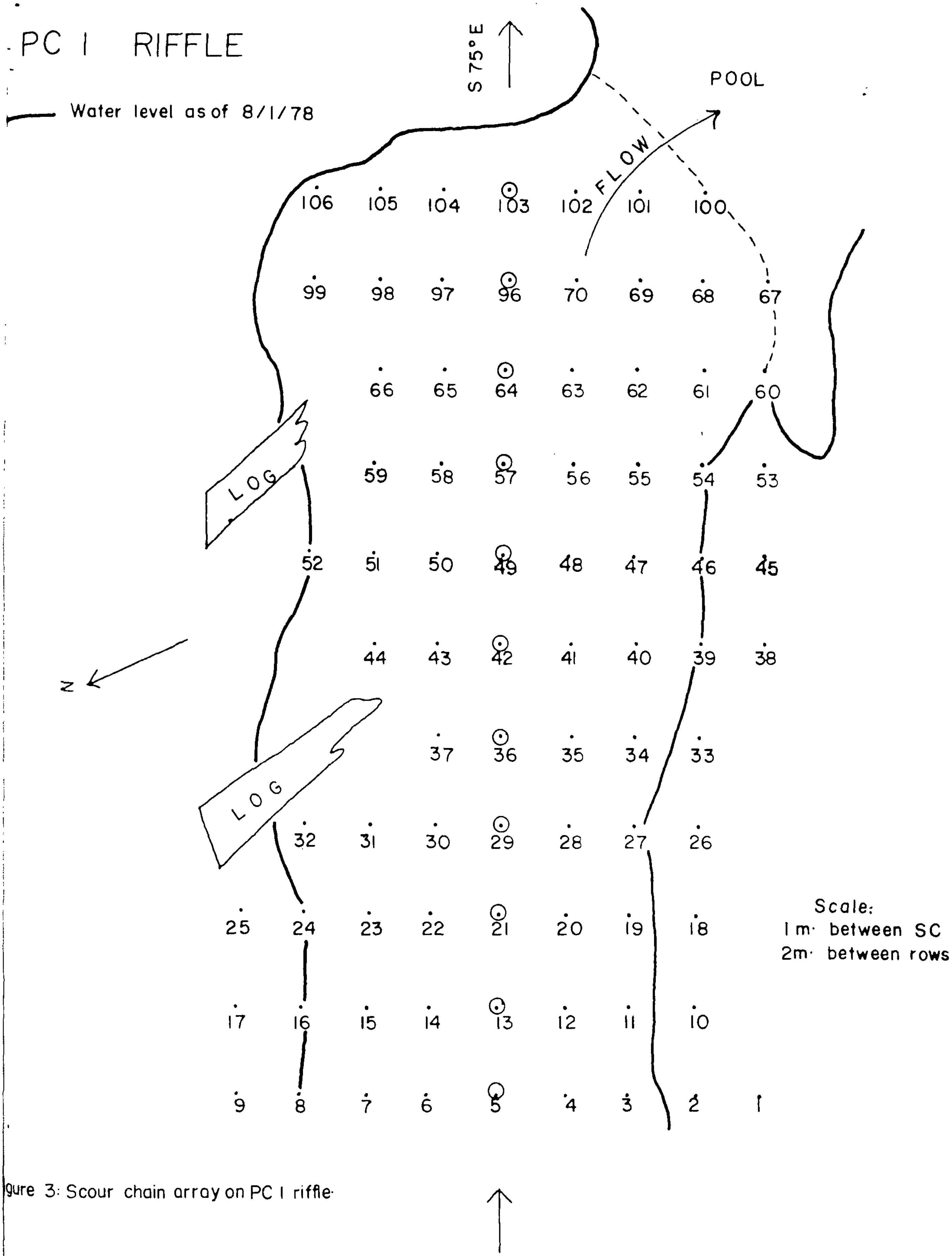
The study reach (Figure 2) was mapped for horizontal control by transit and steel tape survey. Vertical control was obtained by differential leveling. Control stations were established each 50 feet and cross-sectional profiles were determined. (Note: Control stations and elevation values are given in the text, on maps and cross-section figures in ft. as this is still standard surveying practice in the U.S.).

The three riffles used in this study (PC-I, PC-II, and PC-III, figure 2) were instrumented with scour-chains on a 2 m by 1 m spacing. Figures 3, 4, and 5 show the scour chain arrays at each riffle.

The scour chains were installed in flowing water conditions using a tool shown in figure 6. As can be seen, the construction uses standard plumbing fixtures making parts replacement quite easy. Figure 7 shows the sequence of actions necessary to install a scour chain.

Using the scour-chain insertion prope (SCIP), a 60 cm length of No. 16 single-jack steel chain was driven vertically into the gravel at each grid point. The wooden anchor was then driven free by the steel rod, and the SCIP withdrawn. A 15 cm length of chain was left exposed above the gravel surface and a painted, numbered 5/8 inch flat washer was wired to the scour-chain.

The scour-chains were remeasured after each major freshet to determine scour as well as deposition at each



gure 3: Scour chain array on PC I riffle·

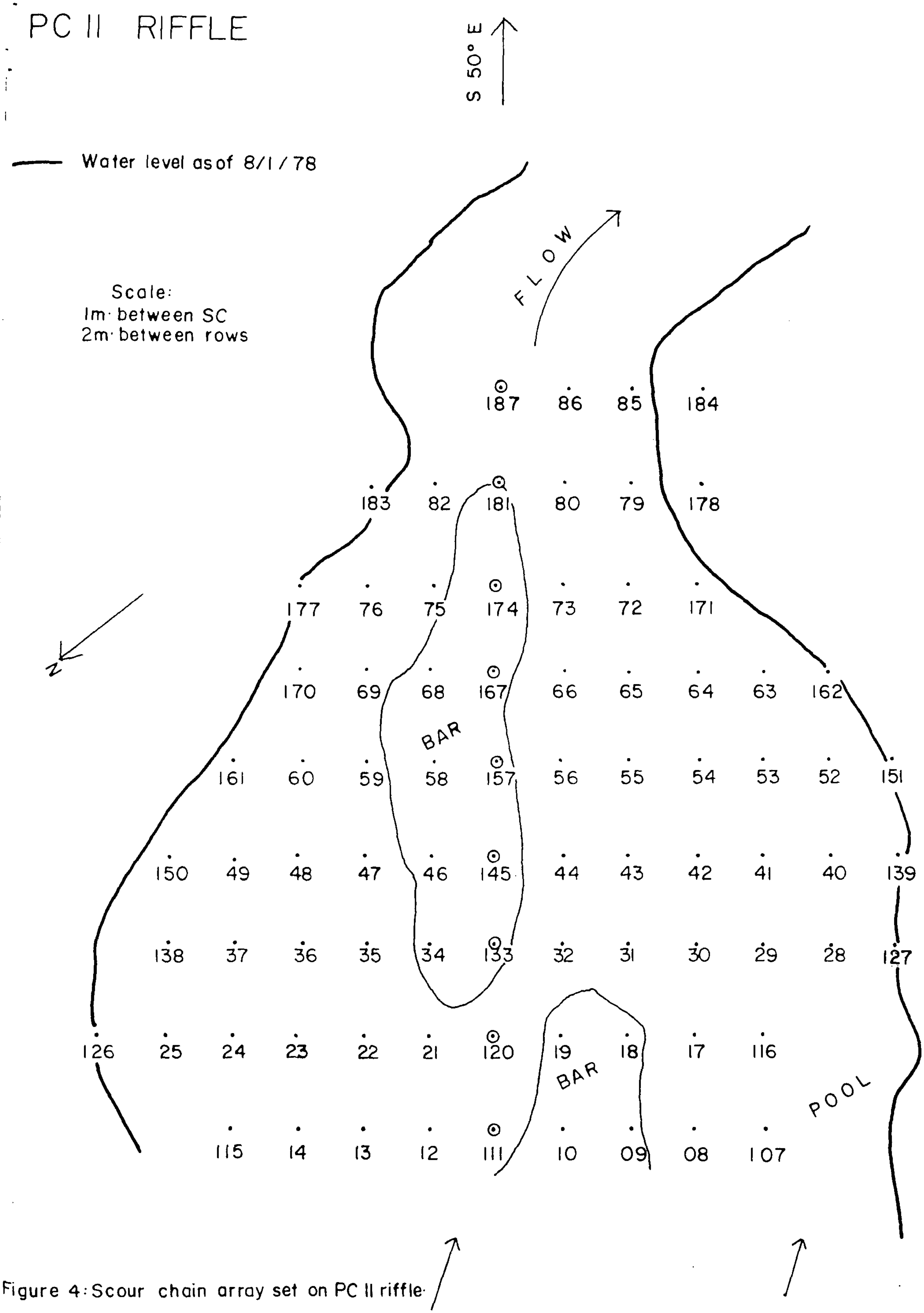


Figure 4: Scour chain array set on PC II riffle.

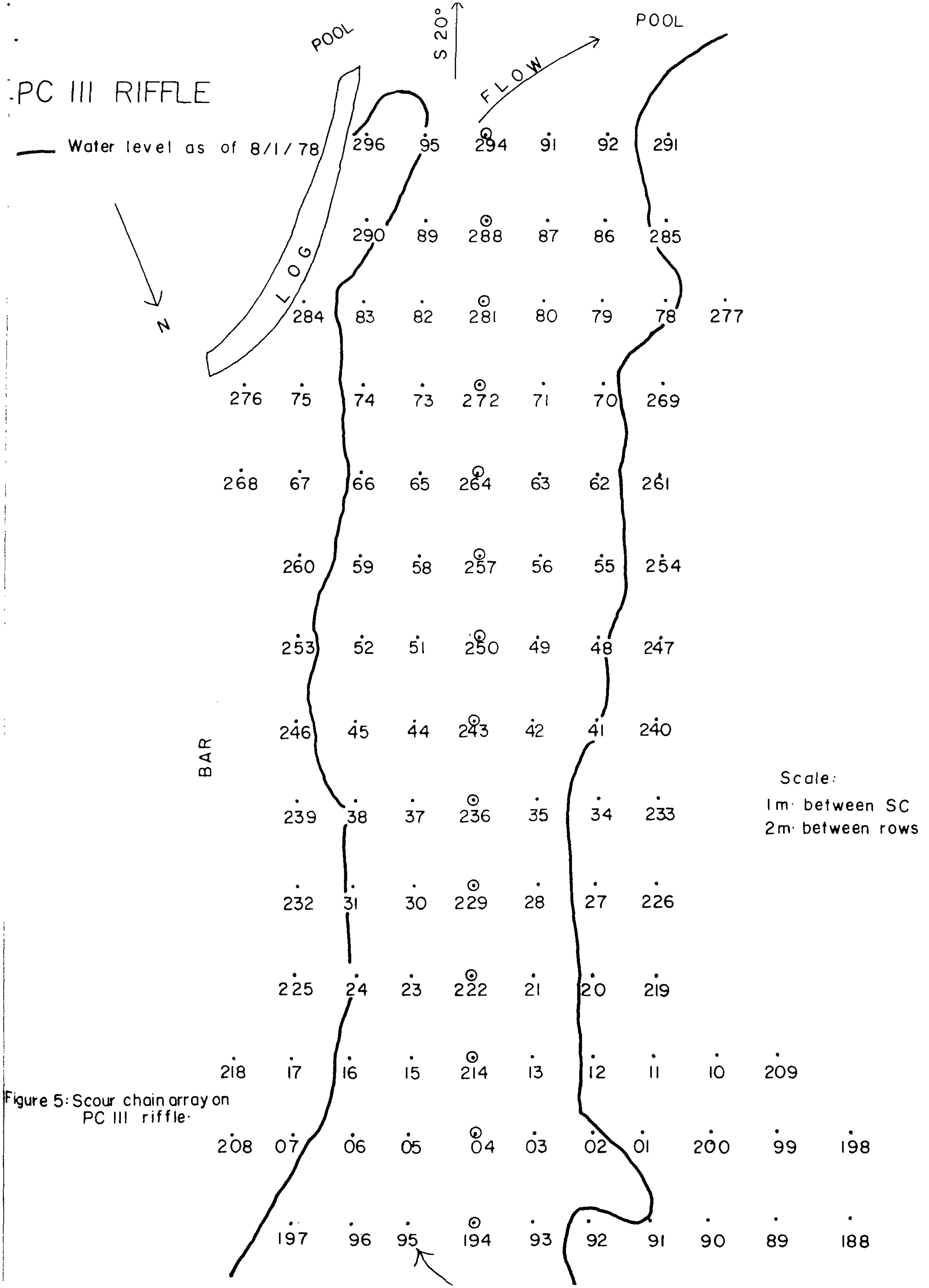
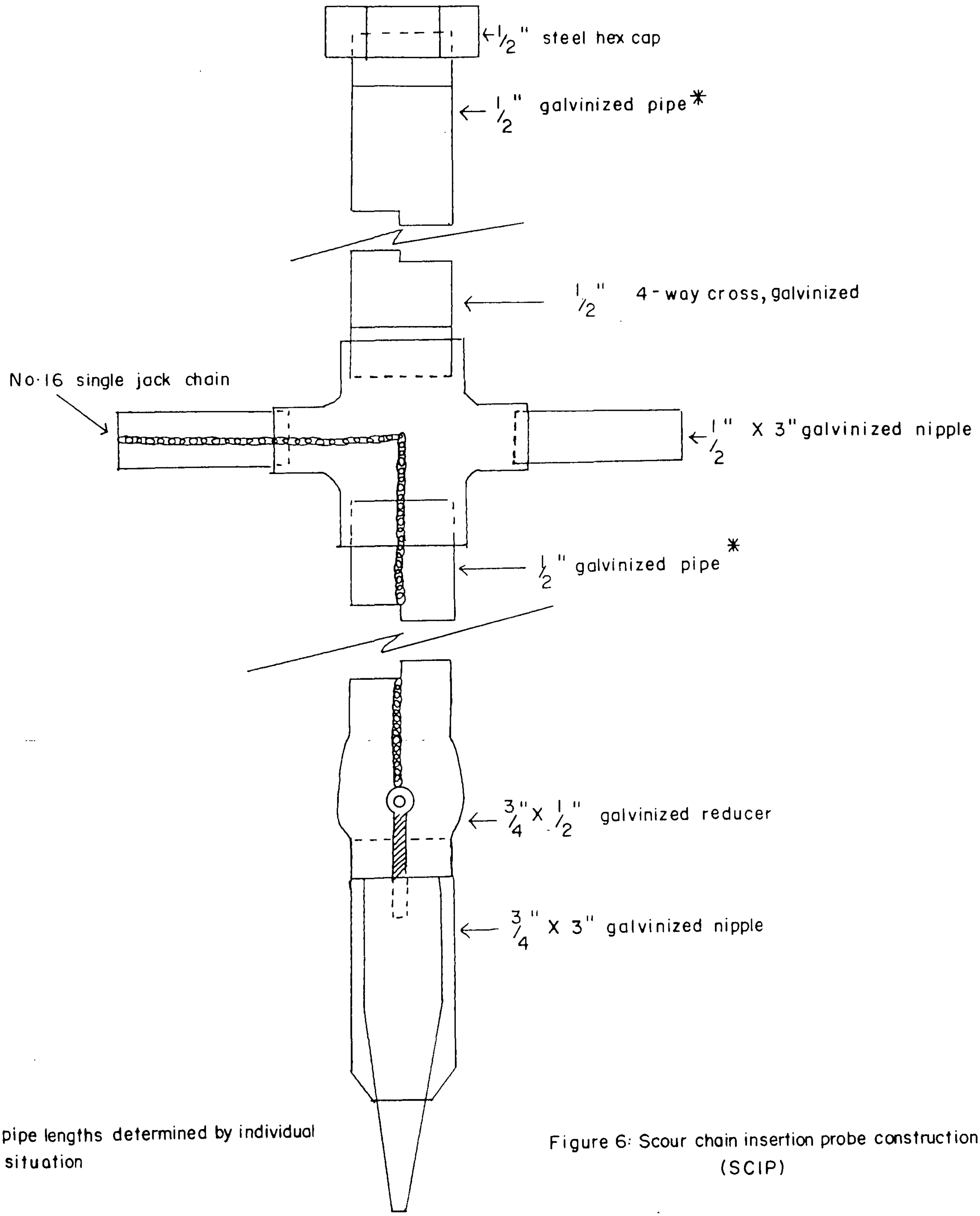


Figure 5: Scour chain array on PC III riffle.



* pipe lengths determined by individual situation

Figure 6: Scour chain insertion probe construction (SCIP)

Scour Chain Insertion Probe
(SCIP)

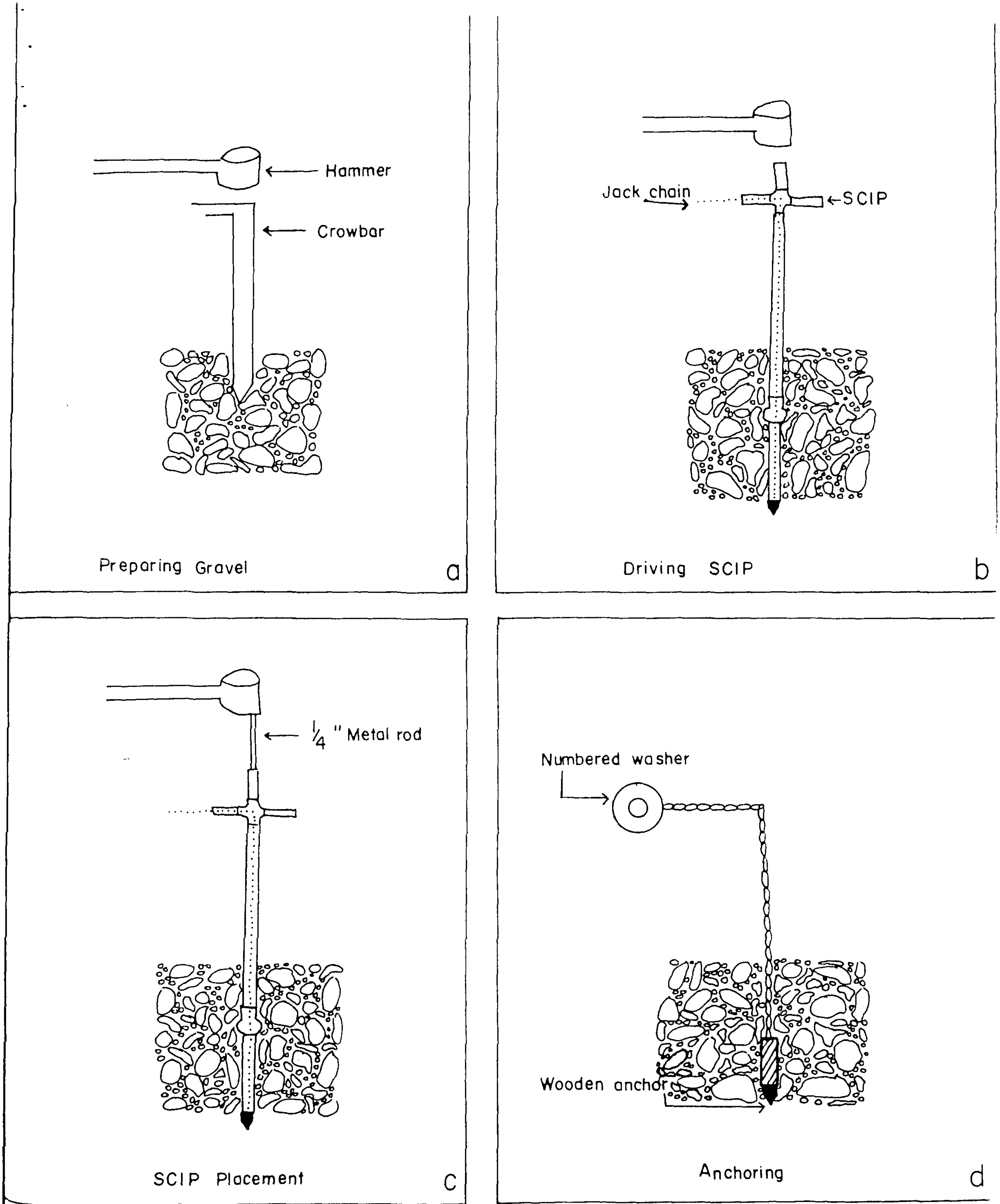


Figure 7: Sequence of actions for installing a scour chain.

point. Inspection of each scour-chain that was underwater was accomplished through the use of a plexiglass bottom bucket (Figure 8).

Peak flows were estimated using two crest-gages located in the middle one-third of the study reach. Figure 9 shows one of the crest-gages. Floating cork and styrofoam material adhered to a calibrated wood staff inside the 2 in. PVC pipe, thus giving an indication of peak flow height. A rating curve for each crest-gage was established by several velocity cross-section measurements using a standard current meter.

Samples of bed material were also obtained at the end of the above three years by the use of CO_2 freeze - sampling as described by Walkotten (1976). One sample per riffle quadrant was obtained each year.

After freezing, the samples were removed from the gravel bed, placed in plastic bags, and transported back to the laboratory for analyses.

Particle-size distribution of the gravels was determined by sieving each sample through a series of brass sieves: 50.8, 25.4, 12.7, 6.35, 2.0, and 0.84 mm diameter. The material of each size class compared to the total thus yielded the particle-size distribution. The percentage of sediments below 0.84 mm was of particular interest as the fine sediment fraction often determines aeration and hence, spawning success.

Figure 8: Scour chains were measured through a clear-bottom bucket after each freshet.

Figure 9: Streamflow discharge was estimated by the use of crest gauges.

Textural composition of the sediment may be presented in graphic form for easy interpretation. Depending on the distribution of sediments and the needs of the analysis, the y-axis of the graph can be scaled with arithmetic, probability, or logarithmic units. Geometric mean (d_g) of a sample is calculated by raising the grain size at the midpoint of each class to a power equal to the decimal fraction of its weight, then multiplying the products of each class to obtain a final product which is d_g provided that 100 percent of the sample is used (see equation 1).

$$d_g = (d_1^{w_1} \times d_2^{w_2} \ldots\ldots\ldots\ldots\ldots \times d_n^{w_n}) \tag{1}$$

where

d_g = geometric mean particle size.

d = midpoint diameter of particles retained by a given sieve.

w = decimal fraction by weight of particles retained by a given sieve.

RESULTS AND DISCUSSION

Gravel Movement

The two winters of monitoring (1978-79 and 1979-80) produced a total of seven freshets that produced measurable gravel movement on the three riffles. Four of the scouring events occurred in 1978-79 and three events in 1979-80. In both seasons, the scouring events occurred during October to December. The largest of the seven events occurred during the storm of Oct. 19-26, 1979 and exceeded 100 cfs. This flow caused local flooding and caused overbank flows in the monitored reach.

Although large flows (some exceeding the smaller flows causing measurable gravel movement) occurred after December of each season, no measurable changes in riffle configuration occurred. I have no way of substantiating any reason for this fact, except to conjecture a guess that after several freshets sufficient to cause movement of gravels, the riffles become quasi-stable to all but very extreme events; an "armouring effect".

Because so few measurable events occurred, little statistical analysis is possible. However, some conclusions seem valid from the data collected. I observed that in each of the seven events where gravel movement was measured, the same pattern of movement occurred. This pattern is shown in Figure 10. At the tail of each riffle (approximately the downstream one-third of the riffle) scour ranging from 6 cm to over 24 cm occurred.

In every case, the tail of the riffles proved to be the least stable, most scour prone portion of the riffle. In fact at PC-I, the last 2.5 m of the riffle changed to a pool reach during the Oct. 19-26 storm.

Stream hydraulics could easily explain this behavior. As the water travels across the rising streambottom (riffle) it increases in velocity. Entering the deeper pool section, the water produces a turbulence "rotor eddy" in the lee of the riffle's tail. This effect is readily seen in wind tunnels or laboratory flumes. The "rotor eddy" scours the tail of the riffle.

The upper third of the riffles, often called the head, were observed to have minimal net gravel movement. What movement did occur appeared to be between 3 cm to 8 cm of scour and then equivalent redeposition. Even after the Oct. 19-26 storm, the largest recorded during this study, no scouring deeper than 8 cm occurred on any of the three riffles.

No definite pattern was detected as to lateral position of scouring and deposition in each reach, except to say that most movement occurred near the thalweg rather than next to the banks.

From these few observations and the conclusions drawn to this point, I find it interesting to note that many authors on salmonid spawning behavior attribute the preferred redd location at the head of riffles - tail of pools, to be due to favorable intergravel water flow gradients at this point. Undoubtedly this is a valid reason as intergravel water flows have been measured and found to be optimal at this location. However, I propose an additional reason, that being that a salmonid which deposits its

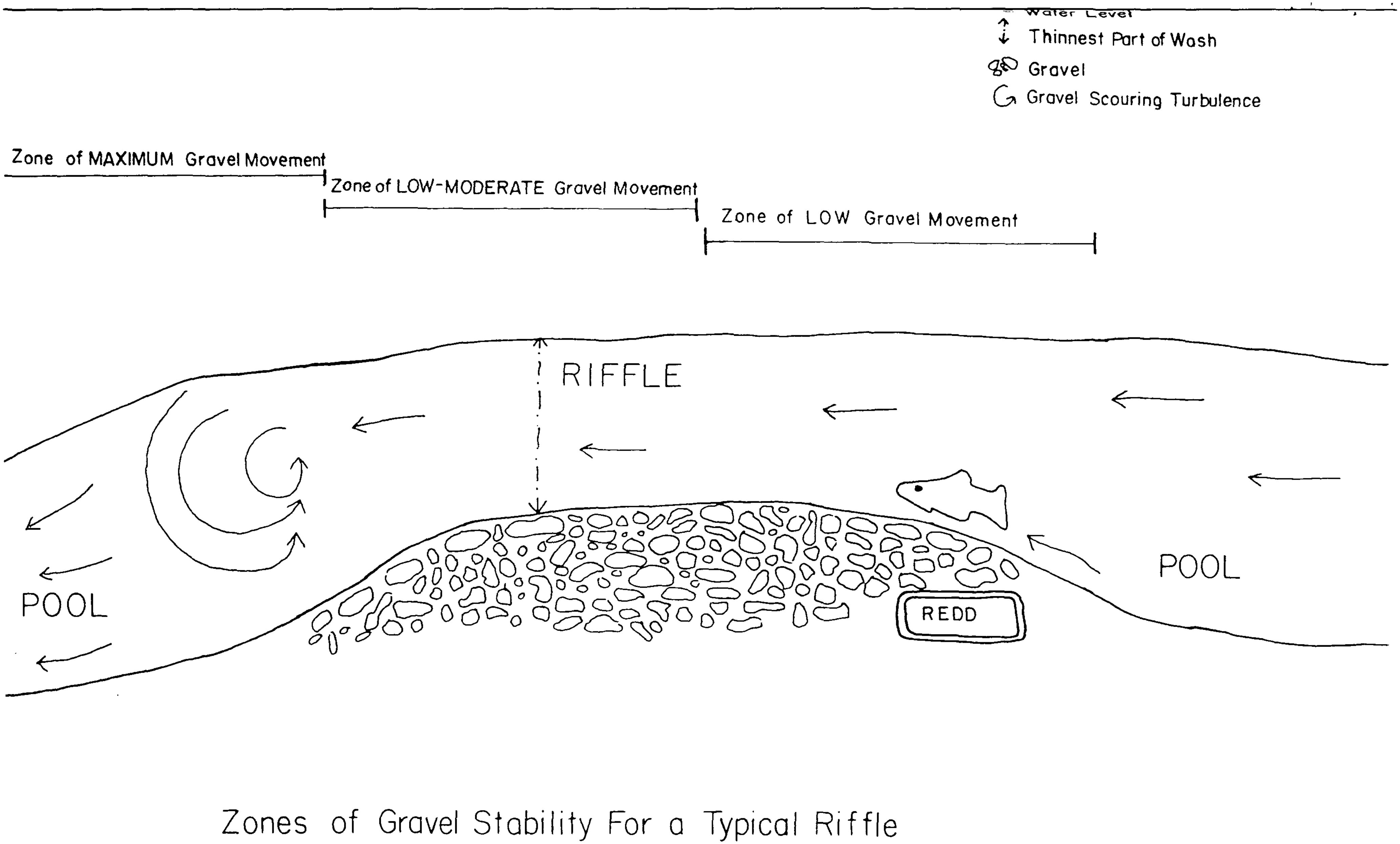


Figure 10: Zones of riffle stability observed on three riffles in Prairie Creek

eggs in the riffle's tail would stand less chance of propagating its genes (due to redd destruction by excessive scouring) than a salmonid using the riffle's head. Therefore, the riffle's head not only has the best oxygenation but also is the most stable location. Hence selection mechanisms in salmonids continue to favor this location.

Gravel Characteristics

The particle-size destribution did not vary significantly from year to year during this study (figure 11). This is not surprising since the principle gravel source for Prairie Creek is the reworked alluvial deposits that make up the streambanks. Analysis of the sieving data also showed no significant difference in particle-size distribution between riffles. Therefore, the curves in figure 11 are averages for the three riffles for each season.

As can be seen in figure 11, there are little fine sediments (less than 0.84 mm) in either year. Although 1979-90 shows a slight increase in fine sediments over the previous year. A possible reason for this is that the sediment samples for 1979-80 were taken at the end of the winter, after the large Oct. 17-26 freshet. Since this was the largest flow for that season, perhaps a net deposition of fine sediments occurred.

Bulk density measurements ranged from 1.7 to 2.1 g cm^{-3} and porosity ranged from 21% to 33%. Because freeze sampling was not possible after the stream level rose, I have no observations as to changes in porosity and bulk density immediately after the first major freshet of the season. Field observations, however, based on a crude penetration resistance estimate (the number of blows of a 2 lb. hammer necessary to drive 30 cm of 1.25 cm reinforcing bar into the riffle) did indicate some loosening up of the gravels occurred after the first major freshet each year.

Table 1 shows some of the grain-size diameters often used to describe or infer properties of coarse-grained soils. Despite its essential role in describing sediments, d_g along is inadequate to estimate the quality of gravel for salmonid reproduction (Lotspeich and Everest 1981). Gravel mixtures with a common d_g can have wide variation in fine sediment content. Since survival-to-emergence of salmonids is directly related to fine sediment content in gravels (Phillips et al. 1975), use of d_g as the sole index to gravel quality could easily lead to erroneous predictions of survival. Similar problems can occur when using percent fines less than a specified diameter to estimate gravel quality.

In addition to d_g, the size distribution of sediment particles in a sample is a useful descriptor of a gravel's reproductive potential for salmonids. Permeability and pore size, which control movement of water and alevins through gravel, are determined largely by the size distribution of grains in a sample. To quantify the distribution of grain sizes in gravels, I have used the sorting coefficient described by Krumbein and Pettijohn (1938). S_o is derived by taking the square root of the quotient

□——□ 1978-79

○——○ 1979-80

GRAIN SIZE ANALYSIS

SHEET 1 OF 1

TEST FOR ____________________

TEST BY ____________________ DATE ____________________

SAMPLE DESCRIPTION ____________________

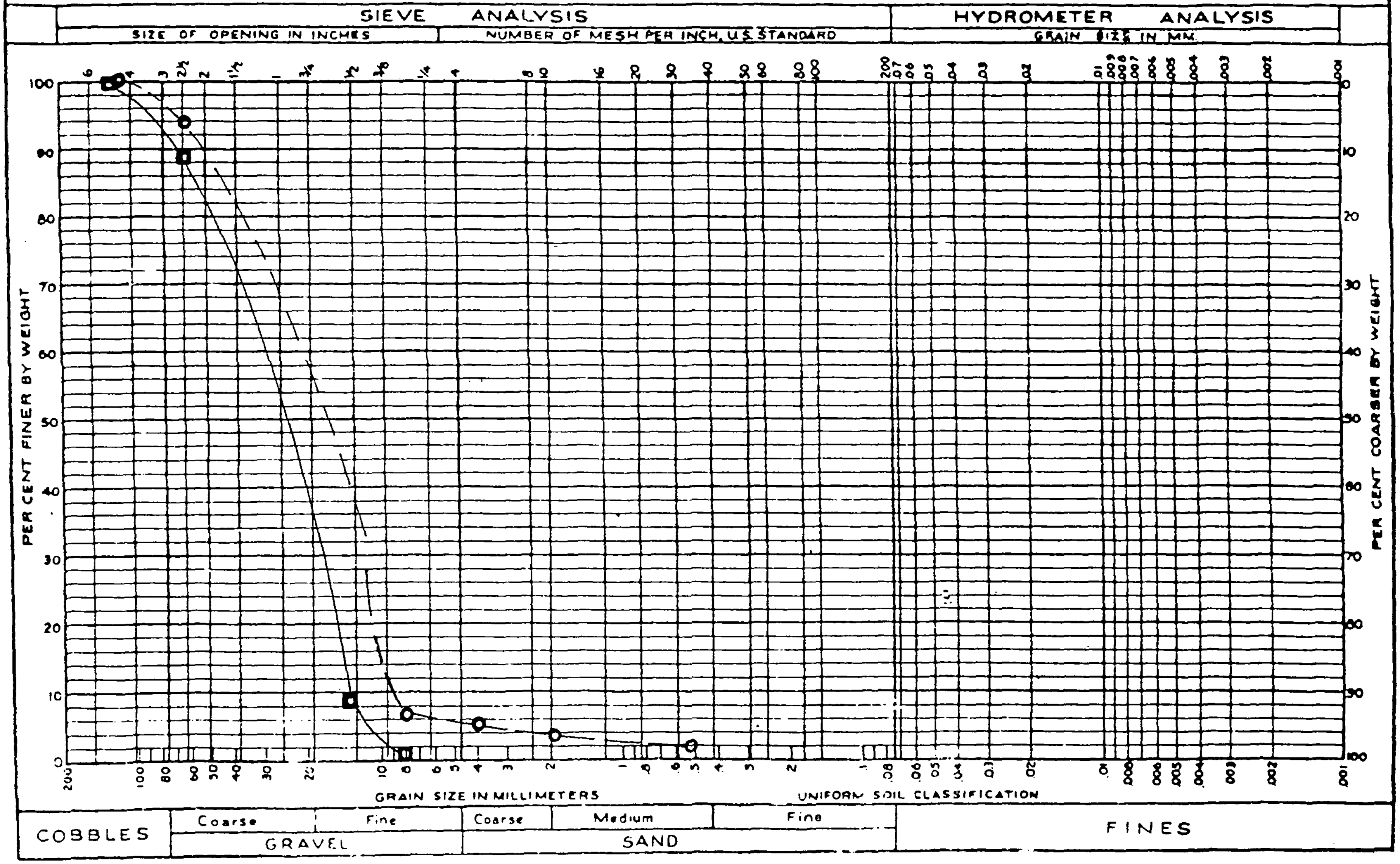


FIGURE 11. GRAIN-SIZE DISTRIBUTION CURVES

OSU-CE

Table 1: Gravel Characteristics, Prairie Creek

	year	
	1978-79	1979-80
Distribution Curve Diameters*	mm	mm
D_{10}	16	9
D_{16}	17	10
D_{25}	23	15
D_{30}	25	18
D_{50}	35	30
D_{60}	45	32
D_{75}	55	33
D_{84}	75	50
Coefficients and Indices		
d_g (geometric mean	36	22
S_o (sorting coefficient)	1.5	1.5
f_i (Fredle Index)	24	15
C_u (Uninformity Coefficient)	2.8	3.8
C_c (Coefficient of Curveture)	0.9	1.0

*The diameters listed are the particle-size diameter at which x % of the sample is finer than that diameter. For example, D_{25} is the diameter at which 25% of the sample is finer than 23 mm in the 1978-79 samples.

of the grain size at the 75th percentile divided by that at the 25th percentile. My choice of the 25- to 75-percent interval is based on the premise that 50 percent of the grains in a sample provide a reliable index of sediment sorting.

By definition of Krumbein and Pettyjohn, a perfectly sorted gravel (with only one grain size) will have an S_o of 1. All imperfectly sorted gravels will have an S_o greater than unity. A sorting coefficient greater than 1 implies that pores between large grains are filled with smaller grains that impede permeability, hence S_o is inversely proportional to permeability. Thus there are two parameters, d_g which is directly proportional to pore size and permeability, and S_o, a measure of the distribution of grain sizes in gravels, which is inversely proportional to permeability.

Using the d_g and S_o, I have used Lotspeich and Everest's Fredle index (f_i), where

$$f_i = \frac{d_g}{S_o} \quad , \qquad (2)$$

as a measure of the quality of the riffles for salmonid reproduction. Fredle numbers for a sediment with one grain size will be equal to the geometric mean because S_o is then 1. Sediments with the same d_g will have f_i numbers less than the mean as S_o increases. Sediments with small d_g are less permeable than those with larger means because pores are small and intragravel flow and movement of alevins is impeded even though S_o might be 1. Also, sediments with large d_g might be slowly permeable when S_o is large because pore spaces are occupied with smaller grains that impede interstitial flow and movement. Thus, the magnitude of fredle numbers is a measure of both pore size and realtive permeability, both of which increase as the index number becomes larger.

It can be seen from the data in Table 1 that the Fredle numbers are quite large and appear to indicate that the three riffles in the study reach have good potential for salmonid reproduction. While the relationship between f_i numbers and survival to emergence of salmonid alevins has not been documented experimentally, Phillips et al. (1975) studied survival to emergence of coho salmon and steelhead trout embryos in gravel mixtures of known composition. Lotspeich and Everest calculated the Fredle numbers for these mixtures and plotted them against survival. Their conclusion was that the Fredle index is responsive to slight changes in gravel composition, survival, and variations in intragravel habitat requirements of individual species. For example, in Phillips et al.'s artifical gravels with f_i of 2, 4, and 8, survival-to-emergence of 30, 60, and 88 percent, respectively, can be predicted for coho salmon, while survival of steelhead trout can be predicted at 45, 75, and 99 percent in the same mixtures. I expect similar results might occur in these riffles.

The uniformity coefficient, C_u, where

$$C_u = \frac{D_{60}}{D_{10}} , \tag{3}$$

and the coefficient of curveture, C_c, where

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}} \tag{4}$$

are engineering indices from which one can infer gradation controlled properties, such as permeability.

The C_u and C_c values shown in Table 1 infer that the Prairie Creek gravels are very uniformly graded and that the gradation did not significantly differ from year to year. Uniformly graded soils, largely in the gravel sizes, usually have high permeability associated with them.

Conclusions

The number of freshets large enough to cause significant gravel movements was quite low (less than four per year) in the two years monitoring occurred. Significant riffle rearrangement occurs on an episodic basis and any further studies must encompass a longer time period if one expects to observe the necessary conditions to more accurately predict the frequency and extent of scouring events.

From the limited observations possible, it appears that most gravel rearrangement occurs due to the first of the larger freshets and after that some form of interlocking or "armouring" occurs to stabilize the riffles. If this is the case, salmonids spawning after these first freshets may have better survival-to-emergence success than earlier spawners as their redds are in stabilized gravel.

Field observations indicate that the upstream (head) portion of the riffles are more stable than the downstream (tail) portion of the riffle. Salmonid spawning preference for this area may be due to this fact as well as better inter-gravel water flow gradients.

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