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A MODEL DESIGN FOR PHYSICAL AND BIOTIC REHABILITATION OF A SILTED STREAM

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EXECUTIVE SUMMARY

This study proposed to develop a methodology for rehabilitating a silt-polluted stream, through the employment of in-stream sediment-flushing devices and to measure the biological impact of rehabilitation on the insect community. The field study phase of this project was conducted in the East Fork and the main stem of Emerald Creek, a tributary to the St. Maries River in northern Idaho. The specific objectives included: 1) conduct a biological and physical inventory of a silted stream; 2) evaluate sediment flushing capabilities of different types of hydraulic structures; and 3) determine recolonization of the rehabilitated areas by invertebrates.

Procedurally the study involved natural field conditions and laboratory simulation. Six sites were established for streambed alteration employing a variety of sediment flushing devices. Control sites were selected specifically for each test site on the basis of similarity of flow, substrate type, and channel geometry. All sites were surveyed, mapped and photographed in order to document the ability of the channel to favorably influence the transport capability of the stream.

Sediment samples were tagged, replaced in the substrate and monitored to examine sediment transport characteristics of Emerald Creek during periods of high flows.

Three basic types of hydraulic structures were constructed to modify the flow characteristics of Emerald Creek. Log drop structures and two types of channel constrictors, rock filled gabions and log dikes were used at different locations.

Changes in the aquatic insect community were monitored in conjunction with measurement of physical changes of the streambed. At each permanent transect the stream was divided into sections. Standing crop and drift samples were taken to describe community characteristics and colonization phenomena.

A species diversity index, derived from information theory by Brillouin was used to describe community changes resulting from in-stream alterations. Three values were calculated: diversity/ individual; maximum diversity, and evenness.

In-stream alterations proved to be effective means for increasing sediment transport, thereby improving insect and fish habitat. Debris jam removal, channel diversion, and gabion deflectors caused flushing of fine sediment from both runs and pools. Log-drop structures scoured pools, thereby increasing the pool-riffle ratio. Post-alteration analysis of test transects yielded higher values of percent cobble, average sediment size and mean channel depth, thus producing a more viable insect habitat.

Community changes resulting from in-stream alterations caused diversity, numbers of species and total number of insects to increase after completion of channel alteration. Insect community changes resulting from in-stream alterations were most pronounced at gabion sites and to a lesser extent at debris jam removal, channel diversion and log-drop sites.

Emerald Creek, by virtue of its natural hydrological cycle, has the ability to flush large quantities of fine sediments annually. However, until the source of pollution sediments is eliminated,

lower portions of the main stem will continue to be subjected to an excessive loading. In-stream alterations proved to be effective for increasing sediment transport, thereby accelerating physical and biological rehabilitation commensurate with retardation of the sediment source.

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INTRODUCTION

This study was conducted to evaluate the physical and biological impact of four types of in-stream alterations in Emerald Creek, a silt polluted stream approximately 50 miles northeast of Moscow, Idaho. Methodology was also developed for rehabilitating streams where the fishery and other recreational uses have been destroyed or greatly reduced by heavy silting.

Siltation frequently occurs downstream of gravel washing operations, placer mining, logging areas, cultivated areas, and below areas where a highway or other construction has left large expanses of unvegetated soil. Good management dictates rehabilitation of wasted streams at the earliest possible time after the washing or placer operation has been discontinued or after the sediment producing watershed has been healed.

Log drop structures, debris jam removal, channel diversion and gabion deflectors were used. Cobble factor, embeddedness, sediment size surrounding cobble, average sediment size, mean channel depth, and benthos were measured at 13 permanent transects (4 control, 9 test) during 1971-1973. Various sizes of tagged sediment were used to qualitatively assess sediment transport potential. Field and laboratory studies of insect drift and upstream dispersion were undertaken to yield insight into colonization rates in heavily silted portions of the main stem of Emerald Creek.

The drop structures were constructed at two sites on the upper reach of Emerald Creek. These structures concentrated the energy of the flow and scoured a hole immediately downstream of the structure.

Considerations in the design of drop structures include hydraulic loading on the structure, backwater effects and scour potential. In general the log drop structures performed favorably.

The flow constricting structures were designed to reduce the channel width and increase the depth of flow during low flow periods thereby increasing the transport capacity of the stream. The silt and fine sands were effectively flushed from the modified reaches leaving cobble and small boulders. Gabion deflectors were used at two sites on the lower reach of Emerald Creek to constrict the flow, while log dikes were used at one additional site to constrict the flow and train the stream to follow a meandering flow path. Design considerations for flow constrictors include forces on the structure, location of structure, meander dimensions, and constriction dimensions.

In-stream alterations were determined to be effective devices for increasing sediment transport, thereby improving insect and fish habitat. Insect drift and colonization were adversely affected by long, low-gradient sandy reaches. Insect settle-out rate on sand was found to be a function of current velocity, light conditions and insect species. It was determined that Emerald Creek, by virtue of its natural hydrological cycle, has the ability to displace much of the polluting sediments once the source of excess sediments can be eliminated.

OBJECTIVES

This study proposed to develop a methodology for rehabilitating a silt polluted stream through the employment of in-stream sediment flushing devices. Additionally, the study evaluated the biological impact of these structures on the insect community which serves as a food-resource base for a viable fishery. The specific objectives were:

1. Conduct a biological and physical inventory of a silted stream.
2. Evaluate sediment flushing capabilities of different types of hydraulic structures.
3. Determine recolonization by invertebrates and vertebrates into rehabilitated areas.

All of the above objectives were essentially satisfied during the course of the study.

STUDY AREA

The field study phase of this project was conducted in the East Fork and the main stem of Emerald Creek, a tributary of the St. Maries River in northern Idaho (Figure 1). Much of the main stem of Emerald Creek suffers from a high sediment concentration resulting from commercial and private mining of garnets and garnet sand.

The East Fork of Emerald Creek originates at an elevation of 4000 feet in the Hoodoo Mountains in Latah County. It flows northeast until it enters a broad valley at its confluence with the West Fork. The main stem flows into the St. Maries River approximately five miles northwest of Clarkia, Idaho. The total drainage area is 36 square miles with a mean elevation of 3000 feet.

Emerald Creek, a low gradient stream, drops approximately 220 feet in the 10 mile section involved in this study. Its width varies from 11-35 feet; the average riffle depth is 2-6 inches with pools 2-4 feet deep during midsummer. During the summer months the velocity ranges from less than 1.0 to 2.3 feet/second and the average discharge for the main stem is approximately 16 cfs.

Geologically, the East Fork is in the Pre-Cambrian belt series. The stream grades into Columbia River basalt below the confluence of the East and West Forks.

Activities taking place within the Emerald Creek drainage include logging, mining, summer livestock grazing, and recreation in the forms of rockhounding, fishing and hunting. Until 1969 the East Fork and its tributaries were subjected to heavy use by rockhounds digging for garnets in the bed and banks of the stream with

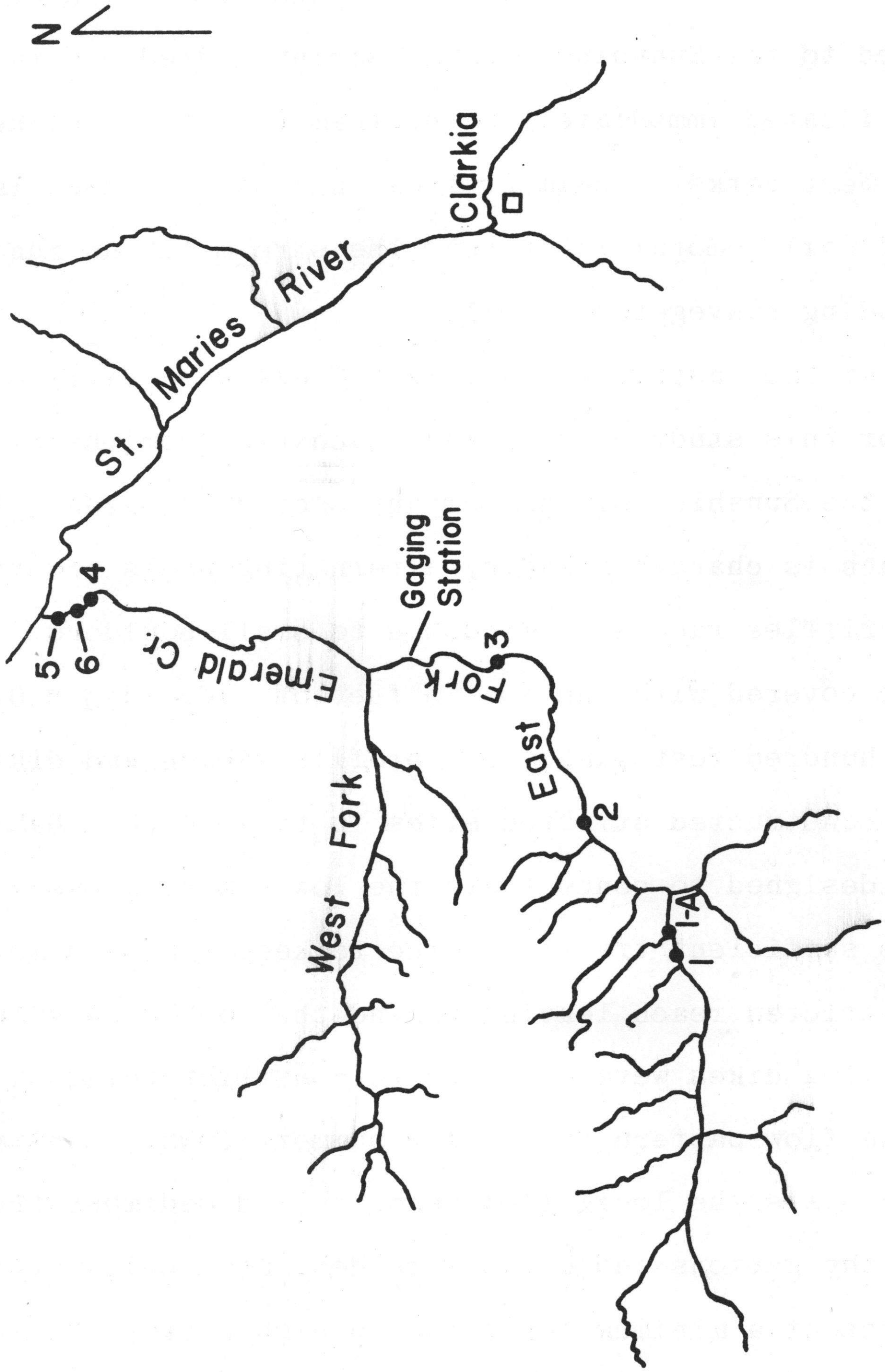


Figure 1
Emerald Creek and Modification Sites as Identified by Number

most of the gravel washed and screened in the streams. Since 1969, digging of garnets has been limited to a 40 acre lease with Emerald Creek having been diverted around this area.

A major source of sediment in the main stem of Emerald Creek can be attributed to the Sunshine Mining Company's dredge site and screening plant located immediately downstream from the confluence of the East and West Forks. Sediment from this 30-acre area is the direct result of soil removal in or near the streambed and runoff from the surrounding nonvegetated soil.

The main stem and East Fork of Emerald Creek were divided into three reaches for this study. The lower reach ran from the St. Maries River to the Sunshine Mining Company's dredging area. This low gradient reach is characterized by alternating pools and riffles. Bed material in riffles ranges from cobble to small boulders. Some of the pools are covered with one to two feet of sand (d_{50} = 0.7 mm) and are several hundred feet long. Low profile gabion and dike deflectors were constructed at three sites in this reach. Gabion structures were designed to concentrate the low summer flows at two sites to provide sufficient tractive force to keep the sand moving through the constricted reach leaving behind the cobble material. At a third site, log dikes were designed to constrict the flow and form a meandering flow pattern during low summer flows. Constricting the flow increases the local flow velocity and sediment transport capacity. Both the gabions and dikes were designed as low profile structures to present a minimum impedance to high winter and spring flows.

The middle reach of Emerald Creek from the dredging operation upstream to the 40-acre garnet removal area was generally in good condition. Bed material ranged from coarse sand to small cobble with most of the material in the course gravel to cobble range. There was an acceptable pool to riffle ratio in this reach.

The reach of Emerald Creek upstream of the garnet removal area was a typical fast-moving mountain stream with the surface bed material consisting of coarse gravel. The major problem on this reach was the lack of pools for fish and the presence of log jams. Three log drop structures were constructed at two sites to create scour holes during the high flow events. In addition, one log jam was modified and monitored to assess its ability to influence the development of scour holes.

PROCEDURES

Physical Analysis of Stream Habitat

Substrate Analysis and Classification

In June, 1971, five sites were selected in Emerald Creek for streambed alteration. Control sites were selected specifically for each test site on the basis of similarity of water velocity, substrate type, depth, and stream width. All sites were surveyed, mapped and photographed in order to adequately document the ability of the channel to rid itself of sediments.

Permanent transects were established at 1 or 2 locations at each site, depending on the length of the test reach. One-half inch steel rods approximately four feet in length were driven into the stream banks at points opposite each other. A nylon cord, leveled and drawn taut between the rods, served as a transect line from which streambed profiles could be determined by measuring the distance from the cord to the bottom of the stream at 1-foot intervals from bank to bank.

The substrate was described at 1-foot intervals using three criteria: 1) cobble factor (presence of all rock larger than 2.5 inches in diameter), 2) embeddedness of the cobble, and 3) size of the sediment surrounding cobble. The substrate description was based on a visual examination of the sediment as opposed to more time consuming and laborious analytical methods. Four pre-alteration and five post-alteration sets of transect data were taken during the study using this eyeball approach. The degree of embeddedness was described using a classification scheme consisting of five categories:

Cobble Embeddedness Classification

5 . . . . . . nearly 100% embedded
4 . . . . . . 75% embedded
3 . . . . . . 50% embedded
2 . . . . . . 25% embedded
1 . . . . . . nearly 0% embedded

Sediment surrounding the cobble was described using the following 4-rank classification:

Surrounding Sediment Classification

1 . . . . . . greater than 1 inch in diameter
2 . . . . . . 1/4 - 1 inch in diameter
3 . . . . . . 1/8 - 1/4 inch in diameter
4 . . . . . . less than 1/8 inch in diameter

The mean substrate sediment size for each site was calculated by averaging 1-foot intercept substrate measurements. Sediment size was described using the 5-rank scheme presented below:

Sediment Size Classification

1 . . . . . . less than 1/8 inch in diameter
2 . . . . . . 1/8 - 1/4 inch in diameter
3 . . . . . . 1/4 - 1 inch in diameter
4 . . . . . . 1 - 2 1/2 inches in diameter
5 . . . . . . greater than 2 1/2 inches in diameter

Sediment Movement

Tagged sediment studies were initiated in the fall of 1971 to examine sediment transport characteristics of Emerald Creek during periods of high flows. Three size classes of sediments weere studied at four locations. Sediment obtained from these locations was dried and tagged in the laboratory with fluorescent paint.

In a moderate riffle, three size classes of rocks were positioned along transects on the streambed. Core implants of tagged sediment were used at three other locations. A core sampler facilitated placement of the implants. In a low velocity reach in the upper East Fork, three 6-inch cores were implanted. At two locations in the lower main stem of Emerald Creek 3-inch cores of tagged sediment were implanted using a 3-inch aluminum tube placed inside the larger core sampler. Unmarked sediments were distributed around the tube, which was then removed leaving a vertical column of tagged sediment in the streambed. Triangulation techniques were employed for marking the exact position of each core.

During the spring of 1972, following high water, core implants and tagged cobble were relocated and resampled using the same techniques by which they were placed. Tagged rock displacement distances and core erosion were recorded in an attempt to document the scour and sediment transport capability of the stream.

Standpipes

A method for measuring the hydraulic conductivity of the streambed using standpipes as a means for determining changes in bed character due to silt deposition was attempted. Calibration curves for the standpipes were developed in the laboratory. However, it was found that bed conditions at our installations along Emerald Creek were not suitable for adequately field testing the standpipes, rigorous field testing of this technique was deferred.

Using a standard falling head permeameter, the hydraulic conductivity of four samples of sand-gravel mixes were obtained. The size distribution of the samples is shown in Table 1.

To obtain indirect measurements of hydraulic conductivity (K), three perforated standpipes were imbedded to a depth of 10 inches

Table 1: Size Distributions for Sand-Gravel Mixes

Sieve Size Inches	Mean Size Inches	Percent by Weight in Sieve Fraction			
		1	2	3	4
0.004					
	0.0055	0	8	9	14
0.007					
	0.0077	0	9	20	29
0.0084					
	0.0117	0	3	5	7
0.015					
	0.0475	18	15	13	10
0.08					
	0.105	21	16	14	12
0.13					
	0.153	19	14	16	16
0.175					
	0.223	20	19	9	7
0.27					
	0.455	22	16	14	5
0.64					

in a sand-gravel mixture placed in the test section of a flume. Flow through the flume was adjusted to a depth just above the sand-gravel mixture. Water within the standpipe was evacuated to a level one inch below the water surface in the flume and the steady discharge with this one-inch head differential was measured. The procedure was repeated for the four samples of sand-gravel referred to above. The hydraulic conductivity (K) and the average discharge (Q) is shown in Table 2.

Table 2: Data for Hydraulic Conductivity

Run No.	Gravel %	Sand %	H_1 ft	H_2 ft	L ft	T av. sec	K cm/sec	Q ml/sec
1	100	0	3.08	1.22	.764	8.69	2.47	94.2
2	79.8	20.2	2.98	1.04	.9	65.8	0.439	52.4
3	66.7	33.3	2.85	1.02	.4	103.6	0.1209	17.1
4	50	50	2.86	1.93	.35	296.4	0.0142	3.37

Design of In-Stream Modification Structures

The first step in a stream channel improvement program is an on-site inspection of the stream and the preparation of an inventory of troublesome reaches. At the site of each proposed modification topographic details, an adequate description of streambed and bank materials, and frequency curves for both annual floods and low flows must be available. If flow records are not available, this information must be generated by some acceptable hydrologic technique appropriate for the basin and for the anticipated investment in modification structures.

After obtaining the necessary information three basic questions must be answered: 1) what is the problem in the troublesome reach, 2) what type of structure is required to relieve or alleviate the problem, and 3) what size of runoff event should the structure be designed to withstand?

One-hundred year flow events for a stream the size of Emerald Creek may be four to six times the average annual flood event. Economics will not permit construction of a structure for the maximum anticipated runoff event. Depending on the type of structure and the planned life of the structure, the design flood selected may vary from structure to structure.

When designing small training structures it must be realized that the structure will be rather trivial in the overall hydrogeomorphic evolution of the channel. Selection of a design flood must be based on the premise that the structure is temporary and that it is specifically designed to influence channel development in a relatively short reach for a limited time period.

Structures constructed in Emerald Creek were designed to withstand a 25-year flood which is approximately 300 cfs at the log drop structure sites and 1400 cfs at the channel constrictor sites.

Drop Structures

Three log drop structures were constructed at two sites on the upper reach of Emerald Creek. This reach is characterized by an incised channel and a relatively steep slope, a necessary requirement for drop structure sites. The incised channel is needed to contain the increased depth of flow behind the structures caused by backwater effects and the steep slope minimizes the upstream extent of its influence. The purpose of a drop structure is to concentrate the energy of flood flows and consequently scour a hole downstream of the structure. The height of the drop structure must be limited to the height that migrant fish can jump.

Two log drop structures were constructed at Site 1, indicated on Figure 1. These drop structures (Figure 4) were based on a design in the Forest Service's Wildlife Habitat Improvement Handbook.

As shown in Figures 2 and 4, two cedar logs were placed perpendicular to the flow with their ends anchored in the stream banks. Two-inch thick wood planks were driven in the streambed on the upstream side of the logs. Construction time was about 20 man hours per structure.

The drop structure constructed at Site 1-A was a variation of the structures at Site 1. As Figure 3 and 4 show, the structure

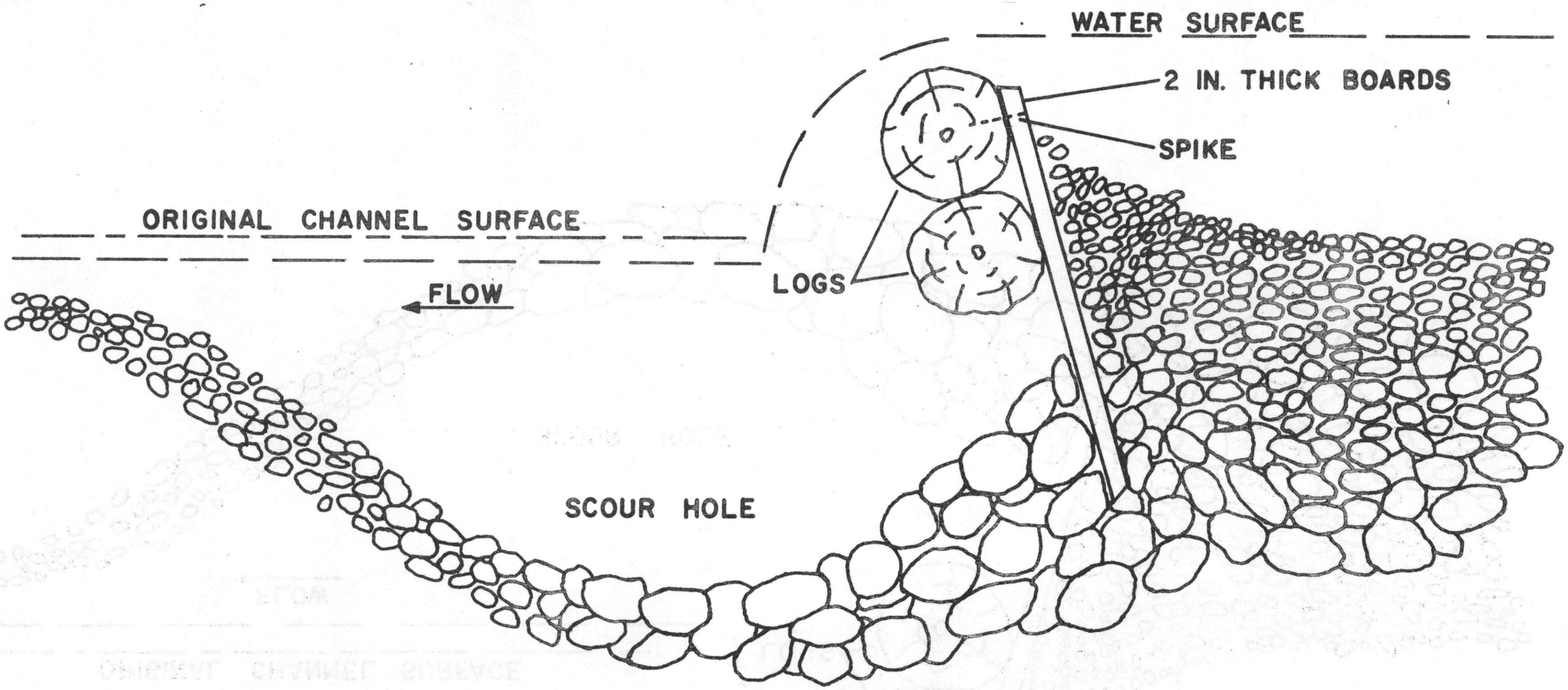


Figure 2

Log drop structure used at site 1

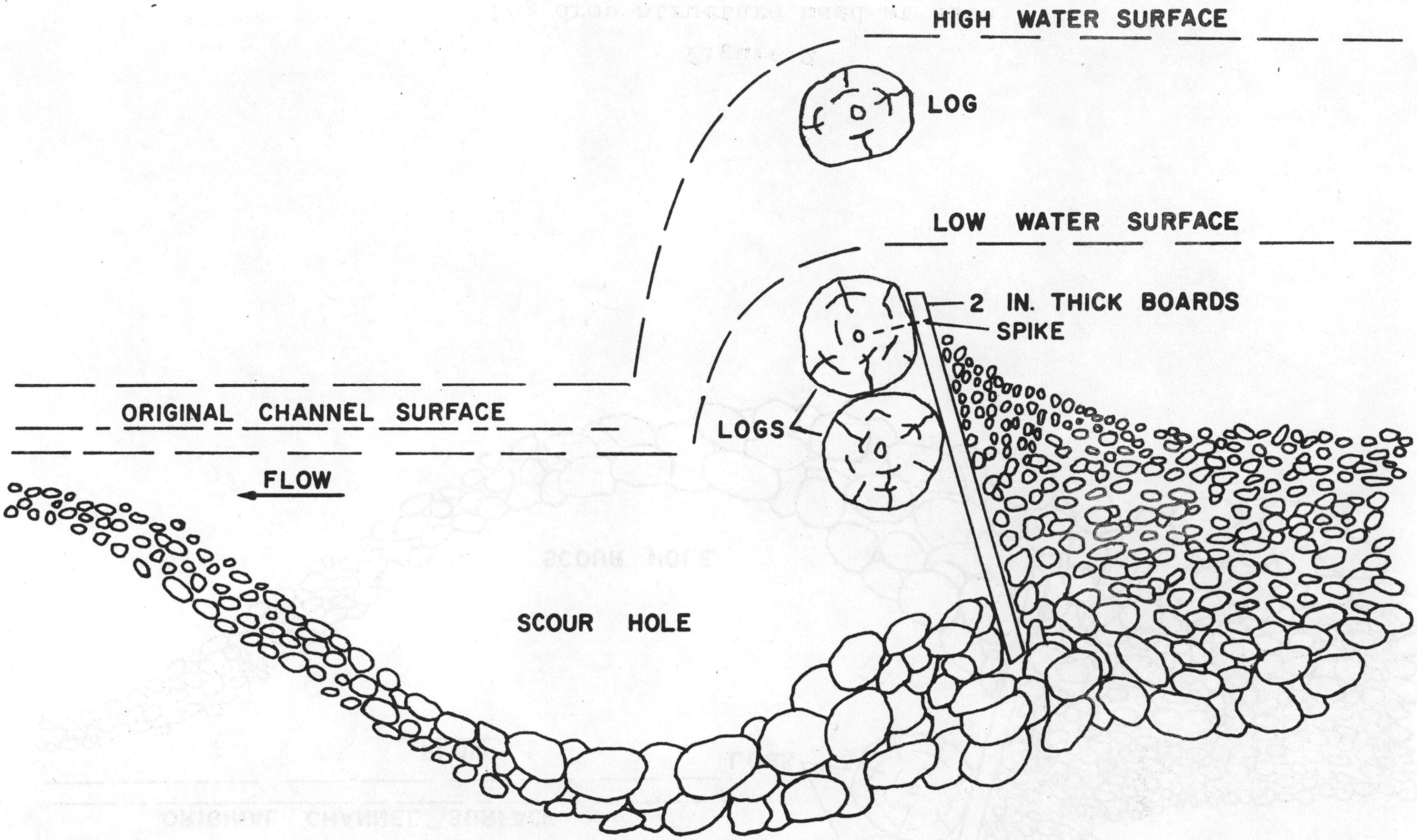
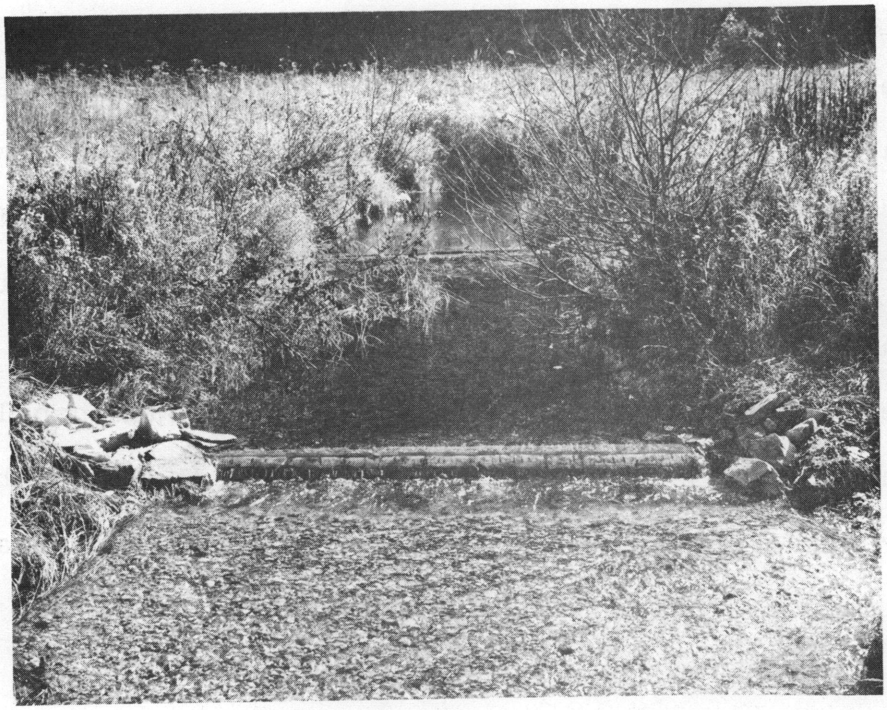


Figure 3
Log drop structure at site 1-A



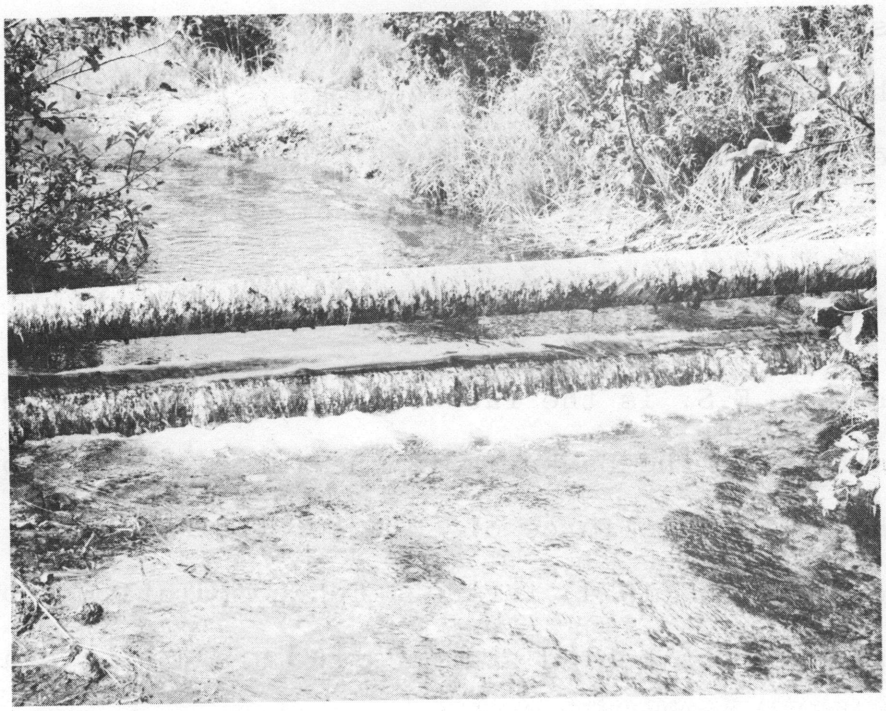


Figure 4

Drop structures at site 1 (top) and the
double log drop structure at site 2 (bottom)

at Site 1-A consisted of three logs with a gap between the top and lower logs. The structure was designed to allow the flow and fish to pass over the low log during low discharge periods. During high discharge periods fish could still pass over the lower log but most of the flow would cascade over the top log and fall with a greater impact and thus increase the scour depth downstream of the structure.

The bed material at Sites 1 and 1-A was predominantly coarse gravel with the mean sediment size (d_m) equal to 0.7 inches.

Factors that should be considered in the design of a drop structure include forces on the structure, minimization of backwater, and scour below the drop structure.

The forces acting on the log drop structure include hydrostatic pressure, soil pressure, weight of soil, ice loading, and water on the boards connected to the logs. The embedment length L_2 of the ends of the log in the bank can be determined using the equation:

$$L_2 = \frac{F.S.FL_1}{2R} \cdot L_2 \geq 3 \text{ feet} \qquad (1)$$

In equation (1), F.S. is the factor of safety, L_1 is the length of the logs between the banks, F is the force on the drop structure, and R is the resistance force of soil per foot of log. The reader is referred to Kelly (1974) for detailed computation procedures.

Increased depths behind a drop structure can be evaluated by using a standard backwater computation. This method utilizes the channel geometry, discharge, and the Manning equation in a trial and error procedure. Computations are started at a known point in the system and depths are calculated at predetermined intervals in an upstream direction.

Depth of a scour hole below a drop structure depends on depth of flow H over the structure, depth of the tailwater D_2, height of the drop structure P, and size of material d below the plunging water. For a given value P and d, deeper flow over ths structure tends to increase scour depth D_S while an increase in tailwater depth D_2 results in a decreased scour depth. There is an optimum set of values for H and D_2 at which D_S is a maximum. This optimum set of values may or may not occur at the maximum discharge.

Smith (1967) presented a detailed description of scour below a drop structure and presents dimensionless curves for solution of the scour depth. As shown in Figure 5, the flow drops over the structure into the tailwater.

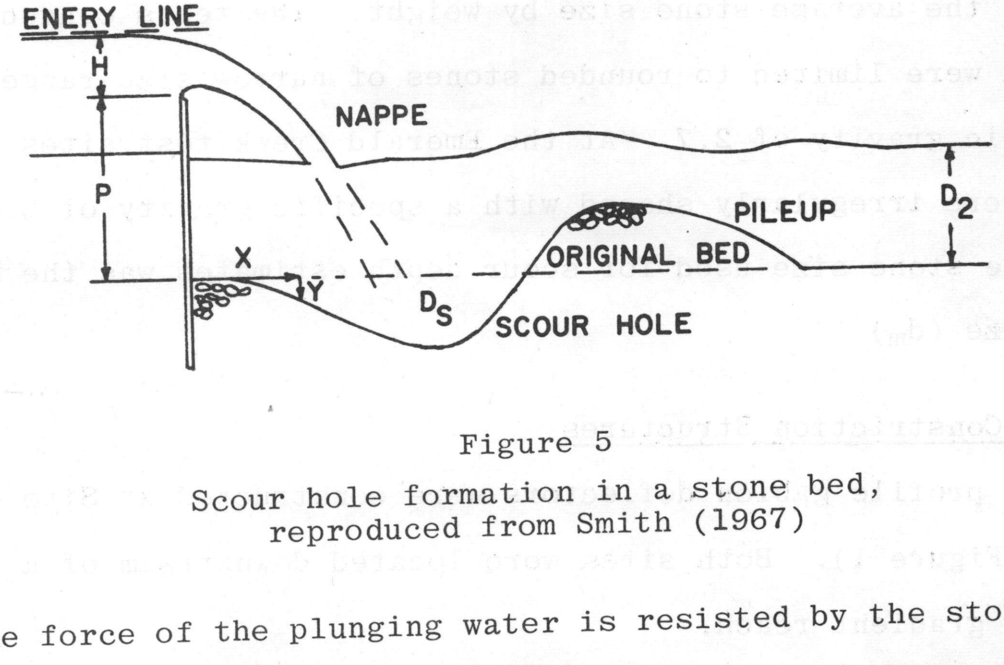


Figure 5

Scour hole formation in a stone bed, reproduced from Smith (1967)

The force of the plunging water is resisted by the stone below the drop structure. Initially drag forces on the stones exceed resisting force and the stones are moved downstream leaving a scour hole.

As scour hole depth increases, the velocity of the falling water, at the point of contact with stones, is reduced. Eventually the scour hole reaches a depth at which resisting forces on the stone exceed the drag force of the falling water and the scour process ceases.

Smith (1967) developed the dimensionless curves shown in Figure 6 that can be used to estimate the depth of scour that can be expected below a drop structure. The range of variables in Smith's curves did not contain the values encountered on the Emerald Creek project. Curves used for Emerald Creek were developed by extending and extrapolating Smith's curves to get the curves shown in Figure 7. At Emerald Creek it was essential that the P value was maintained low enough to allow the migration of fish past the structure.

Stone size d used by Smith is the equivalent spherical diameter of the average stone size by weight. The tests conducted by Smith were limited to rounded stones of narrow size range with a specific gravity of 2.7. At the Emerald Creek test sites the stones were irregularly shaped with a specific gravity of 2.65 - 2.7. The stone size used for scour depth estimates was the mean stone size (d_m).

Channel Constriction Structures

Low profile gabion deflectors were constructed at Site 4 and Site 5 (Figure 1). Both sites were located downstream of a riffle in a low gradient reach.

At Site 4, the bed material consisted of sand (d_{50} = 0.7 mm)

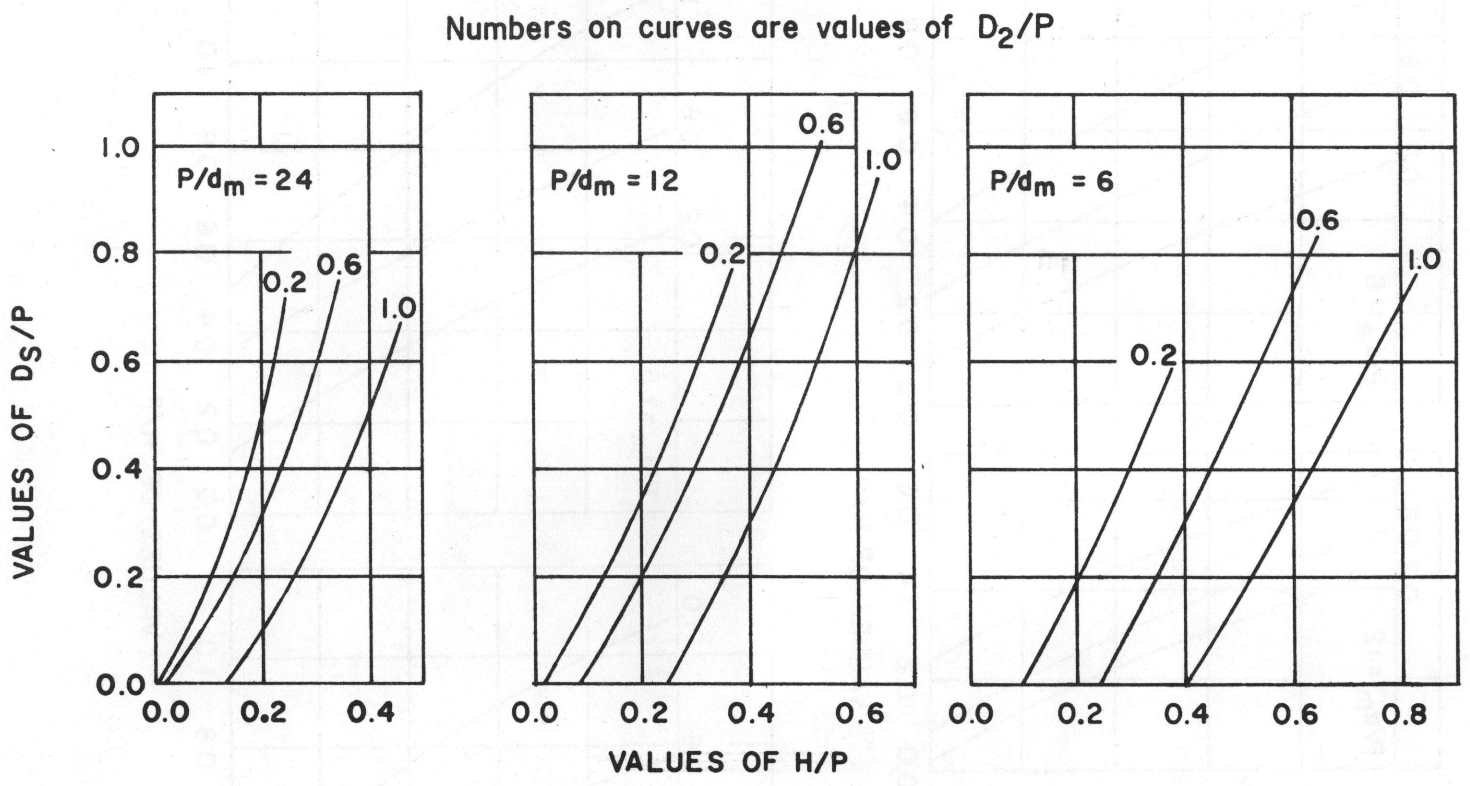


Figure 6
Dimensionless curves for scour depth [reproduced from Smith (1967)]

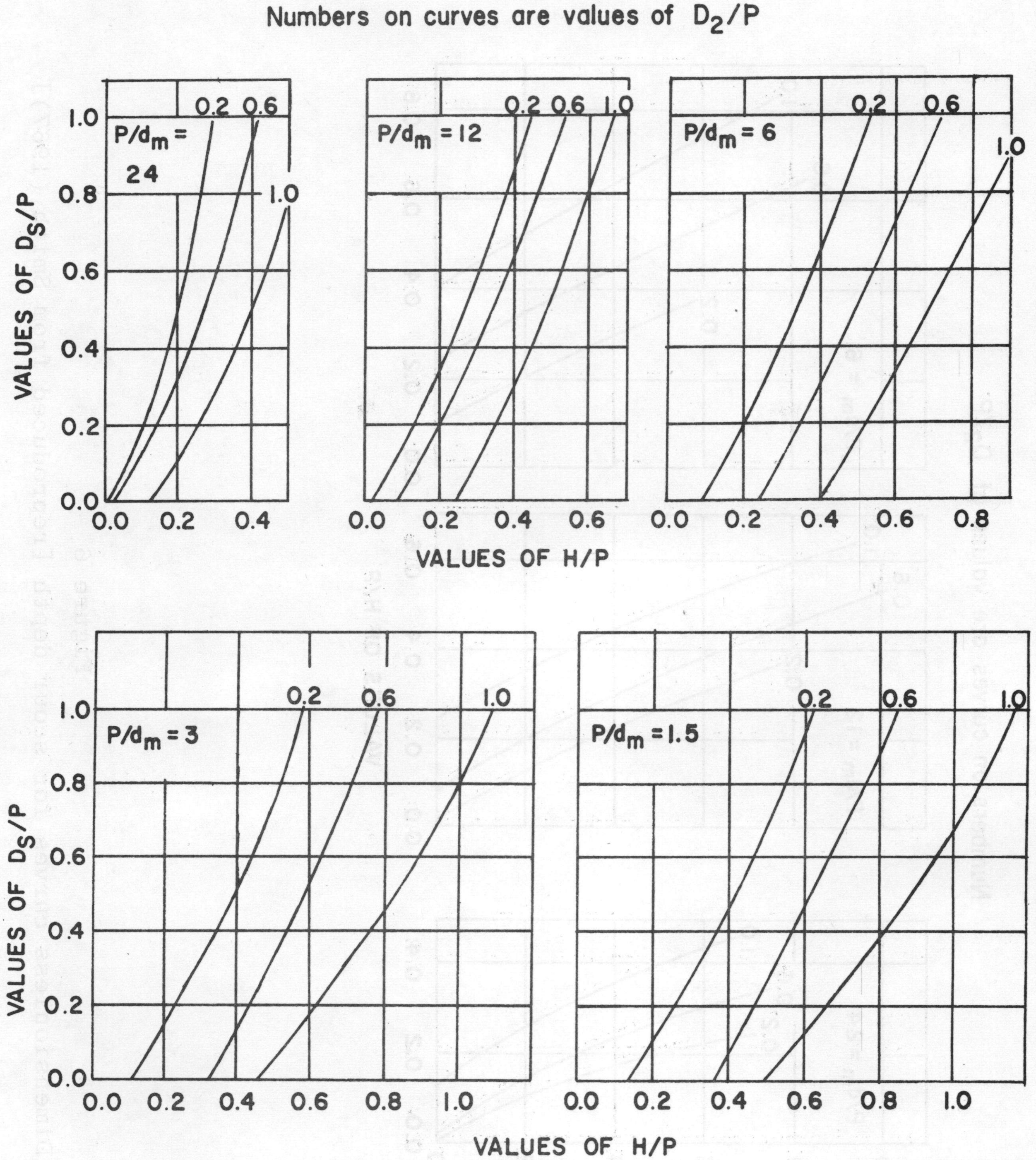


Figure 7
Extended dimensionless curves for scour depth

1 to 2 feet deep covering cobble and small boulders. Two opposing gabions were designed and built to constrict the channel during low flow periods ($Q \leq 20$ cfs) and increase the sediment carrying capacity, thus removing the sand cover and exposing the cobble and small boulders (Figure 8).

At Site 5, two parallel gabions were constructed on the same side of the channel to constrict the flow between them and the far bank during low flow periods (Figure 9).

Site 6 was located just downstream of Site 4 in the same sandy reach. At Site 6 log dikes were installed by anchoring logs to the bottom of the channel. The dikes were placed to constrict the flow and produce a meander pattern during low discharge periods ($Q < 20$ cfs). The intention at this site was not to scour down to the cobble but to form a channel through the sand that would become armored with 2 to 4-inch material.

The flow of water and the formation of ice create forces which must be resisted by the log or gabion and its supporting elements. The force of the moving water on a structure per unit length can best be determined using the concept of momentum. The momentum equation is:

$$F_{H1} - F_{H2} - F_R = \rho q(V_2 - V_1) \qquad (2)$$

which, when solved for F_R is:

$$F_R = 1/2\gamma(2D_1\Delta D - \Delta D^2) - \rho q^2 \frac{1}{D_1 - \Delta D} - \frac{1}{D_1} \qquad (3)$$

F_R is the force in pounds per unit length the log or gabion and its supports must resist if the structure is to remain stable.

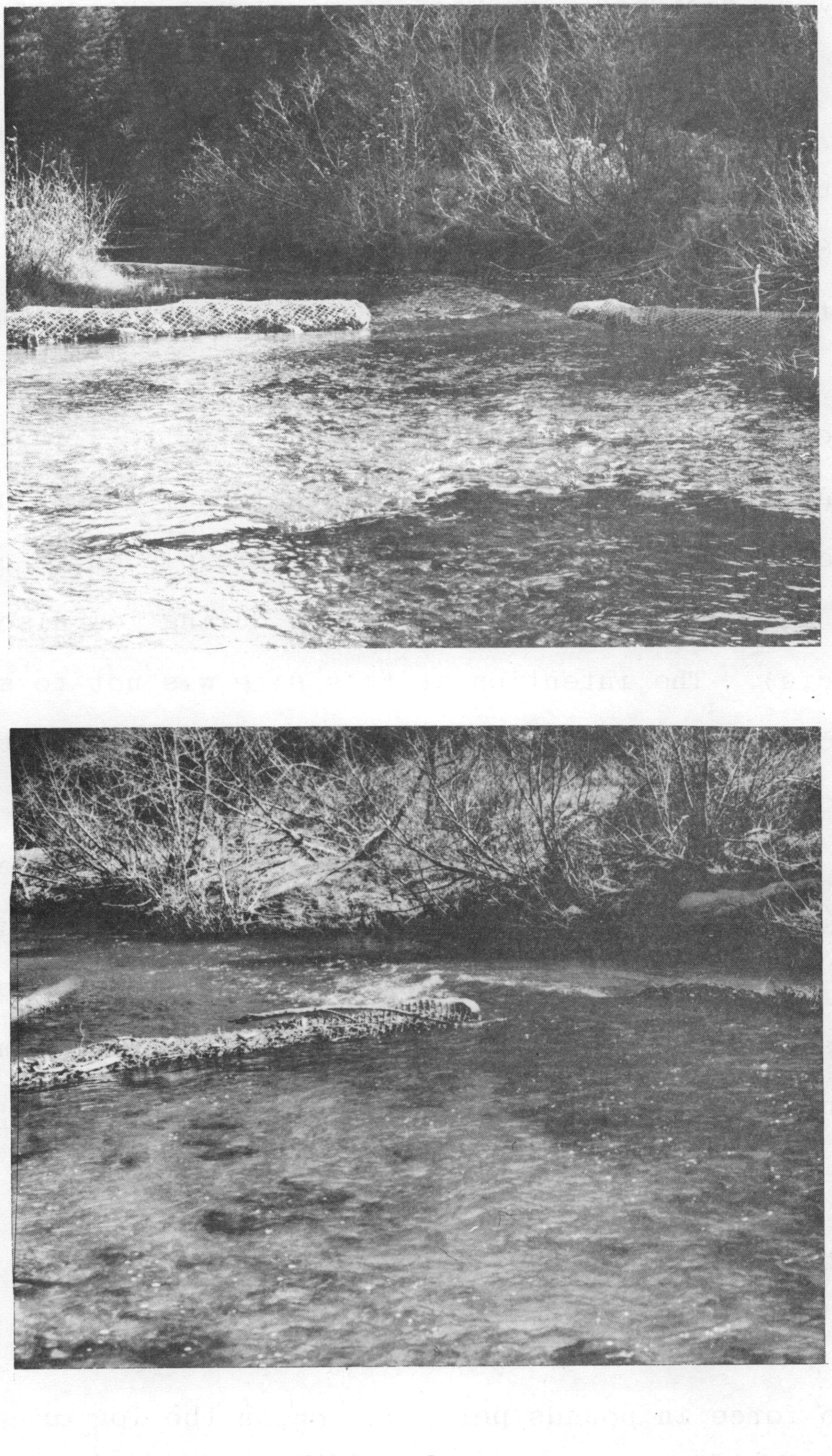


Figure 8
Gabion constrictor at site 4 showing
two different flow stages

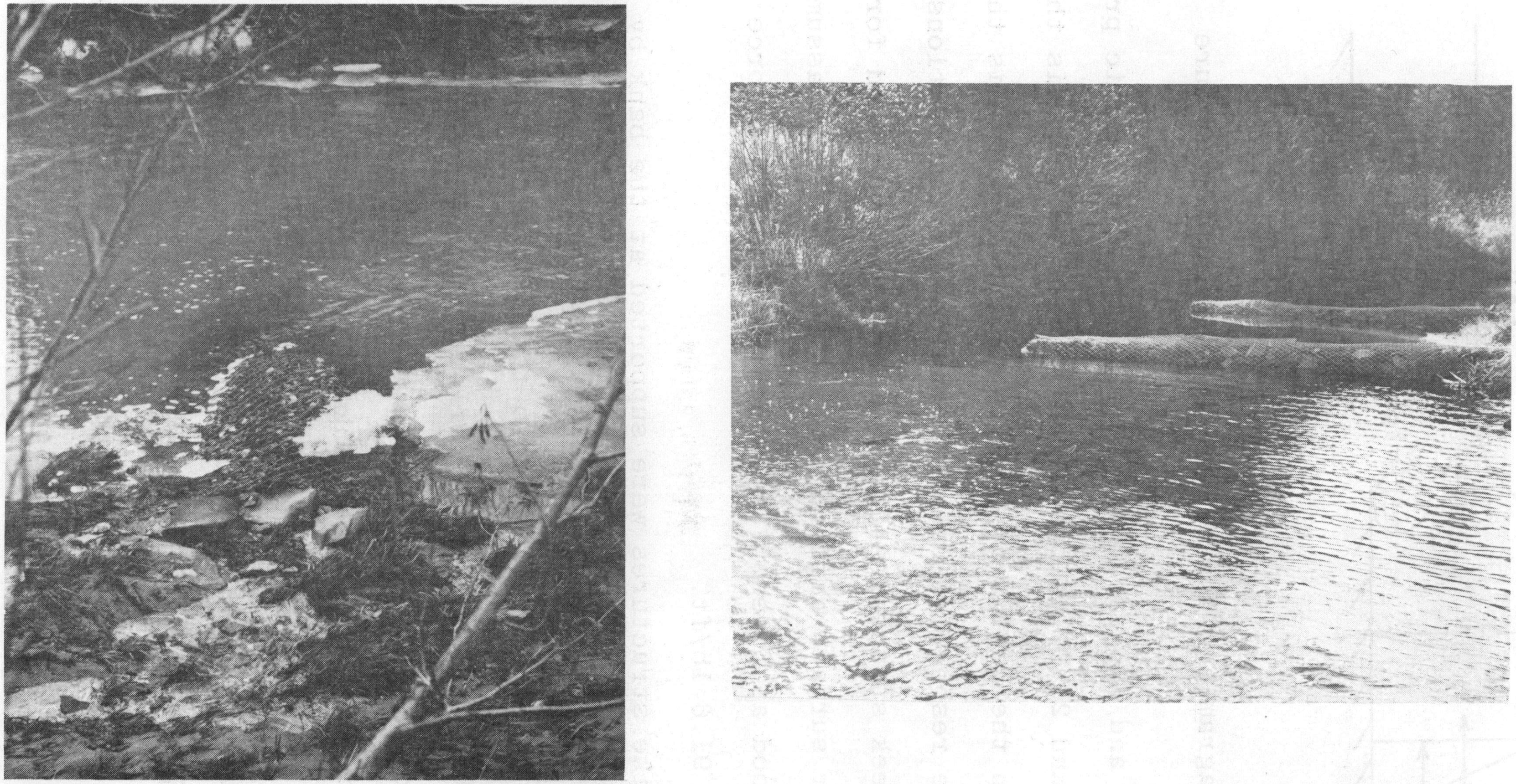


Figure 9
Gabion constrictors at site 5 showing one gabion overtopped by high flow (L) and both gabions at low flow (R)

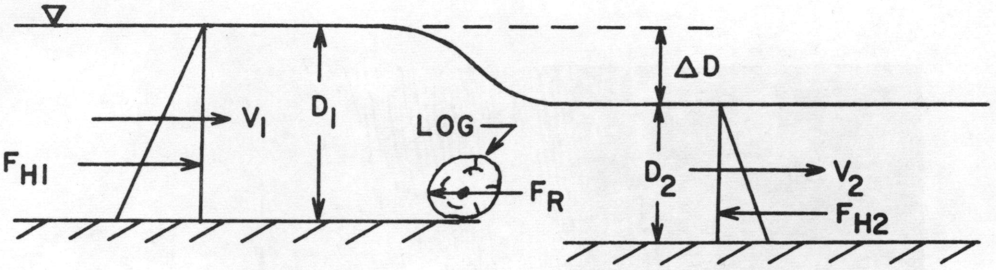


Figure 10
Force diagram for log or gabion in-stream structure

The forces F_{H1} and F_{H2} are the forces due to hydrostatic pressure at Sections 1 and 2, D_1 is the depth at Section 1, ΔD is the difference between the depths at Sections 1 and 2, and V is the average velocity at the respective upstream and downstream sections. For the Emerald Creek structures the 25-year flood was used for design. A maximum water surface difference (ΔD) of 1 foot was assumed. For the 25-year flood at Sites 3, 4, and 5 the resulting force per unit width (F_R) was 91.6 lb/ft.

The log dike structures were supported at the bank by burying one end of the log and in the stream by driving 1/2 inch diameter steel pins alongside of the log into the sand and lower substrate.

The stability of the gabion deflectors depends on the weight of the structure. However, the ends were buried in the banks to prevent erosion adjacent to the bank. It was observed that ice has a tendency to freeze through and around the upper part of the gabion. The rising water level associated with a thaw exerted an uplift force on the gabion due to the bouyancy of the ice attached to the gabion. Water expands by approximately 10 percent when it freezes. Thus, the uplift of a piece of ice, 6 feet long and 1 foot thick, attached to the gabion would be about 34 pounds per foot of gabion. The ice attached to the gabion not only adds to the surface area to be acted on by the force of the flow but it also decreases the resisting force of the gabion (friction) by reducing the effective weight of the structure.

If the Froude number of the flow in a stream is in the subcritical range, any structure placed in the stream will cause an increase in flow depth upstream of the structure. The velocity of flow will decrease as a result of this depth increase and the sediment carrying capacity of the stream is reduced in the reach. Therefore, when designing a stream modification structure, it is necessary to minimize the backwater effects of the structure.

Backwater resulting from channel constrictions, such as gabion deflectors or log dikes, is not a problem during low flow. The effect on high flow depths upstream of the constriction can be estimated using the momentum and continuity equations. If the gabion has a low profile, backwater effect will be minimal at high flows.

Meander Forming Structures. Dikes constructed of logs or rocks can be used to change a relatively straight, shallow, slow velocity reach of a stream to a meandering reach with deeper and faster moving water. By constricting the channel at low flow an increase in tractive force is achieved and the transport rate is higher. Meander forming structures are designed so that silt will be transported through the reach during low flow periods and be deposited behind the structures as water levels are receding from peak flows. The stream power associated with high discharges is adequate to move the unwanted sediment without the help of the modification structures. The structures are designed to be overtopped during high flow and have a minimum impact on stream depth.

Literature on dikes and meanders presents some general rules on dike placement and geometry. After observing existing dike systems, Winkley (1971) stated tht dikes should be spaced from 1 to 2 times the length of the next upstream dike. Franco (1967), after doing laboratory studies of dike systems, concluded that the most efficient system of dikes is one with the dikes perpendicular to the main flow direction, the crest of the dike sloping up from the water end to the bank end, and the crest of each dike lower than the dike upstream.

Meander patterns of a natural river or stream are the result of numerous factors such as geological conditions, slope of the streambed, amount of sediment in the water, and erodibility of the bed and banks of the stream. Virtually all unbraided streams have a meandering pattern and, according to Leopold and Wolman (1960) it is unusual for a reach of a natural stream to be straight for a distance exceeding 10 channel widths.

Modification of a natural stream channel should be accomplished in a manner which will not alter it greatly from the natural meander pattern. Natural meander patterns have been observed by Inglis (1947), Leopold and Wolman (1960), and Zeller (1967). These observers developed expressions that relate the meander length M_L (Figure 11) to the water surface width B, the meander width M_B to the water surface width, and the meander length to the meander radius of curvature M_R.

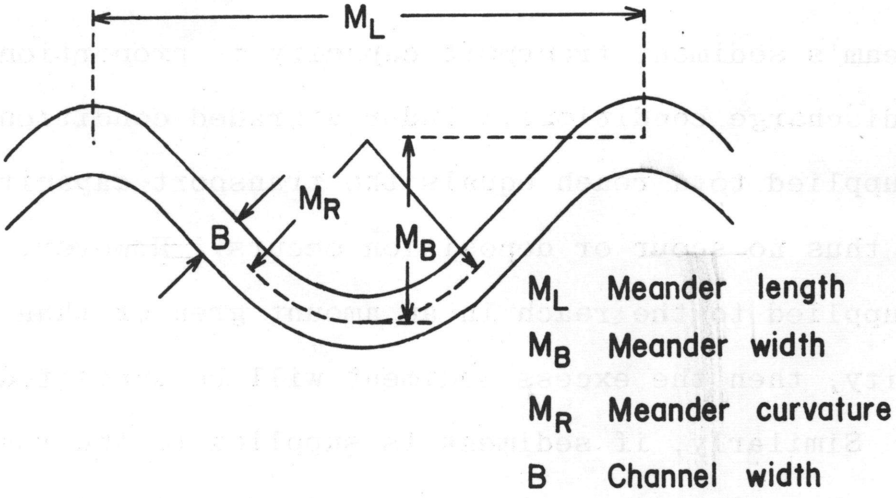


Figure 11

Definition sketch for meanders, reproduced from Graf (1971)

The modifications to a natural channel should result in meander dimensions within the limits given by the expressions of Table 3. Modifications which do not result in meander dimensions within the limits of a natural stream may result in excessive scour or failure of the modification structures to control the flow as designed.

Table 3: Dimensions of natural channel meanders

Meander Length M_L	Meander Length M_B	Radius of Curvature M_R	Reporter
$10.9\ B^{1.01}$	$2.75\ B^{1.1}$	$0.26 M_L^{1.02}$	Leopold & Wolman (1960)
$6.6\ B^{0.09}$	$18.6\ B^{0.99}$		Inglis (1947)
$10.0\ B^{1.025}$	$4.5\ B^{1.0}$		Zeller (1967)

A stream's sediment transport capacity is proportional to slope and discharge conditions. Under a graded condition the sediment supplied to a reach equals the transport capacity of the stream thus no scour or deposition occurs. However, if sediment is supplied to the reach in an amount greater than its transport capacity, then the excess sediment will be deposited within the reach. Similarly, if sediment is supplied to the reach in an amount less than its transport capacity, sediment will be picked up or eroded and carried out of the reach. For natural conditions, such as for a mountain stream, the processes of erosion and deposition depend on the availability of sediment sizes which can satisfy the sediment transport capacity of the stream.

For a stream that has become heavily silted it may be necessary to increase the local sediment transport capacity of the stream to erode or flush the smaller-sized sediment out of the reach. The sediment transport capacity of a stream may be increased by placing structures within the channel which will reduce the flow width and increase the depth and velocity of the flow.

The Lane Diagram has been used effectively in the past for the design of stable channels in noncohesive materials. By dividing the values of particle diameter for a given value of tractive force by the factor of safety, a modified Lane Diagram can be developed which shows permissible tractive force values for given particle sizes with no factor of safety. The curves developed by Lane have a factor of safety of 1.25. These modified tractive force values would be those for which the particles are just stable and a tractive force greater than the permissible tractive force would start some of the particles in motion.

The modified Lane Diagram can be used for predicting the minimum tractive force required to insure erosion and transportation of a specified size fraction of sediment out of the reach. The net result of transporting the smaller particles out of a reach is to increase the d_{50} size of the streambed particles within that reach.

By converting the tractive force ($\zeta = \gamma DS$) into its components of specific weight of water (γ), depth (D), and slope (S), the Lane Diagram can be converted to the curves shown in Figures 12, 13, 14 and 15 which have the variables of depth, slope and representative sediment size for various background values of stream turbidity.

The curves can be used for designing the minimum depth of flow that would result in a tractive force which would flush some of the particles out of a reach and tend to develop the desired d_{50} or d_{75} for the streambed within the reach. The procedure for design is:

1. Select the desired sediment size distribution in terms of the d_{50} or d_{75}.
2. Determine the local slope of the reach.
3. Select the proper design curves (Figures 12, 13, 14 and 15) on the basis of particle size and content of fine sediment in the water.
4. On the proper curve, the design depth is determined by the intersection of the slope curve and the d_{50} or d_{75} size depending on the curve used.

It is important that the local slope of the reach near

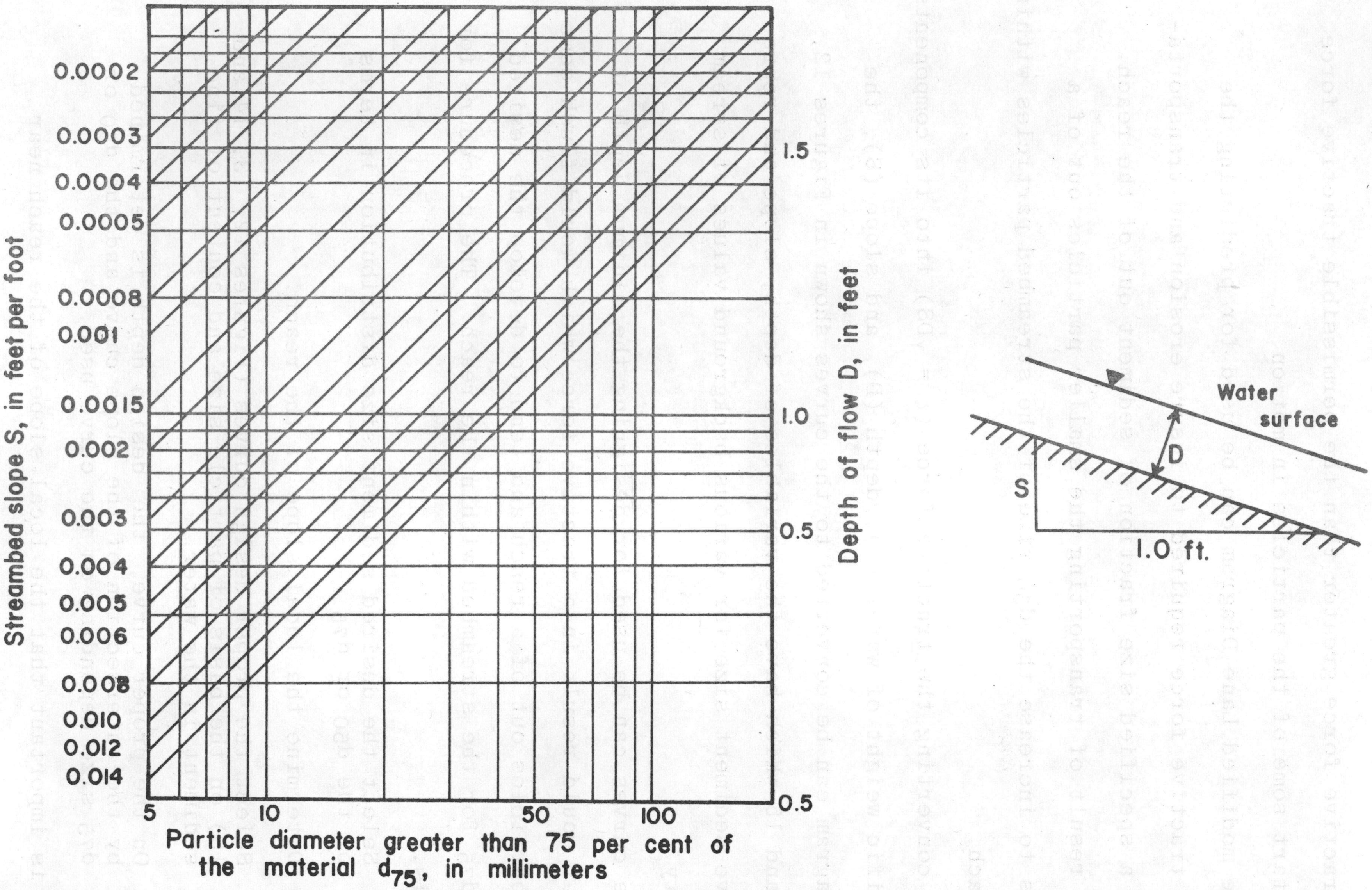


Figure 12

Expected d_{75} of bed material for a given streambed slope E
and depth of flor D for coarse noncohesive material

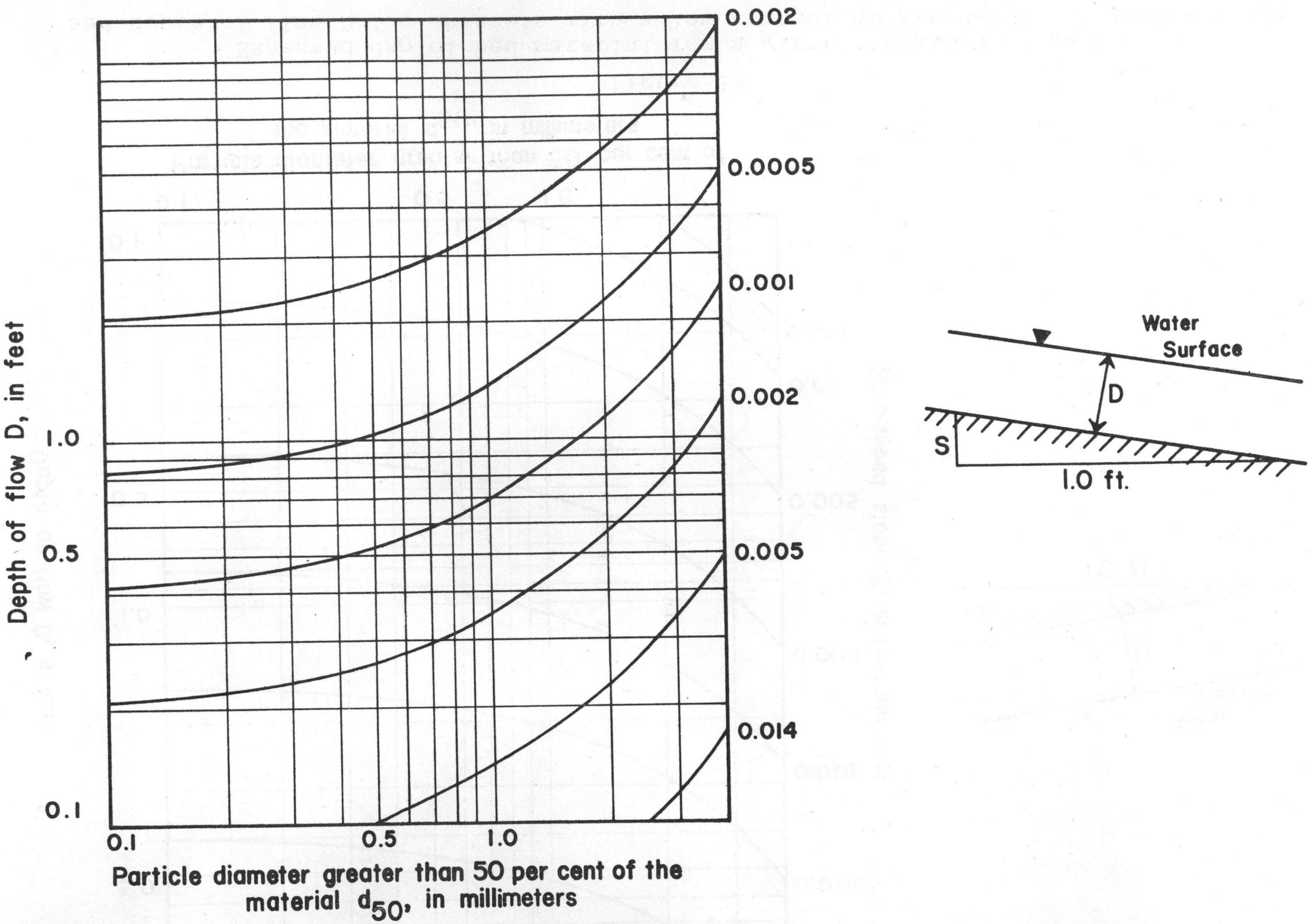


Figure 13

Expected d50 of bed material for a given streambed slope S and depth of flow D for channels with clear water

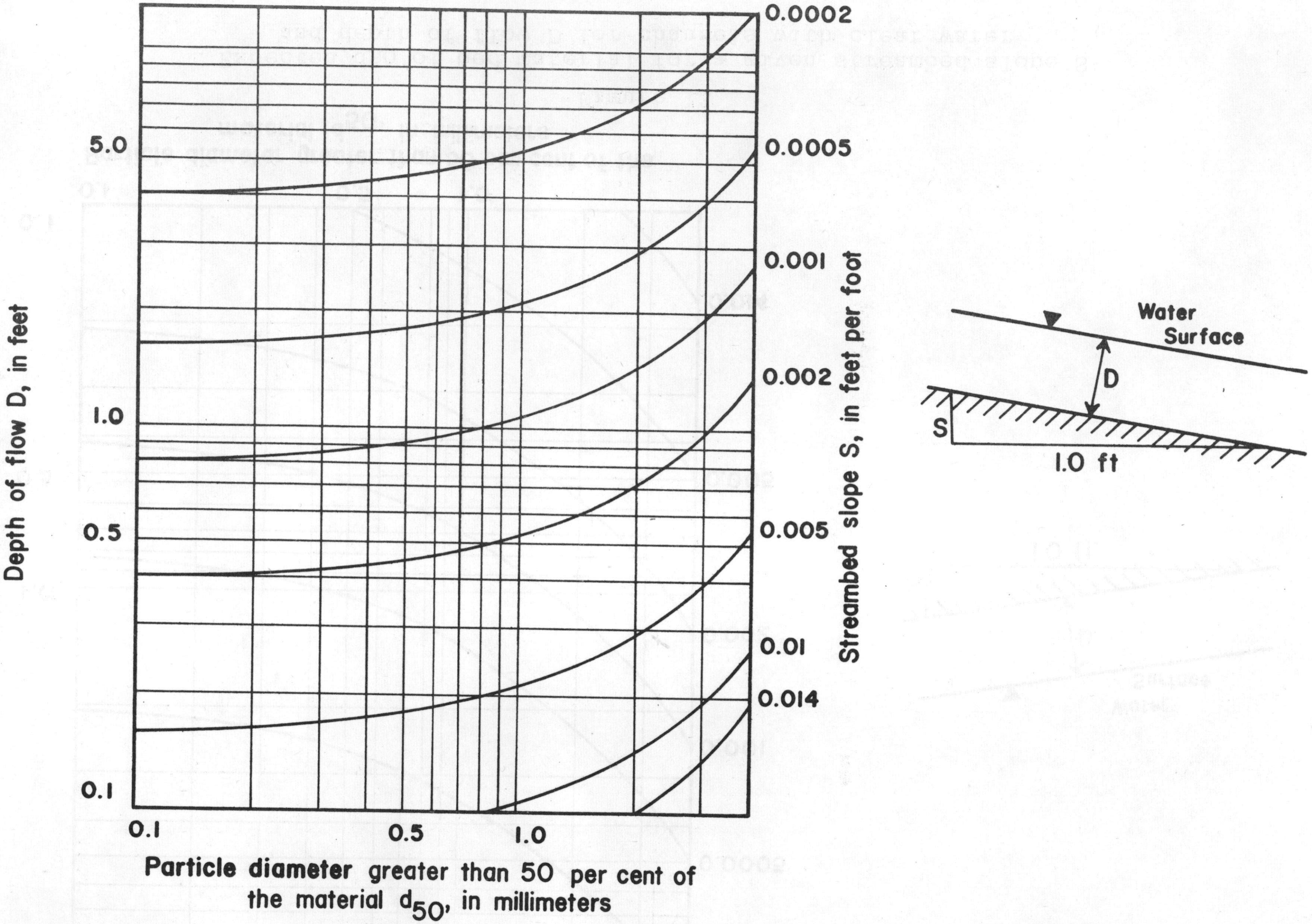


Figure 14

Expected d_{50} of bed material for a given streambed slope S and depth of flow D for channels with a low content of fine sediment in the water

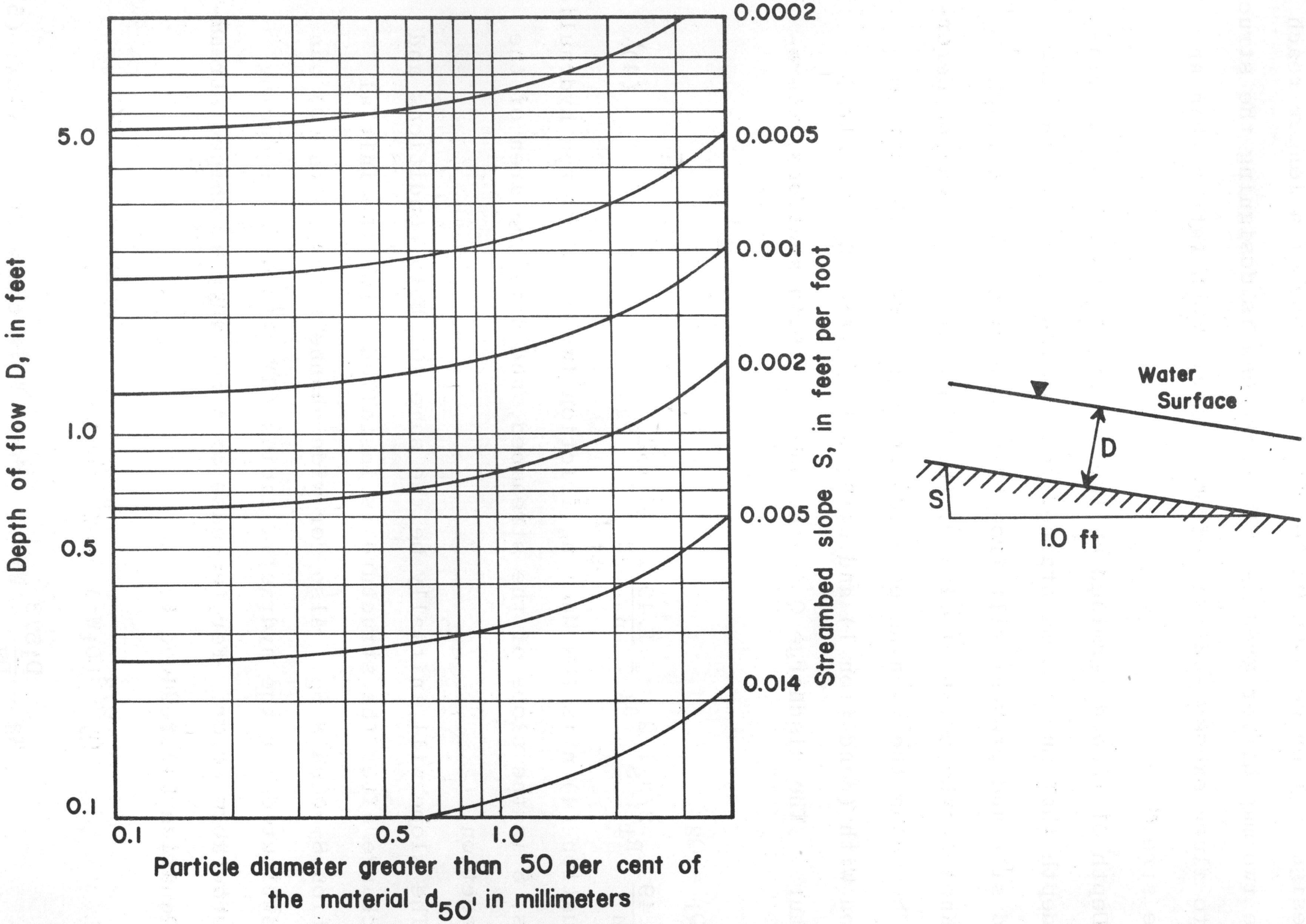


Figure 15

Expected d_{50} of bed material for a given channel slope S
and depth of flow D for channels with a high content of fine sediment in the water

the design section be used rather than the slope of a longer reach as the two may differ greatly. Further, one is designing the structure to flush excess sediments from a local reach rather than an entire stream.

Depth of flow determined by the design procedure is the minimum depth that must be maintained year around to remove the unwanted silt and prevent silt from being deposited in the reach.

Knowing the depth of flow D, the width of flow W can be determined by using the Manning equation and considering the stream section with (condition 1) and without (condition 2) a control structure. The discharge Q is the same for both sections, therefore:

$$Q_1 = Q_2$$

and $$\frac{1.49}{n} R_1{}^{2/3} S^{1/2} A_1 = \frac{1.49}{n} R_2{}^{2/3} R^{1/2} A_2 \qquad (4)$$

In equation (4) n is the Manning friction factor, R is the hydraulic radius, S is the slope of the streambed, and A is the area of the flow section.

The slope will initially be the same for both conditions and will change after the structure is installed. For the initial condition S_1 equals S_2. Also for wide channels the depth (D) can be substituted for the hydraulic radius (R) without introducing an appreciable error. For the case of a rectangular shaped streambed, equation (4) reduced to:

$$D_1{}^{2/3}(D_1W_1) - D_2{}^{2/3}(D_2W_2)$$

or

$$W_2 - \frac{D_1}{D_2}{}^{5/3} W_1$$ where W is the width of flow. (5)

The design procedure is:

1. Measure the width and depth of flow at the channel section.
2. Determine the depth of flow (D) using the design curves.
3. Use equation (5) to determine the width of flow (W_2) which corresponds to the width of opening of the control structure.

Gabion deflectors at Site 4 and Site 5 were constructed by placing rocks ranging from 1 to 24 inches in diameter within a wrapping of 8 foot wire chain link fencing. The rock was obtained from the stream channel and surrounding area. The 9 foot gabion sections were wired together to add length to the structures and placed perpendicular to the streamflow (Site 5) or sloped downstream (Site 4) to constrict the flow width during low flow. The gabions were constructed to a height of just greater than one foot to allow the higher flows to move freely over the top of the structures. Construction time for the gabion deflectors was one man hour per foot of gabion.

After construction the gabions were very porous with only 1 to 2 inches of head loss through the structures. It was hoped that they would eventually "seal" with finer material and that vegetation would grow on the surfaces exposed above water.

Log dikes used to form the meander at Site 6 were constructed by placing logs on the streambed perpendicular to the flow and holding them in place by burying the end in the bank and driving steel pins into the substrate on the downstream side of the logs. Construction time for the log dikes was three man hours per pair of dikes. Four pairs of dikes plus 2 single dikes were used to form the meander.

Biological Analysis of In-Stream Rehabilitation

Benthic Species Diversity

Changes in the aquatic insect community were monitored in conjunction with measurement of physical changes of the streambed. At each permanent transect (test and control), the stream was visually divided into sections A, B and C (e.g., thirds or halves depending on stream width). A modified Hess square-foot sampler was used to sample each section. A small hand rake was used to agitate the bottom sediments, causing insects to be washed into the sampler net. Four pre-construction and five post-construction sets of samples were taken from each transect. In the laboratory, samples were sorted and insects identified using keys by Usinger (1968), Hynes (1969), Jensen (1966), Peterson (1960) and Smith (1968).

A species diversity index, derived from information theory by Brillouin (1956) was used to describe community changes resulting from in-stream alterations. Three values were calculated using equations by Margalef (1957):

Diversity/Individual

$$H = 1/N \, \mathrm{Log}_2 N!/N_1!N_2!\ldots N_s! \quad \text{(bits/individual)} \qquad (6)$$

Maximum Diversity

$$H_{max} = 1/N \, \mathrm{Log}_2 N!/(m'!)^{s-r}(m'+1)!)^r \quad \text{(total bits)} \qquad (7)$$

Evenness

$$\text{Evenness} = H/H_{max} \qquad (8)$$

where N equals total number of individuals and N_1, N_2 . . . N_s equals the number of individuals per species. Evenness reflects the degree of equal or even distribution of numbers per species.

It is high with nearly uniform distribution, low with a clumped distribution and numerically ranges from 1.0 - 0.0.

Dispersion and Colonization -- Field Study

Lower reaches of the main stem of Emerald Creek are characterized by long sedimented runs, often 330 feet or more long, having a nearly homogeneous substrate of sand. A study was conducted in July and August of 1972 to determine the fate of insects drifting into these highly unfavorable areas.

A long silted run occurring between distinct riffles was investigated. The run was approximately 250 feet long and located in the main stem of Emerald Creek about 1 mile upstream from the Emerald Creek-St. Maries River confluence. Drift nets and wire baskets (12 x 12 x 6 in., made of 2 x 4-inch hardware cloth) filled with cobble were used to sample insect drift and colonization rates.

In an attempt to determine how far insects drifted across these sandy areas, drift nets were positioned at three locations in these sandy areas, drift nets were positioned at three locations in the sanded reach approximately 75 feet (24 m) apart. The first net was 17 feet (5 m) downstream from a riffle which served as a source for drifting insects. A control net was established in the riffle approximately 75 feet (24 m) upstream from the first test net (refer to Leudtke, 1973 for details).

On three successive nights the control net and one test net sampled insect drift. The sampling period began about one hour before dark and ended one hour after sunrise. The nets were emptied every five hours to avoid possible "back-flushing" resulting from net overloading by debris and insects. Water velocity was measured using a Gurley Midget Current Meter before each sampling period. Six readings were taken at different positions directly upstream from the mouth of the drift net.

Two basket samplers were placed at the control and each test site. Baskets were positioned near each net at the onset of the drift sampling period and emptied 24 hours later. To prevent loss of insects during sampling, a net was held immediately downstream from the basket to collect insects being washed away while the basket was removed from the water. The basket was quickly put into a 30 gallon plastic ocntainer half-filled with water. Cobble were removed and washed clean of insects.

In late August, 1972, a study was conducted to determine if insects could successfully move upstream on sand substrates. An open-ended linear channel (4 x 32 feet) was constructed of plywood boards and positioned in the thalweg of a sanded run. Drift nets were positioned at the downstream end of the channel to collect drifting insects. Water velocity in the channel was approximately 0.7 ft/sec, the water depth 7 inches.

Three insect species (<u>Dicosmoecus</u> sp., <u>Pteronarcys</u> sp. and <u>Acroneuria</u> sp.) were used as test organisms. Late-instars were used in order to better facilitate monitoring of movements.

Daylight tests were conducted between 1 and 4 p.m., night tests approximately one hour after sunset to 1 a.m. Each species was individually tested. Ten specimens were used for each test and replicated three times. They were introduced into the middle of the channel and observed continuously for 15 minutes. A fluorescent tagging technique developed by Brusven (1970) was employed; an ultraviolet light enabled visual observations of tagged insects at night.

Insect Dispersion and Colonization -- Laboratory Study

In an attempt to better describe insect drift across silted reaches, tests were conducted in a laboratory channel using a drift model by McLay (1970) and Elliott (1971) to describe insect movement and settle-out rates. Insect species, current velocity (0.4, 0.7 and 1.0 ft/sec) and light conditions (light and dark) served as variables.

A regression equation developed by McLay (1970) and Elliott (1971) describes the relationship between numbers of insects caught in a drift sampler and the distance of origin from the net:

$$N_X = N_O e^{-RX} \tag{9}$$

where N_X is the number of insects in the drift sampler,

N_O is the initial number of drifting insects,

e is the base of natural logarithms (2.718)

R is the "settle-out" rate and

X is the distance upstream from the sampler (e.g., the origin of drifting insects).

Settle-out rates were calculated using a multiple regression program (MULTREGR).

The laboratory channel consisted of two sections, eight and ten feet long and 10 inches wide, connected by a flexible joint to permit differential slope adjustment. Both sections were of similar construction, having a plywood base, 1/4-inch plexiglass walls and braces and a fiberglass bottom. The channel was divided into eight 2-foot sections. A net was positioned at the outflow of the channel to collect test specimens drifting out of the system. A small hydraulic jack was used to adjust the gradient of the stream. A 3/4 h.p. centrifugal pump with a maximum discharge of 100 gal/minute was used to circulate water through the stream. Temperature was maintained at approximately 12^{O}C with a thermostatically controlled 3/4 h.p. refrigeration unit. Evaporation was minimized by covering the channel with two mil clear polyethylene sheeting. Sediments used in the channel were obtained from various field installations on Emerald Creek.

Four insect species, Arcynopteryx sp., Brachycentrus sp., Ephemerella grandis (Eaton), and Pteronarcella sp., all common to Emerald Creek, were used in laboratory tests. Test specimens were collected in the field and held in a circular laboratory stream described by Brusven (1973). Each replication consisted of 20 insects (1 species) introduced into the middle of the water column at the upstream end of the channel. After 15 minutes, insects were recovered and recorded for each 2-foot quadrant and outfall net. Three replications were made for each species at each water velocity (0.4, 0.7, and 1.0 ft/sec) under both light and dark conditions. Different specimens were used for each replication.

RESULTS AND DISCUSSION

Rehabilitation of silt-polluted streams requires detailed quantitative and qualitative analysis of streambed sediments since it has been shown that the substrate is one of the primary factors affecting the distribution and abundance of aquatic insects (Cummins, 1966; Prather, 1971; and McClelland, 1972). Heavily silted or sedimented streams generally manifest lower species diversity and productivity than clean unsilted streams. Laboratory substrate-preference studies have shown that riffle insects prefer stone and cobble substrates over sand and silt (Cummins, 1966; Prather, 1971; and McClelland, 1972).

The substrate parameters of "cobble factor", embeddedness of cobble, and surrounding substrate size around cobble used in this study are believed to be useful descriptors of effective insect habitat and are extensively used.

Evaluation of Log Structures

As shown in the contour maps in Figures 16 and 17, the performance of the downstream drop structure at Site 1 was acceptable. A one-foot deep hole was scoured below the drop structure and was lined with rock from 6 to 10 inches in diameter. Using the dimensionless curves in Figure 7, the predicted depth of scour D_S was 2 feet. Thalweg profiles in Figure 18 show the profiles before, one year and two years after modification of the stream with this drop structure. The profile downstream of the second drop structure shows the scour hole and the rise in elevation just downstream of the scour hole where much of the coarse scour material was deposited. Scour below the upstream structure at Site 1 was limited by the high tailwater caused by the downstream structure.

The drop structure at Site 1-A scoured a hole 1.5 feet deep as shown in the contour maps of Figure 19 and the thalweg profiles in Figure 20. The scour hole was lined with stones in the range of 6 to 10 inches in diameter. Predicted depth of scour using the curves in Figure 7 was 3 feet. This additional depth of scour at Site 1-A is a result of the large drop height at this site.

At low flow the water plunges over the lower log, but the high flow plunges over the top log resulting in a significant increase of kinetic energy working on the bed. The stones underneath the boards have been scoured away leaving the boards almost completely exposed on their underside.

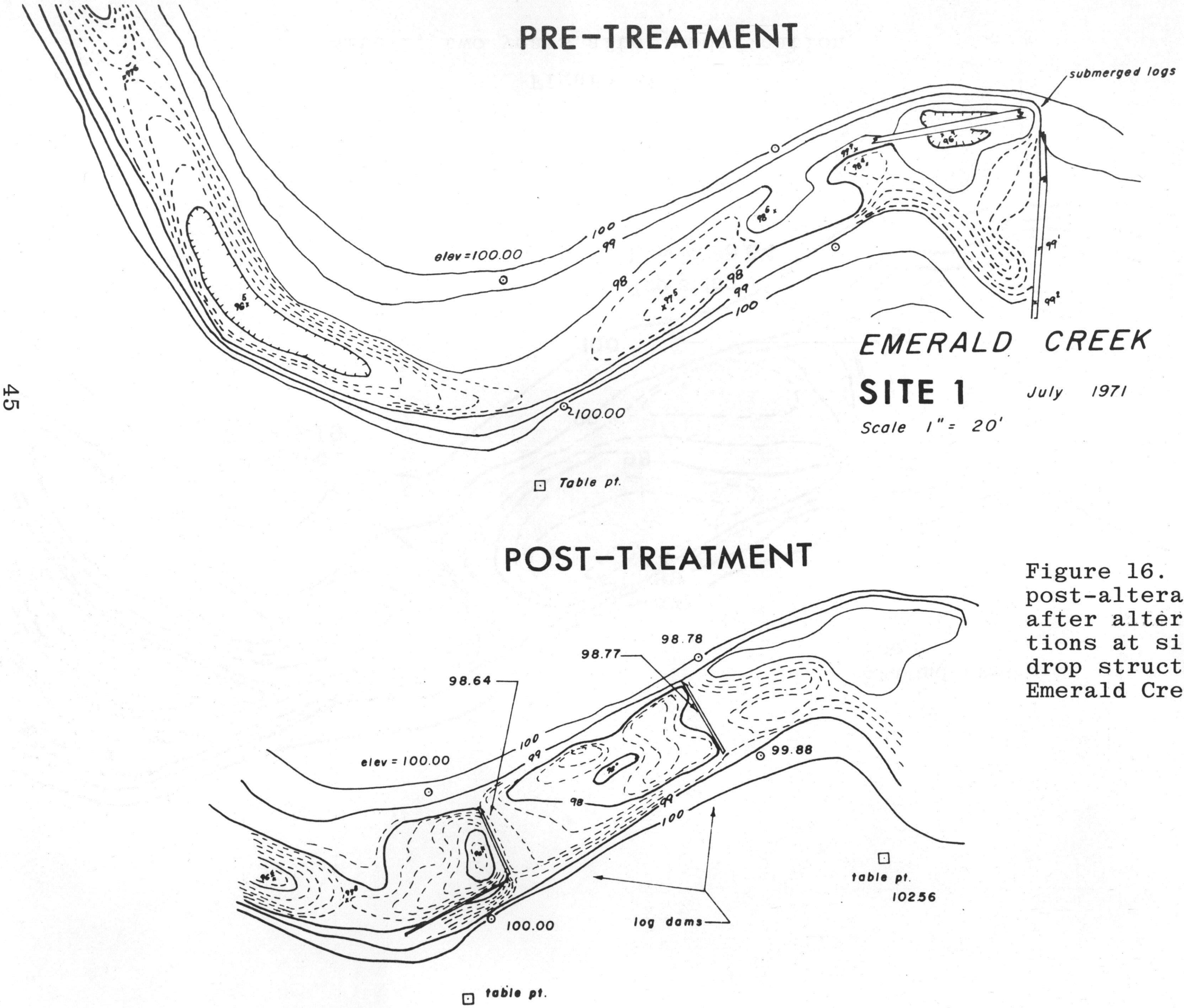


Figure 16. Pre- and post-alteration (1 year after alteration) conditions at site 1 (log drop structures) in Emerald Creek.

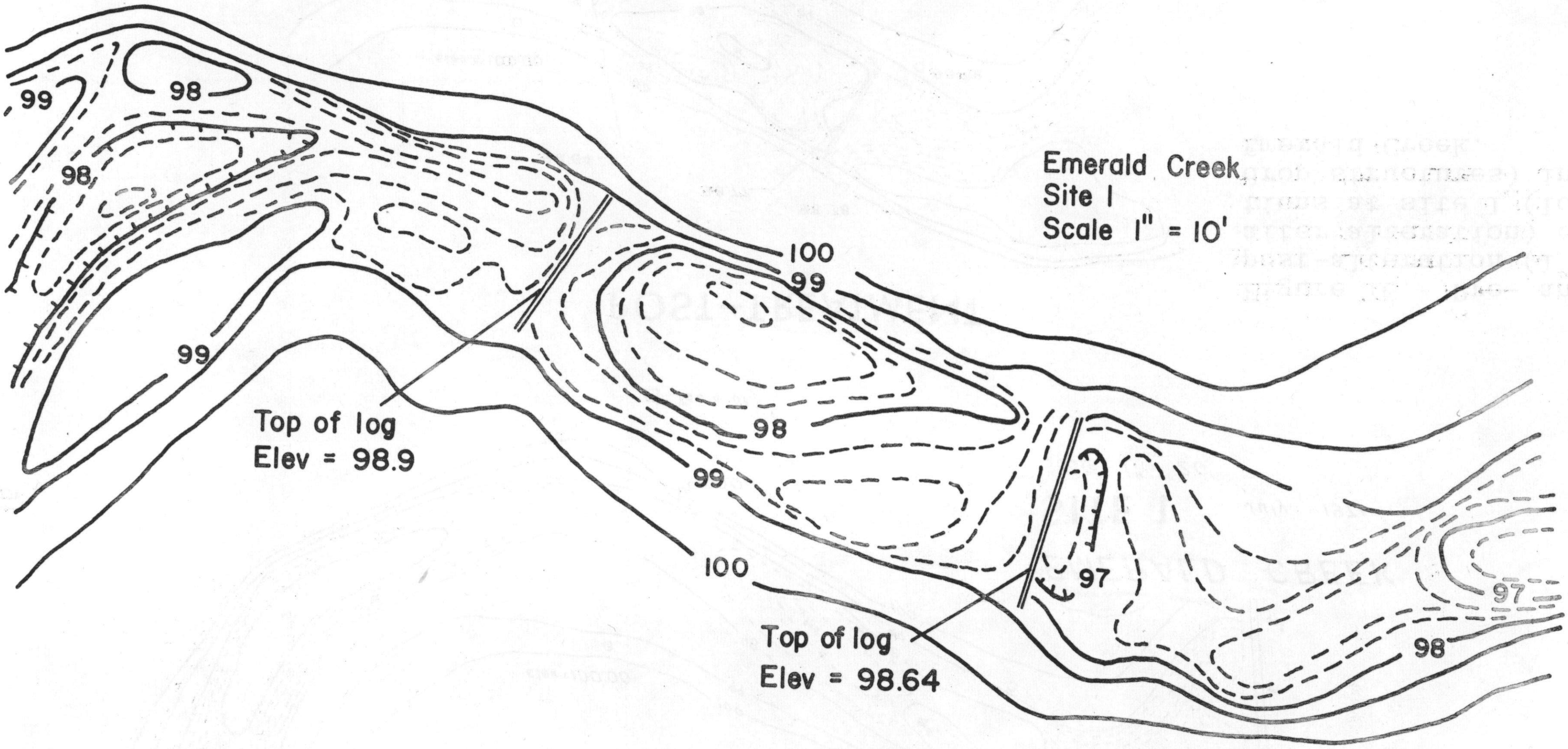


Figure 17
Site 1, two years after modification

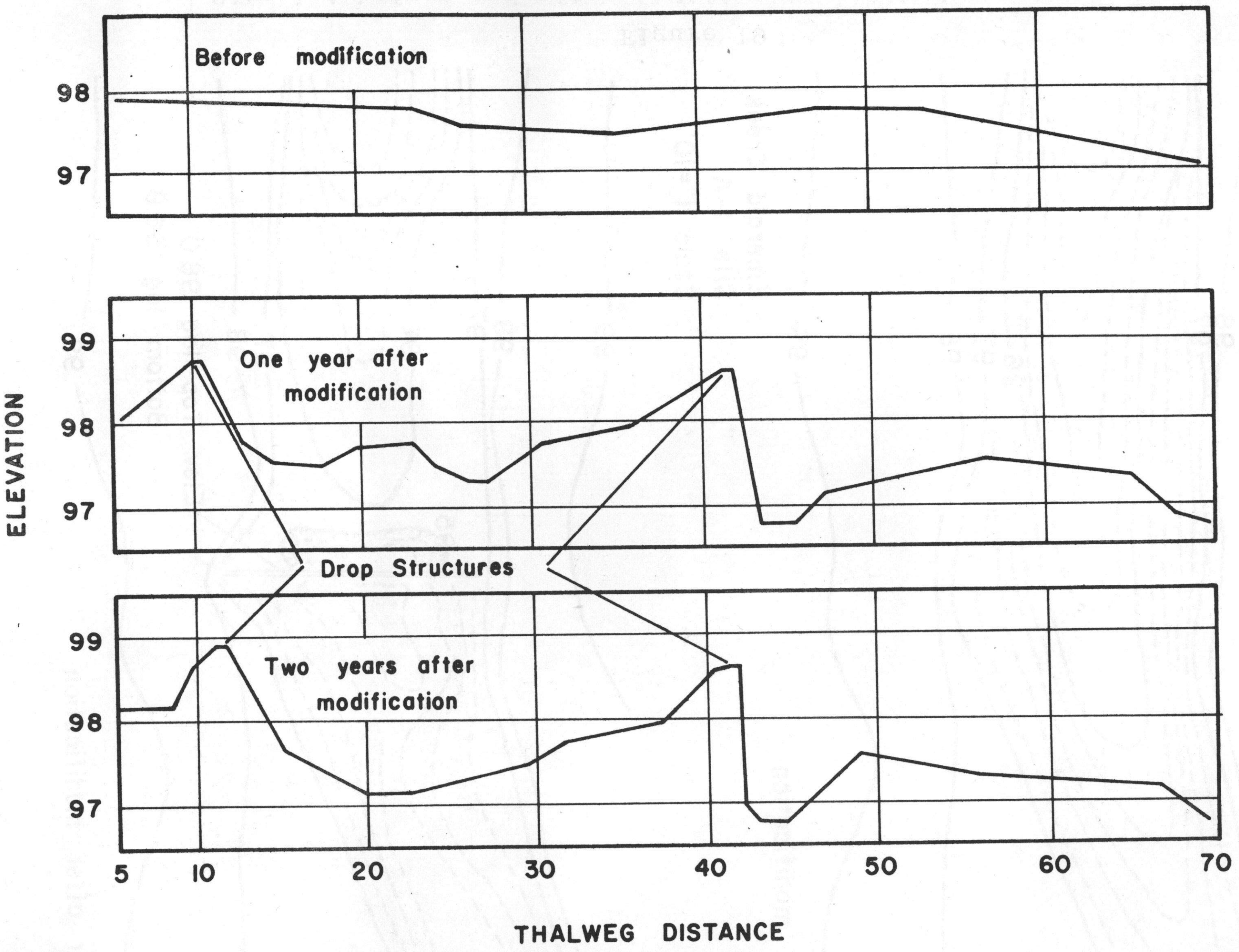


Figure 18

Thalweg profiles, site 1

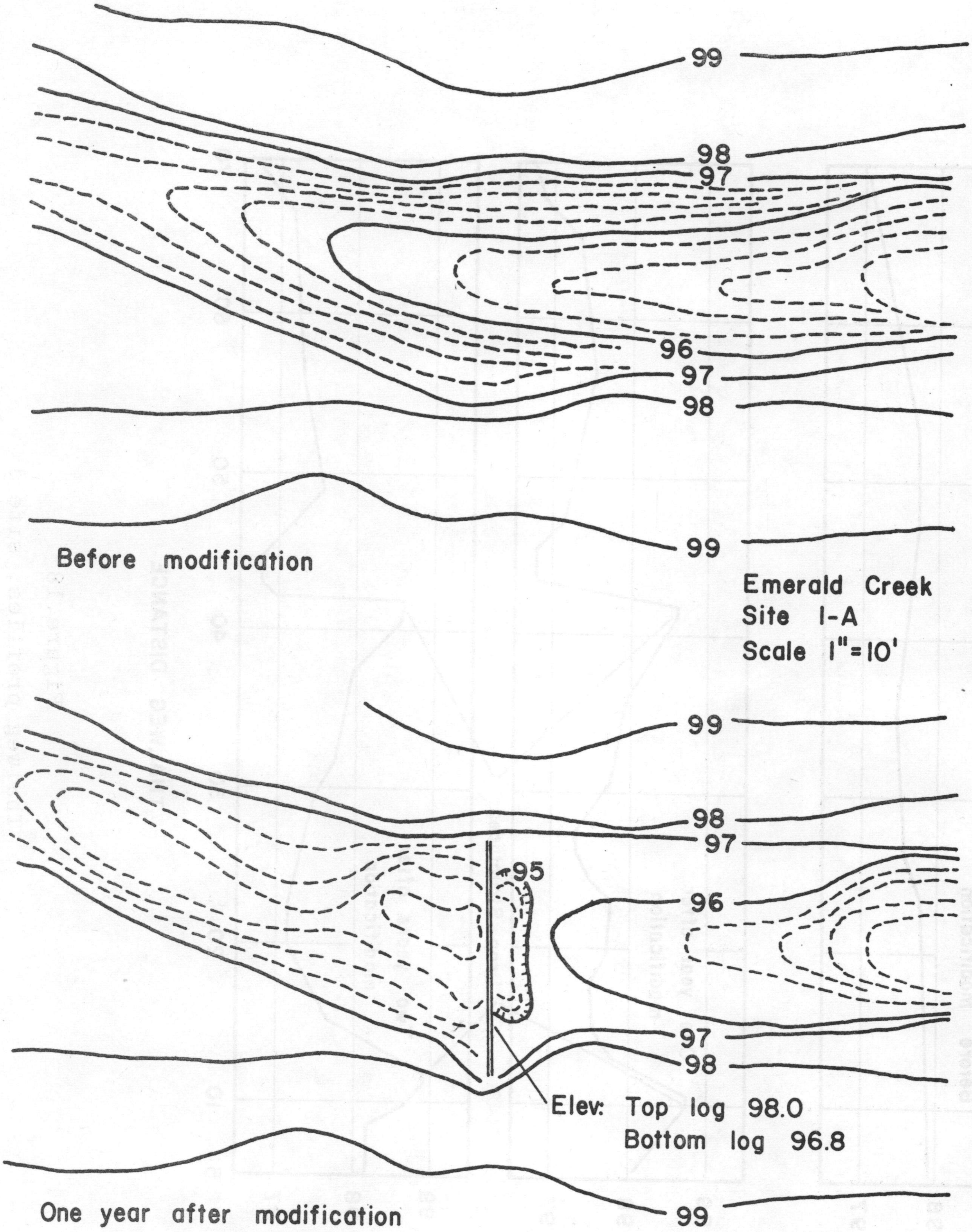


Figure 19
Site 1-A before and after modification with drop structure

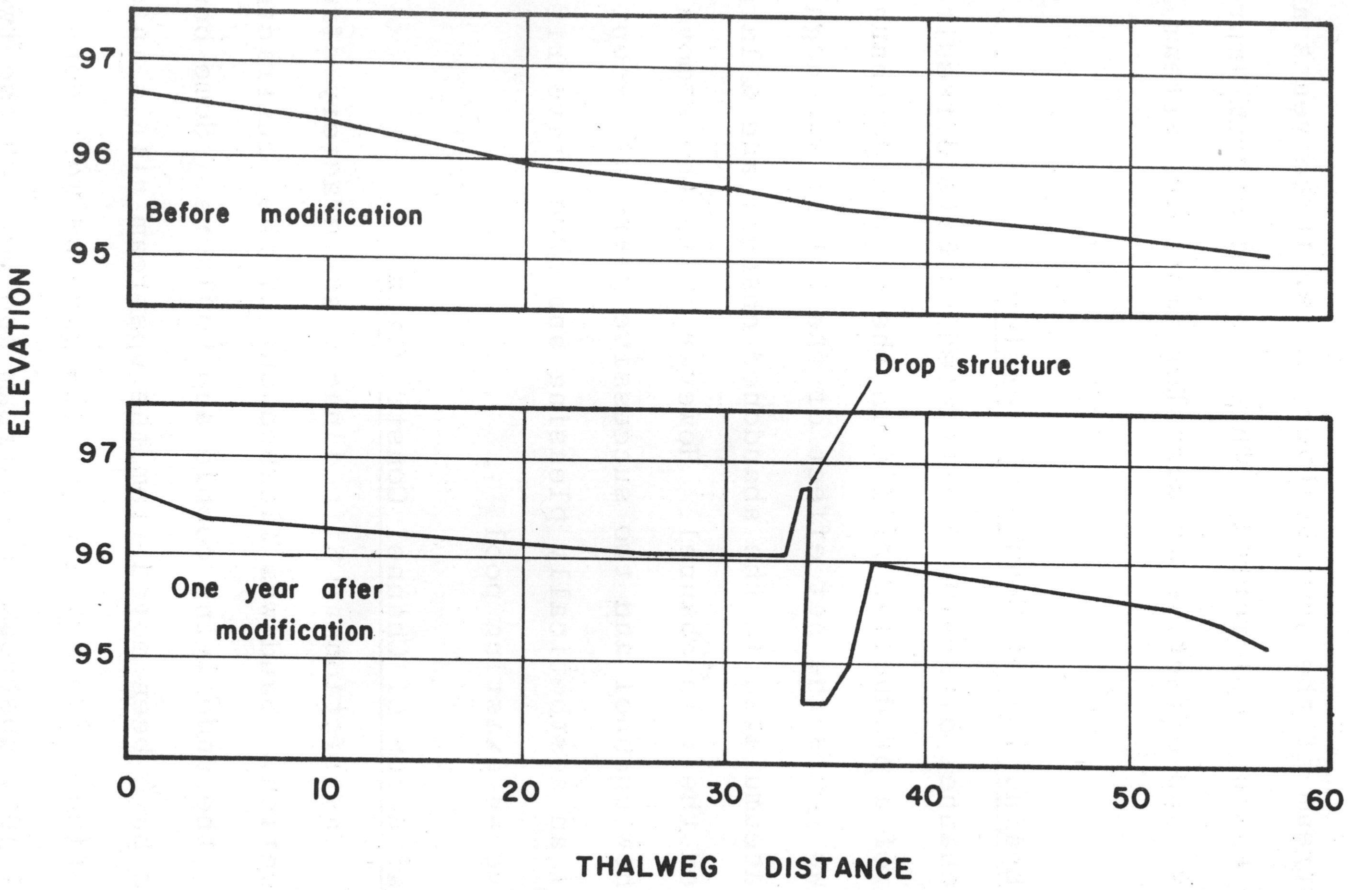


Figure 20
Site 1-A, thalweg profiles

Evaluation of Log Jam Removal

Removal of the log jam at Site 2 created a riffle upstream in what was formerly a silted pool. Some scouring occurred on the left bank downstream of the jam; however, after three years an aesthetically pleasing pool formed. This type of stream improvement is an inexpensive and effective measure for improving stream habitat.

Evaluation of Channel Diversion

The small channel diversion constructed at Site 3 resulted in the development of a productive riffle in the shortened channel. For the first two years the net effect of the cutoff was negative. Silt and algae accumulated in the abandoned channel and a large cedar log blocked the main channel. However, with the removal of the log in the new channel and two successive years of exceptionally high runoff an aesthetically pleasing and productive riffle was created above an existing pool.

Evaluation of Channel Constrictions

The gabion constriction at Site 4 had a satisfactory effect on the stream section. Sand was flushed out of the constricted channel exposing the underlying cobble and boulders. Some boulders appeared to have been moved from the upstream riffle into the modified section. Two years after the gabions were constructed the bed material just upstream, downstream and between the two gabions consisted of cobble and boulders ranging from 6 to 12 inches in diameter.

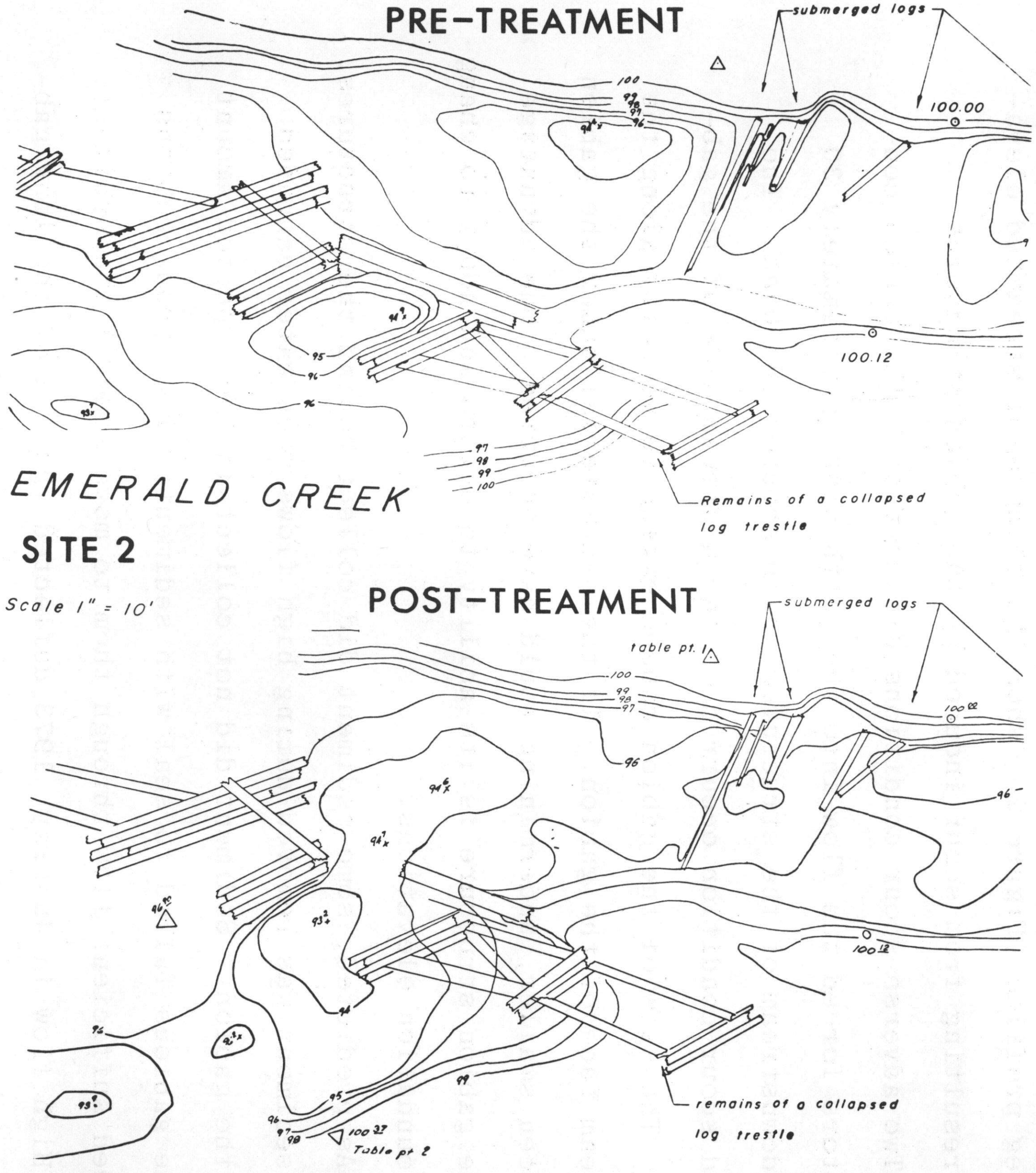


Figure 21
Pre- and post-alteration (1 year after alteration) conditions at site 2 (debris jam removal) in Emerald Creek

Contour maps of site 4 in Figure 22 and 23 show the change in the streambed's topography due to the gabion structures. The thalweg profiles (Figure 24) show the changes of streambed elevation resulting from scour induced by the gabion structures.

Two adverse scour conditions did develop. The gabion constrictors forced the flow into the north bank approximately 30 feet downstream of the structures which scoured the bank. The second scour condition occurred on the upstream side of the gabions. The skew of the gabion caused excessive velocity along the upstream face of the gabion. If the bed material under the gabion had been smaller, undermining would have occurred. One advantage of the gabion structure is its ability to deform and adapt to changing foundation elevations.

As predicted, some sediment did collect behind the structures. This sediment was removed during high flows when water cascaded over the gabion. Sediment did not collect in the expected amount as the gabions failed to seal with sediment. The porous gabions allowed sufficient flow through them to move some of the sediment.

High flow in Januray, 1973 deflected the end of the long gabion at site 4 as shown in Figure 23. However, this did not seem to affect the performance of the gabion. During an even higher flow in January, 1974 which was estimated to be in the range of a 300-year flood, a middle section of the long gabion at site 4 was dislodged and moved approximately 20 feet downstream. This failure in no way reflects faulty design as the gabions were designed to withstand up to a 25-year flood. However, stronger connection between the gabion sections may have prevented the failure.

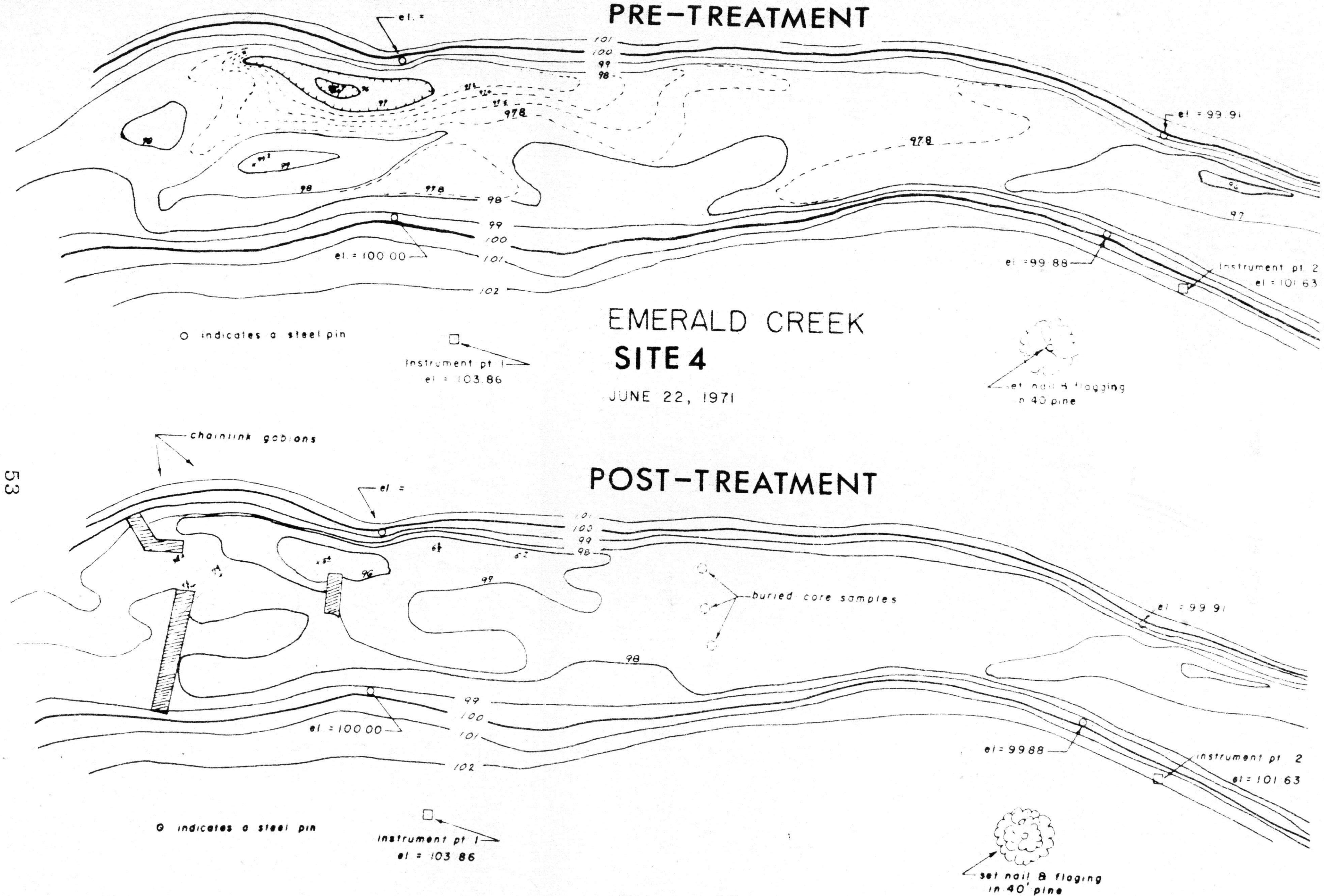


Figure 22

Pre- and post-alteration (1 year after alteration) conditions at site 4 (gabion deflectors) in Emerald Creek

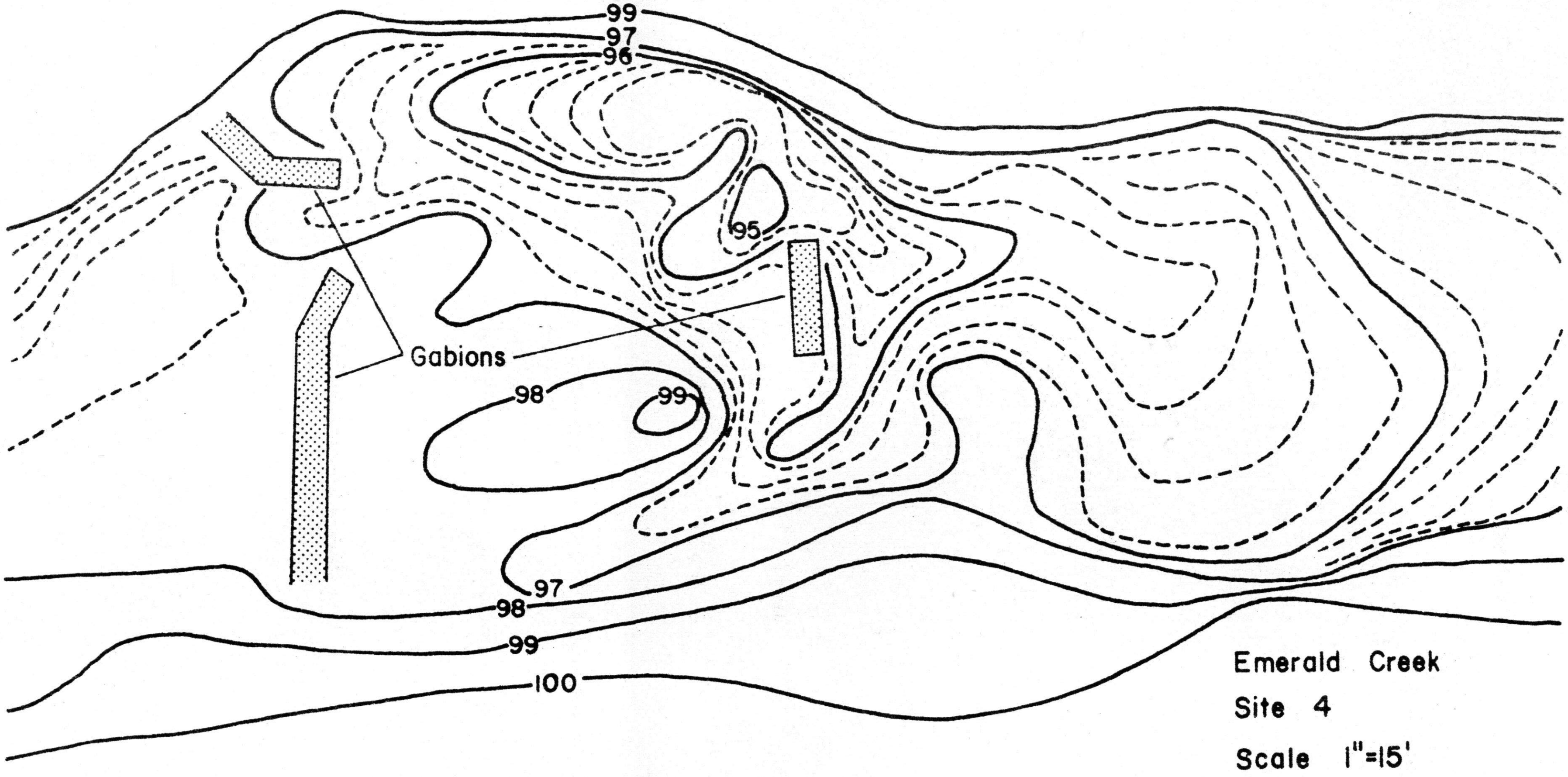


Figure 23
Site 4, two years after construction of gabion constrictors

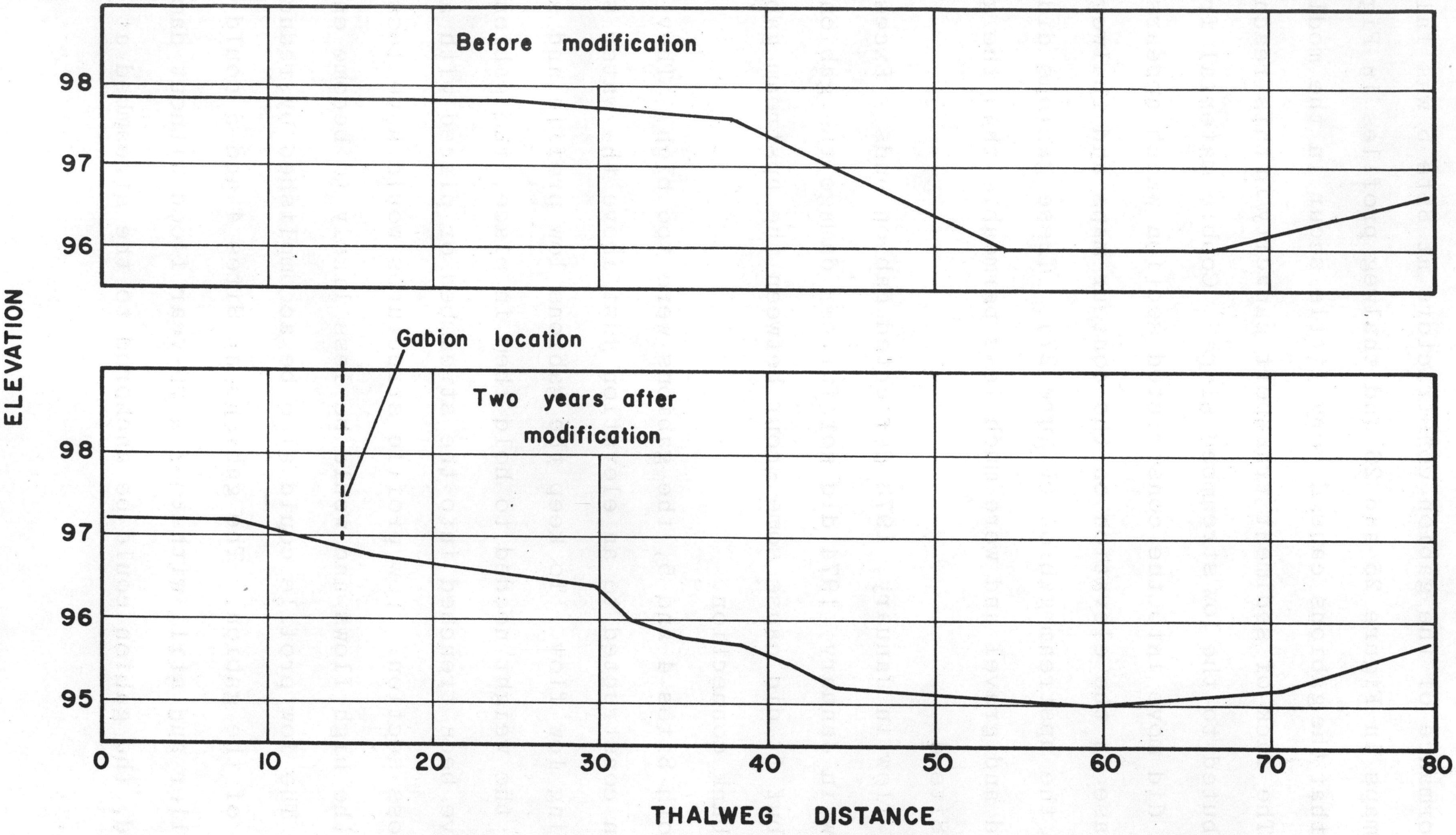


Figure 24
Site 4, thalweg profiles

Performance of the gabion constrictors at Site 5 was fair. Contour maps in Figure 25 and 26 and thalweg profiles in Figure 27 show that the gabions caused very little scour in the modified reach. The lack of sediment transport capacity in this reach can be attributed to the low streambed slope. Cobble material from upstream did move into the constricted section which appears as an increase in the elevation on the contour maps and thalweg profiles at the upstream gabion (Figure 27). These gabions did seal with sand and gravel and were much less permeable than the gabions at Site 4.

High flow in January, 1973 deflected gabion ends. Excessively high flow in January, 1974 did not further damage the gabions at Site 5, but it did cause some scour between the upstream gabion and its bank connection.

At both Sites 4 and 5, the gabions were too high. They should have been constructed to an elevation just above the water surface during low flow. To keep the gabions low profile and still maintain the weight needed to hold them in place, the gabions could have been trenched into the streambed or placed with a flattened cross section. Low profile structures would have less effect on the high flows and would be less likely to become encased in ice. The low profile could also be accomplished by reducing the size of the gabion. The gabions at Sites 4 and 5 could have been smaller and still withstood a 25-year flood without damage. If needed, the gabion could be anchored to the streambed at the free end.

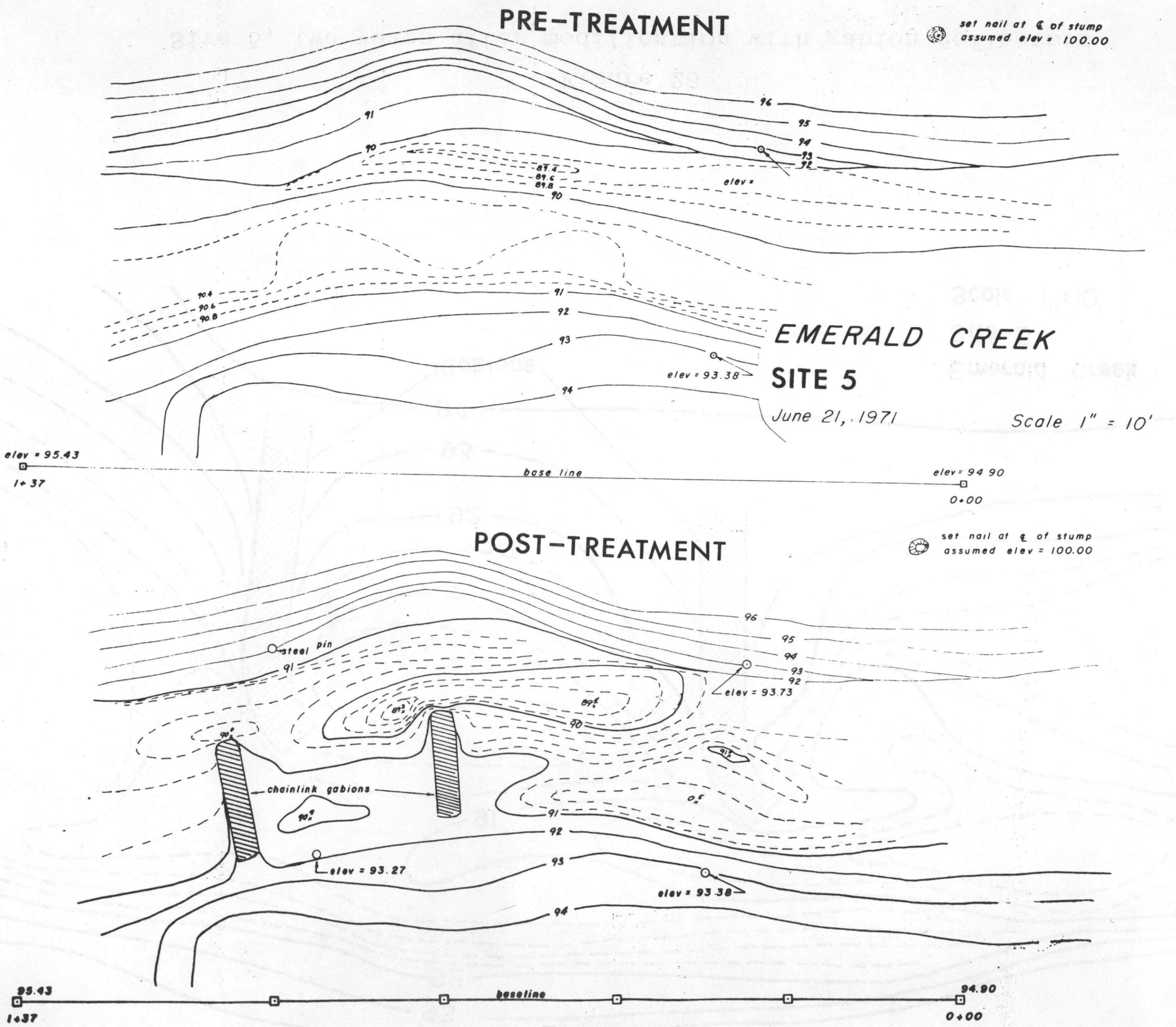


Figure 25

Pre- and post-alteration (1 year after alteration) conditions at site 5 (gabion deflectors) in Emerald Creek

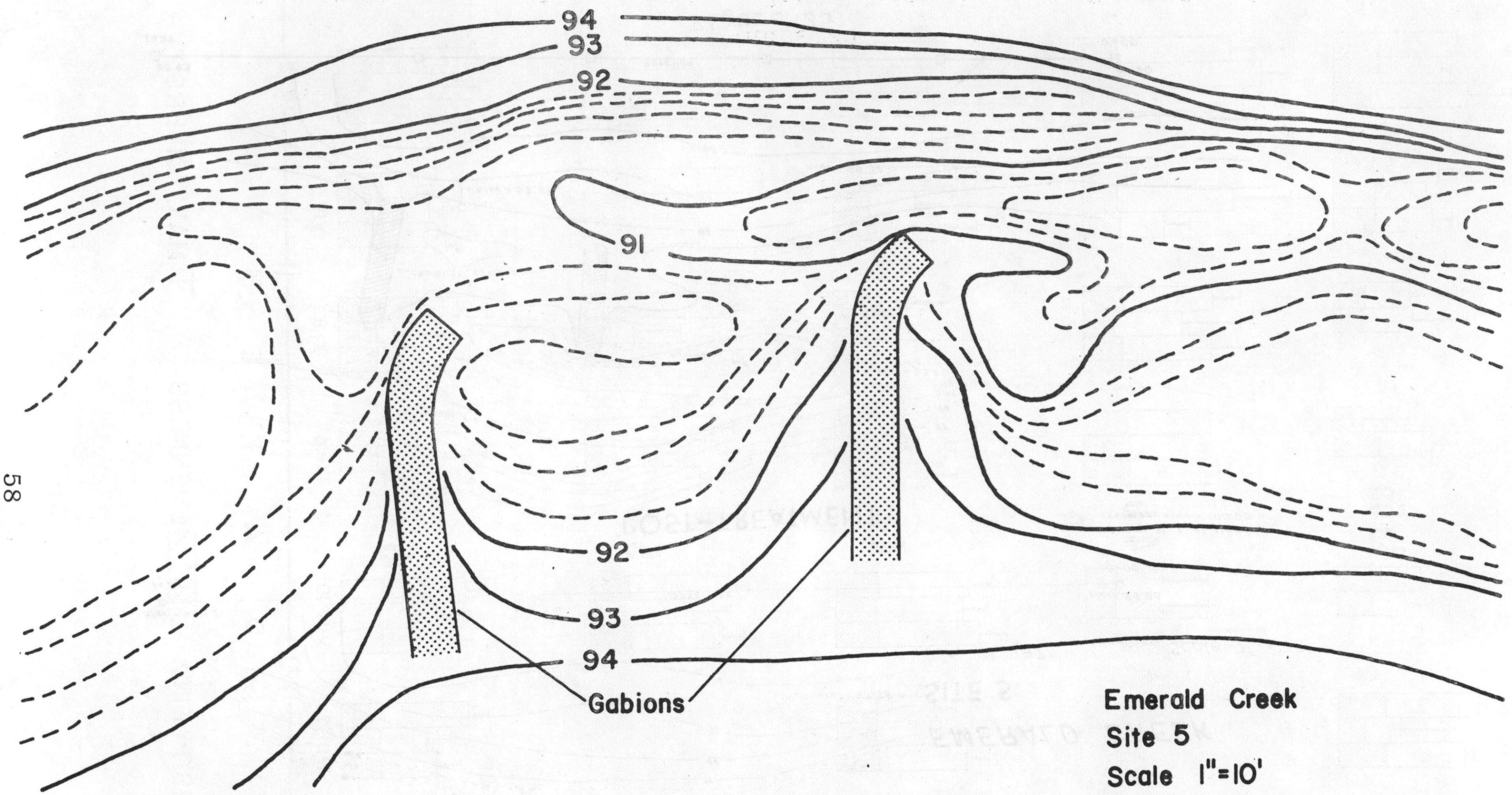


Figure 26

Site 5, two years after modification with gabion deflectors

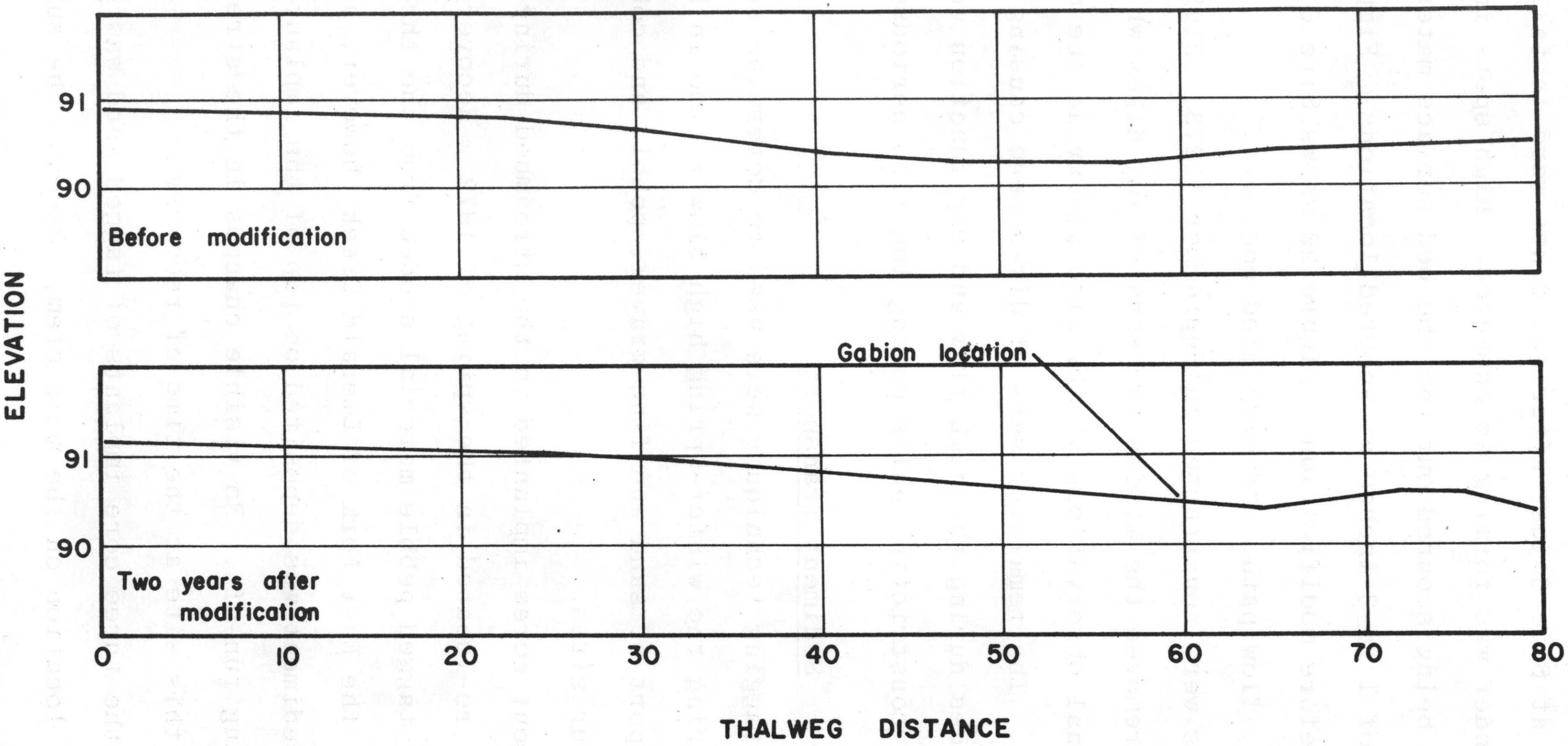


Figure 27
Site 5, thalweg profiles before and after modification

Observations at Site 6 just after log dikes were installed indicated the meander was forming as expected. High spots in the meander path were being scoured out and the bed surface material was in the range of 1 to 3 inches at scoured locations. Figure 28 shows Site 6 before modification. Figure 29 shows Site 6 including log dikes, flow path, and projected contours.

The log dikes were constructed in September, 1973. High flow in January, 1974 removed the middle two sets of log dikes which precluded additional observations at the site as far as the meander was concerned. The remaining sets of dikes were causing negligible disturbances during the high flow and may function well as single channel constricting units during low flow periods.

Sediment Transport

Fluorescent tagging techniques were used to determine sediment transport during the winter-spring high flow regime in Emerald Creek. Transport of sand and fine gravel, pebble and cobble was studied at four sites.

Tagged sediment cores implanted in the streambed during the fall of 1971 were re-located in the spring of 1972. Recovery data indicates that no tagged pebble material eroded from the three core positions in the East Fork of Emerald Creek; however, about one inch of new sediment was deposited on top of the implanted cores during spring run-off. No visible changes in the streambed were observed at this site at the time of recovery.

Only one of the three core implants of tagged sand was recovered at the first location on the main stem. Because the survey

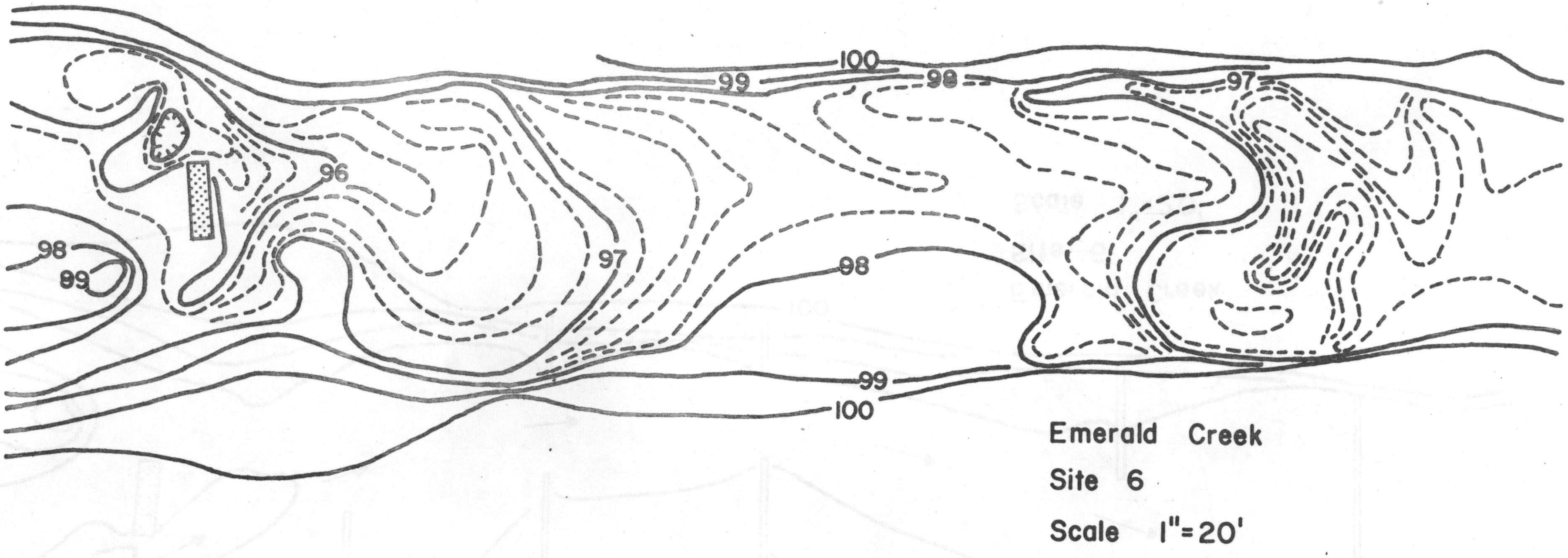


Figure 28
Site 6, before modification

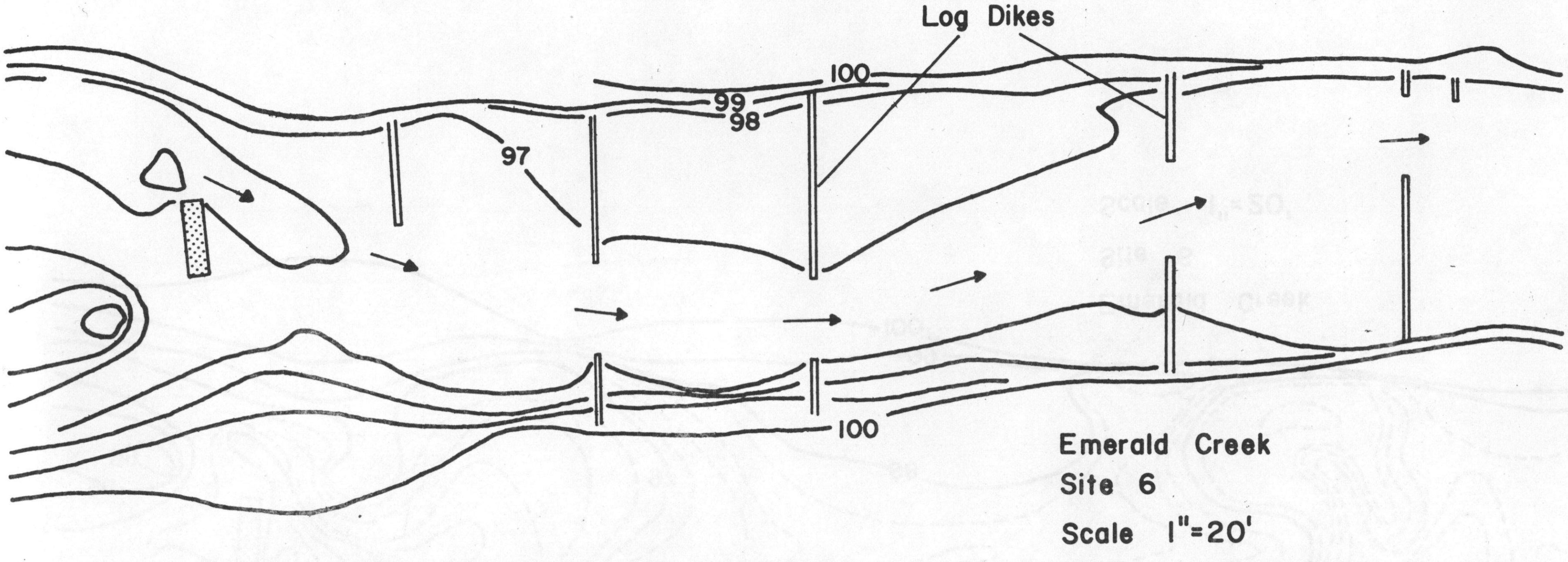


Figure 29
Site 6, showing log dikes, flow path (arrows) and projected contours

technique used to relocate core implants was precise, it is assumed that cores A and C (Figure 22) were completely eroded during high flow. In contrast, approximately 12 of the 24 inches of tagged sediment were removed from core B by spring flows. The gabion upstream from the core implants may have caused deposition of sediment in the center of the streambed, thereby reducing erosion of core implant B.

The core implants at the second main-stem location were completely washed away during the spring runoff. During the fall of 1971 when the cores were implanted, this site had a sand substrate over two feet deep. During spring runoff, the sand was completely eroded exposing the armored bottom.

Results of these studies indicate a massive displacement of fine sediments in the lower reaches of the main stem of Emerald Creek during the late winter-spring high water regime. As high flows decrease in late spring, fine sediments are redeposited in long, low-gradient main stem runs and pools.

In the spring of 1972, an attempt was made to recover three sizes of tagged material placed on transects in the streambed in 1971. Seven of eleven 6-inch cobbles were recovered; the average distance travelled was 11.2 feet with a range of 0-32 feet. Nine of ten 3-inch cobbles were recovered; average displacement distance was 18.6 feet (range .5 - 32.5 feet). Only two of the ten 1-inch gravel were recovered; one at the original transect line, the other 48 feet downstream.

Results of tagged sediment studies indicate that Emerald Creek has the capability of transporting large quantities of sediments, and would readily return to pre-mining conditions once the sources of excess sediment are eliminated.

Hydraulic Conductivity

Results for the direct and indirect measurements of the hydraulic conductivity (K) were summarized in Table 2. For each sand-gravel mixture the value of K for the direct measurement was plotted against the discharge (Q) for the indirect measurement. This calibration curve and the curve developed by Terhune (1958) are shown in Figure 30.

The reader should note the two curves in Figure 30 are not in agreement. Some of the difference can be attributed to slippage of water down the outside of the pipe from above the gravel surface. This flow was reduced by Terhune by using a disk collar around the standpipe at the gravel surface. The remainder of the difference would have to be attributed to differences in equipment and procedures.

The lower end of the solid curve in Figure 30 shows the most pronounced effect of slippage. At a hydraulic conductivity less than 0.1 cm/second or a discharge less than 15 ml/second, the amount of water finding its way into the standpipes by slipping down the side becomes a substantial part of the total amount of water entering the standpipes. At high values of Q, greater than 52 ml/second, discharge is affected by the maximum intake tube capacity which, for the intake tube used, was 156 ml/sec.

A few points are mentioned to help with field application. Since the hydraulic conductivity can vary greatly within a small

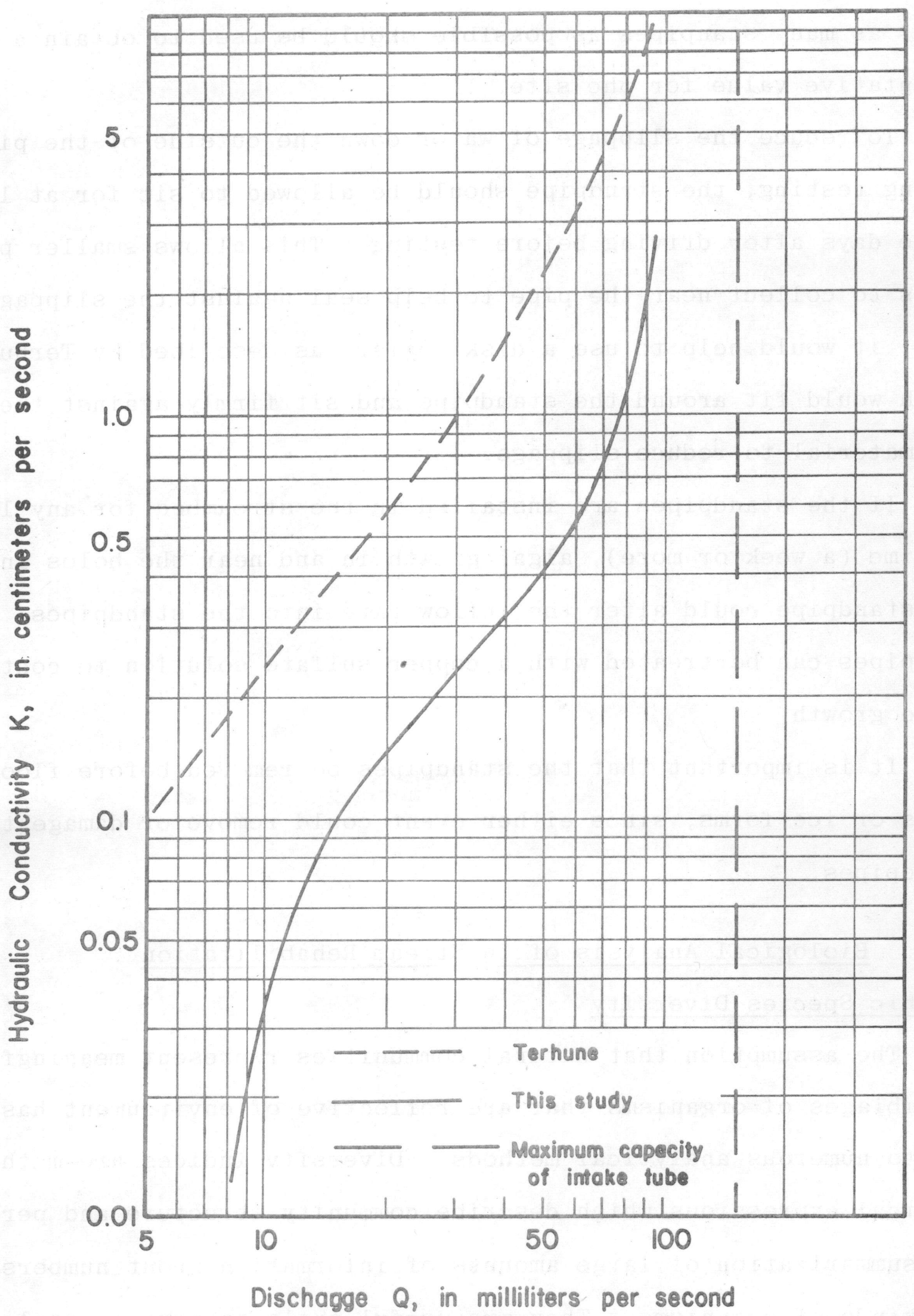


Figure 30

Calibration curve for standpipe

area, as many stanpipes as possible should be used to obtain a representative value for the site.

To reduce the slippage of water down the outside of the pipe during testing, the standpipe should be allowed to sit for at least three days after driving before testing. This allows smaller particles to collect near the pipe to help seal against the slippage. Also, it would help to use a disk collar, as described by Terhune, which would fit around the standpipe and sit firmly against the bed material to reduce slippage.

If the standpipes are installed in the streambed for any length of time (a week or more), algal growth in and near the holes in the standpipe could alter the inflow rate into the standpipes. The pipes can be treated with a copper sulfate solution to control algae growth.

It is important that the standpipes be removed before flood flows or ice forms, since either event could remove or damage the standpipes.

Biological Analysis of In-Stream Rehabilitation

Benthic Species Diversity

The assumption that natural communities represent meaningful assemblages of organisms that are reflective of environment has led to numerous analytical methods. Diversity indices are mathematical expressions which describe community structure and permit summarization of large amounts of information about numbers and kinds of organisms. They are useful tools to aquatic ecologists, allowing mathematical evaluation and comparison among communities.

Indices derived from the field of information theory (e.g., Shannon (1948), Brillouin (1956)) have become widely accepted and are now used by a majority of researchers. The diversity index after Brillouin (1956) was used in this study because the sampling program came closest to meeting the assumptions of the Brillouin. In using this function, samples were treated as entities to be studied for their own sake, and not as random samples of a larger parent population.

Species diversity was used to analyze community changes commensurate with rehabilitation. Transect (a) for each site represented the control; transects (b) and (c) represented test transects.

Log Drop Structure. Substrate characteristics at the unaltered transect (1-a) remained relatively constant during the study. In contrast, test transects 1-b and 1-c showed substantial increases in average channel depth following construction of log drops as a result of scouring. Average sediment size did not change noticeably for either test location.

Diversity per individual, maximum diversity, and evenness remained fairly constant at control transect 1-a during the study (Figure 31). Numbers of insect species were relatively uniform throughout the 2-year period; total numbers fluctuated greatly during the season, but exhibited similar trends in both 1971 and 1972 (Figure 32). Diversity and numbers of species at the two altered transects (1-b, 1-c) most closely approximated the control transect (1-a). Total numbers of insects appeared to be the least

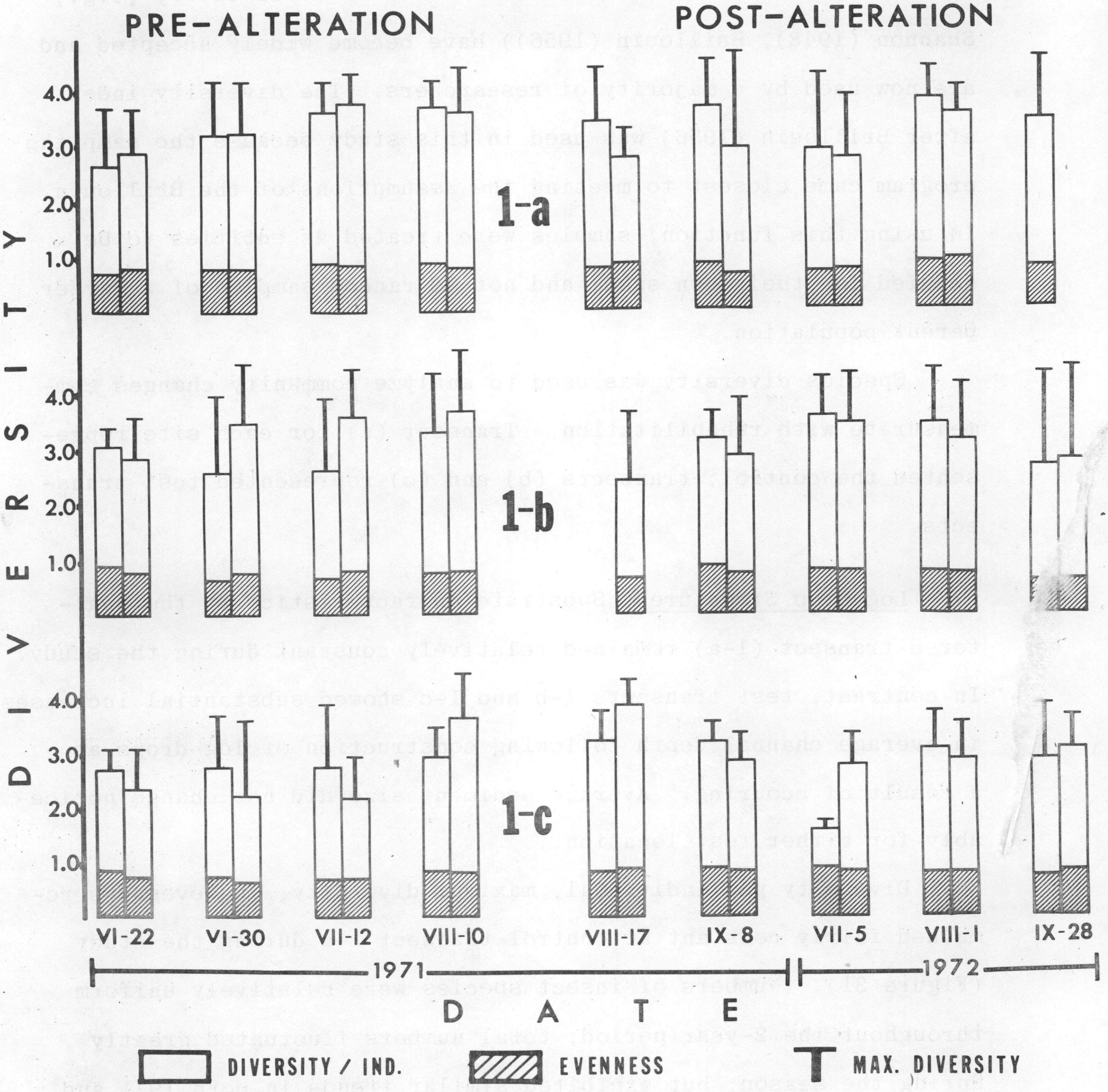


Figure 31

Diversity per individual, maximum diversity and evenness for pre- and post-alteration samples from transects 1-a, 1-b and 1-c curing 1971-1972

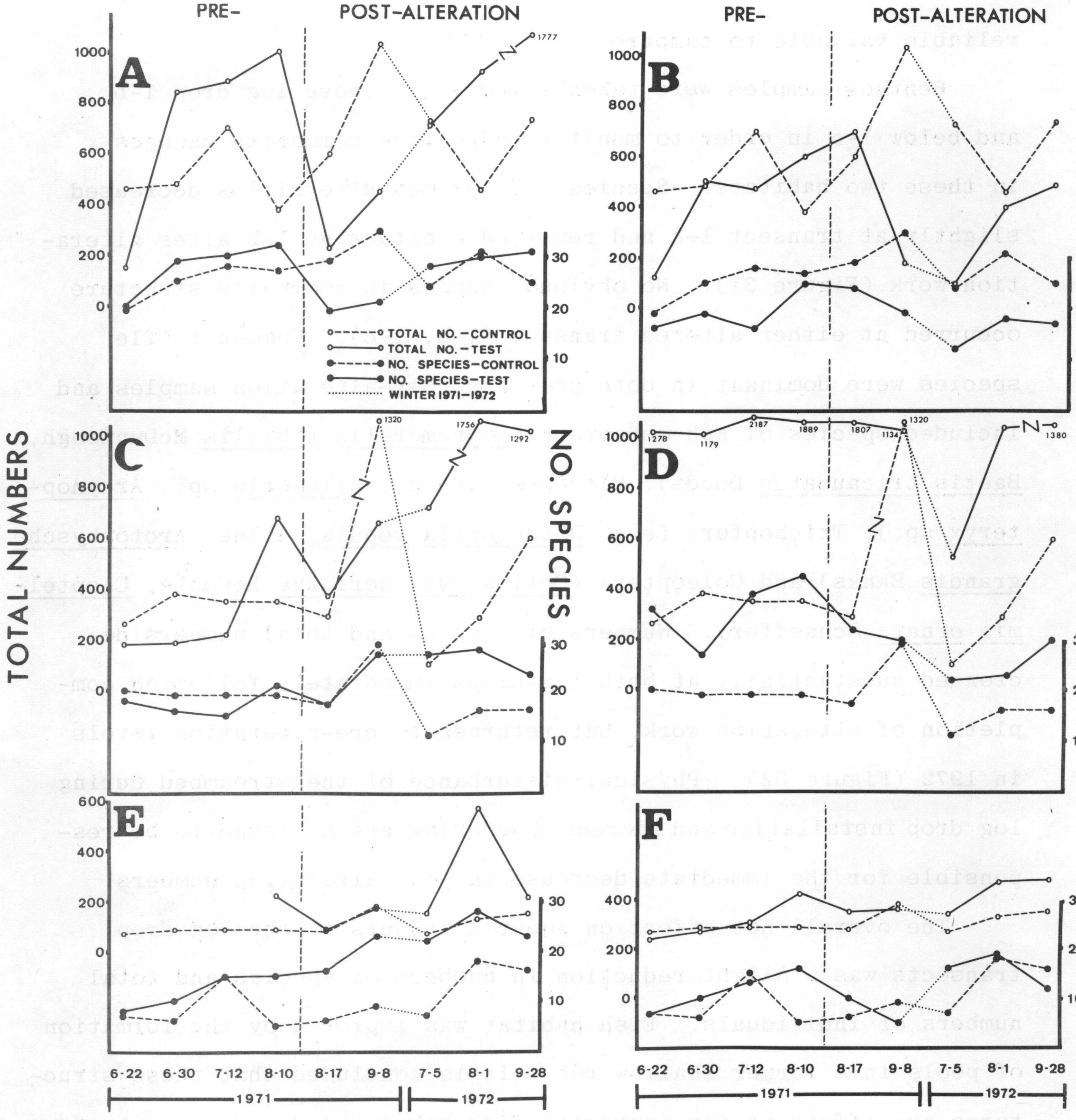


Figure 32

Numbers of species and total numbers for sites 1, 3, and 4 and associated transects. A. 1-a, 1-b; B. 1-a, 1-c; C. 3-a, 3-b; D. 3-a, 3-c; E. 4a-5a, 4-b; and F. 4a-5a, 4-c. Control transects designated as (-a); test transects (-b) and (-c) reliable variable to compare.

Benthos samples were taken immediately above log drop 1-b and below 1-c in order to monitor respective community changes in these two habitats. Species and maximum diversities decreased slightly at transect 1-c and remained constant at 1-b after alteration work (Figure 31). No obvious changes in community structure occurred at either altered transect (1-b, 1-c). Common riffle species were dominant in both pre- and post-alteration samples and included species of Ephemeroptera (Emphemerella tibialis McDunnough, Baetis tricaudatus Dodds), Plecoptera (e.g., Alloperla sp., Arcynopteryx sp.), Trichoptera (e.g. Rhyacophila vepulsa Milne, Arctophysche grandis Banks) and Coleoptera (Optioservus seriatus LeConte, Cleptelmis ornata Schaeffer). Numbers of species and total numbers decreased substantially at both log drops immediately following completion of alteration work, but returned to pre-alteration levels in 1972 (Figure 32). Physical disturbance of the streambed during log drop installation and increased scouring are believed to be responsible for the immediate decrease in post-alteration numbers.

The overall net effect on aquatic insects at the log drop transects was a slight reduction in numbers of species and total numbers of individuals. Fish habitat was improved by the formation of pools in a former shallow run. It is concluded that these structures are effective for improving fish habitat and are not extremely detrimental to insect populations. Log drops cause significant scouring in localized areas; however, they are not effective for removing fine sediment from low gradient, long silted riffles and runs. Construction of log drops with decay resistant tree species (e.g., cedar) assures maximum life of the landscape. A log drop of the type built in Emerald Creek required approximately 16-20 man hours to construct. It is believed that these structures are sound investments, restoring health to the biotic community for a relatively small input of time, cost and effort.

Debris Jam Removal. A structure believed to be an effective fish barrier was partially removed at Site 2, thereby permitting the flushing of fines and passage of fish. Contrary to popular belief, naturally occurring debris jams do not usually block fish passage. The principal damage caused by debris jams is sediment accumulation behind the jam, resulting in a loss of spawning gravels and reduced insect production.

The substrate at control transect 2-a changed little during the 2-year period for values of percent cobble, embeddedness, average sediment size and mean channel depth. In contrast, post-alteration analysis indicated sections A, B and C of test transect 2-b showed increases in average sediment size and mean profile depth. Removal of the log jam caused an immediate increase in velocity, changing the pool conditions to a free-flowing riffle. Initially, the main current flowed across section A, flushing the finer sediments. By June, 1972, the thalweg had shifted to section C, causing a flush of fines from section C and deposition of same in sections A and B.

Species and maximum diversities, number of species and total numbers of individuals of control transect 2-a gradually increased during pre-alteration sampling but remained stable during post-alteration samples (Figures 33 and 34). Species and maximum diversities, evenness and numbers of species did not change appreciably at altered transect 2-B immediately following debris jam removal (Figure 33 and 34). However, species diversity, evenness and numbers of species dropped noticeably in 1972. Total numbers of individuals increased immediately following alteration and remained at high levels in 1972 (Figure 34).

It was believed that flushing fine sediments from a reach thereby exposing underlying cobble, would have a "positive" effect on the benthic community resulting in higher species diversity. While fine sediments were flushed from transect 2-b, leaving a cobble substrate, diversity decreased in post-alteration samples. Benthos samples were taken immediately downstream from the transect. This area became a homogeneous riffle after partial removal of the debris jam and produced larger numbers of riffle-type insects (e.g., the mayflies *Ephemerella tibialis*, *Baetis tricaudatus*, *E. margarita*; the stoneflies *Alloperla* sp., *Arcynopteryx* sp., and *Actoneuria* sp.) and several slow-water forms (e.g., the dipterans *Hexatoma* sp., *Rhabdomastix* sp., *Tabanus* sp., *Liriope* sp., and *Palpomyia* sp.). It appears that pre-alteration streambed conditions were more diverse, allowing a larger number of species, but fewer numbers of individuals.

The debris-jam removal work required less than 15 man-hours and no heavy equipment. A large spillway was produced, allowing fish passage and riffle formation upstream and downstream from

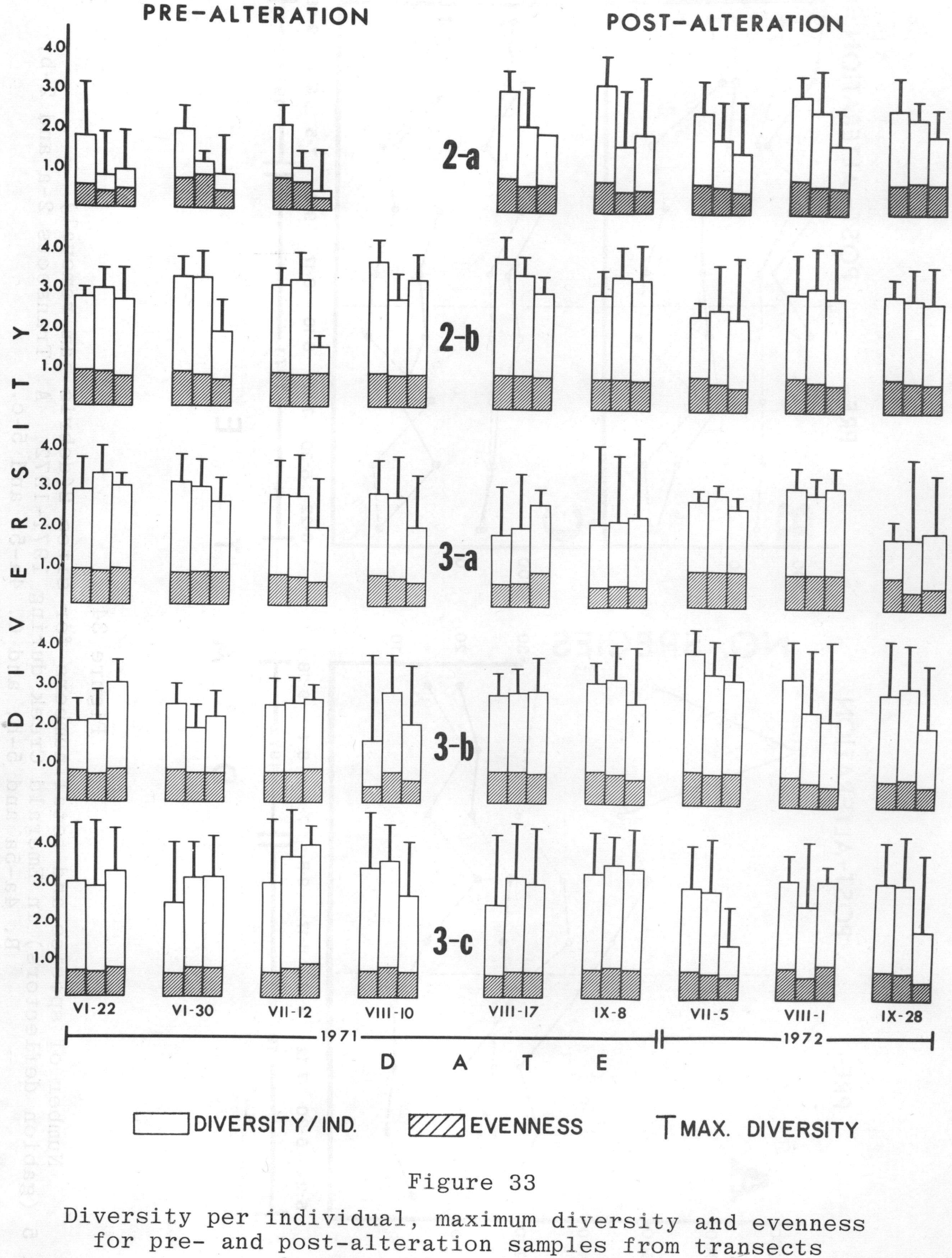


Figure 33

Diversity per individual, maximum diversity and evenness for pre- and post-alteration samples from transects 2-a, 2-b, 3-a, 3-b and 3-c in Emerald Creek during 1971-1972

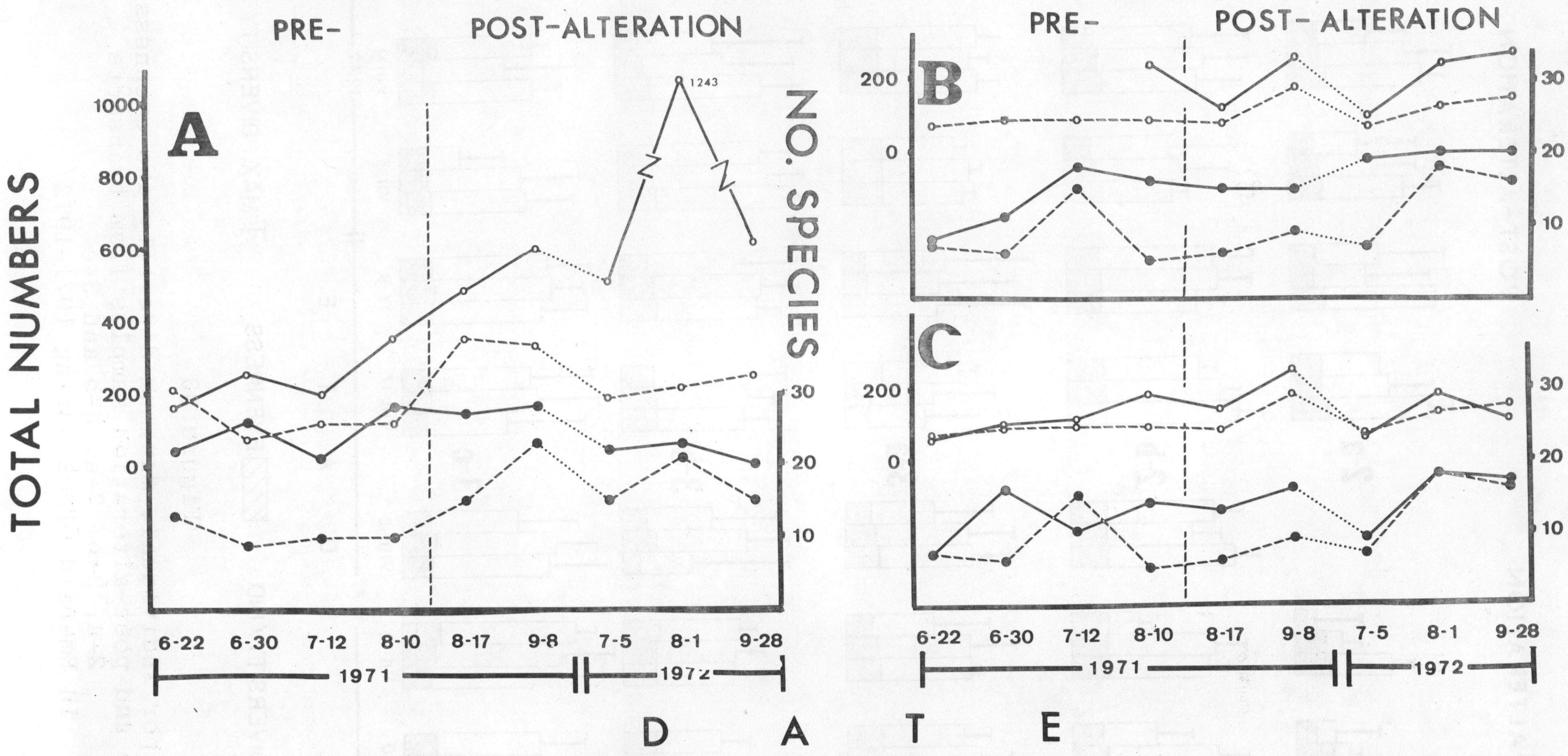


Figure 34

Number of species and total numbers for sites 2(debris jam removal) and 5 (gabion deflectors) in Emerald Creek during 1971-1972. A. Transects 2-a and 2-b; B. 4a-5a and 5-b; and C. 4a-5a and 5-c.

the jam. An aesthetically attractive spillway also scoured a pool which was inhabited by trout. This type of in-stream alteration, when warranted, is an inexpensive, effective method for increasing sediment transport, thereby improving insect and fish habitat.

Channel Diversion. A channel blockage structure was built at test site 3 for the purpose of improving riffle conditions. One branch of a bifurcated channel was blocked off, thereby directing all water through a common channel.

Transect 3-a was established as a control for both test transects, 3-b and 3-c. Sections A and C of the control transect (3-a) decreased in percent cobble and average sediment size during 1971, whereas section B increased in same. The thalweg was located in section B, resulting in an accumulation of silt and algae in sections A and C but not B.

Increased water velocity from channel diversion at Site 3 was apparently concentrated in section A at transects 3-b and 3-c causing scouring in both A sections and deposition of sediment in B and C sections. This was most noticeable following spring runoff in 1972.

Diversity per individual, maximum diversity and evenness showed extreme seasonal fluctuations at control transect 3-a during 1971 and 1972 (Figure 33); however, there was a similar trend of decreasing diversity for both years. Late summer increases of Ephemerella inermis (Eaton) appear to have caused reduced species diversity and evenness.

Post-alteration samples from transect 3-b had higher values of diversity, numbers of species and total numbers of individuals than pre-construction samples (Figure 32 and 33). Species composition underwent considerable change at this site as a result of streambed alteration. Slack-water species (e.g., Tricorythodes minutus Traver, Centroptilum sp., Oreodytes sp., Brychius sp. and Sigara sp.) were replaced by common riffle forms (e.g., Ephemerella tibialis, E. margarita, Ameletus sp., Heptagenia criddlei McDunnough, Zaitzevia sp., Cleptelmis sp. and Arcynopteryx sp.).

In contrast, post-alteration samples from 3-c indicated a net effect of lower numbers of species and total numbers of individuals (Figure 32); diversity was nearly constant, except in section C where it decreased (Figure 33). No striking changes in species composition occurred at test transect 3-c. There appeared to be a slight reduction in some Diptera following alteration work.

Concentration of flow through a single channel at Site 3 resulted in increased numbers of species and total numbers at transect 3-b but a decrease in same at transect 3-c; changes in the streambed at transect 3-b are believed to more accurately reflect the post-alteration conditions at this site.

Channel diversion has been shown to be an effective means of increasing riffle area. However, prospective diversion sites should be carefully studied to insure that such measures will result in a net increase in insect and fish habitat.

Gabion Deflectors. Gabion deflectors were constructed at Sites 4 and 5 in the lower reaches of the main stem of Emerald

Creek. Both test sites were located in heavily silted runs extending over 300 feet in length.

The substrate characteristics of sections A and B of control transect 4-a - 5-a did not significantly change during the study period. However, section C exhibited increases in percent cobble and average sediment size between 1971 and 1972. Also, less sand deposition was noted during the summer of 1972 than 1971. Since no alterations were made at this site, these observed changes were assumed to be reflective of natural seasonal and yearly flow fluctuations. Spring runoff was extremely high in 1972 and undoubtedly accounted for the scouring and flushing of fine sediments from this section.

At transect 4-b, percent cobble and average sediment size increased in sections A and B and remained constant in C following gabion construction. The most significant substrate changes occurred in section B, where the greatest current velocity was generated.

Gabions at Site 5 did not cause pronounced flushing of fine sediments as occurred at Site 4. Apparently the stream constriction was inadequate to generate water velocities capable of transporting sand. Also, the low gradient in this reach reduced the effectiveness of alterations during low flows. However, sediment transport was increased during the spring runoff of 1972.

At control transects 4-a and 5-a, diversity per individual, maximum diversity, evenness, numbers of species and total numbers of individuals were moderately variable during the study period, with 1972 values consistently higher than those from corresponding dates in 1971 (Figures 32 and 35). Increases in the above values in 1972 correspond with increased percent cobble and average sediment size for this site in 1972.

Species and maximum diversities, evenness, numbers of species and total numbers were noticeably higher at alteration transect 4-b in 1972 post-alteration samples (Figures 32 and 35). Species composition of the insect community underwent substantial changes in sections A and B; mayflies and caddisflies increased, while Diptera decreased. Many slow-water forms (e.g., Sialis sp., Sigara sp., Oreodytes sp.) were eliminated and replaced by common riffle species (e.g., Baetis tricaudatus, Ephemerella flavilinea, Hydropsyche sp., Cheumatopsyche sp., Pteronarcella sp. and Arcynopteryx sp.).

Although diversity and numbers of species decreased slightly at transect 4-c after alteration, there was an obvious shift in species composition (Figures 32 and 35). This faunal shift, i.e., from slow water forms to riffle species, was most pronounced in section C where average sediment size increased following gabion construction.

The overall net effect of the gabion deflector at Site 4 on the aquatic insect community was an increase in numbers of species and total numbers. Certain sections showed substantial increases while other sections exhibited slight decreases. Mayflies showed greatest increases in number of species and total numbers in post-alteration samples.

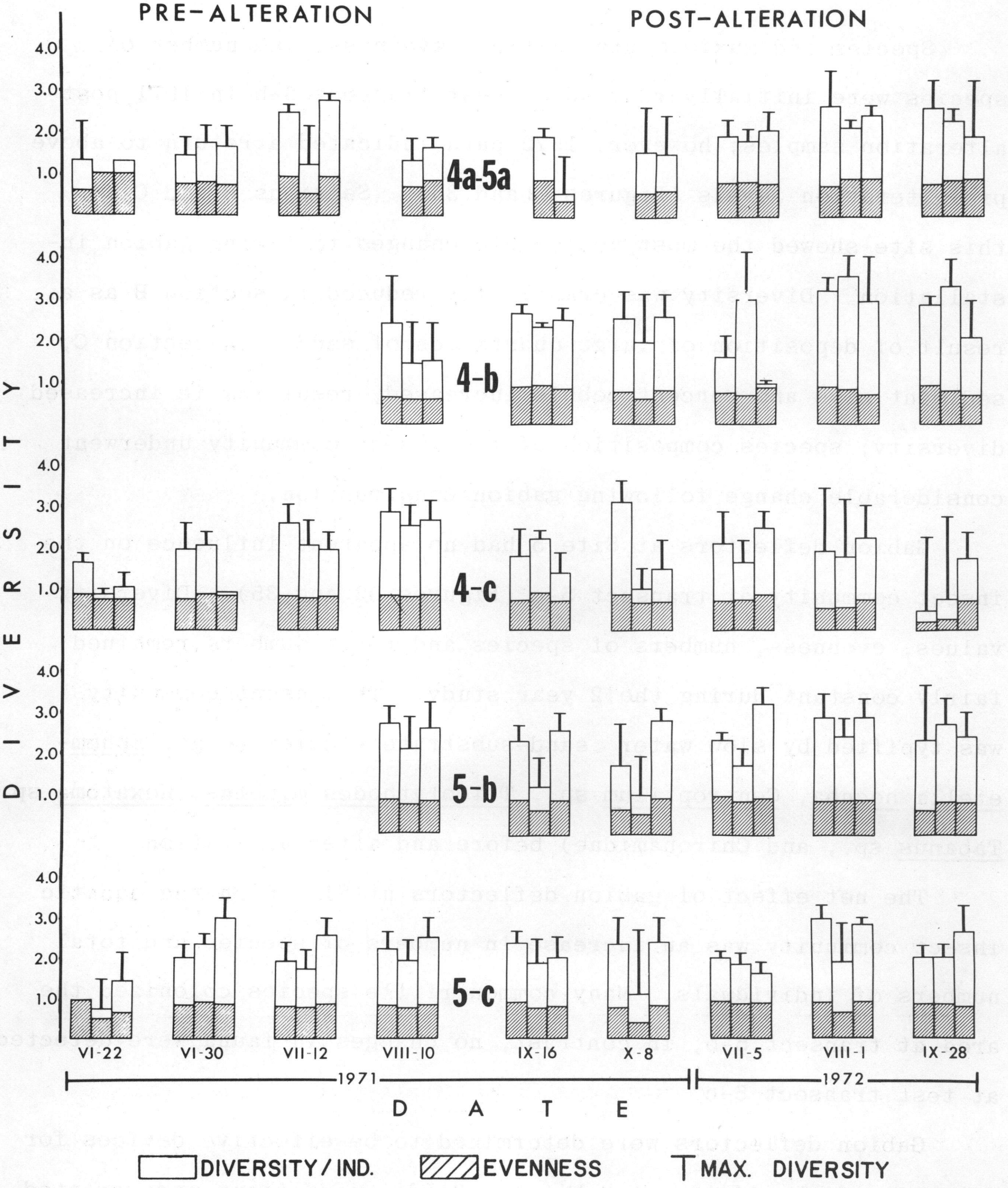


Figure 35
Diversity per individual, maximum diversity
and evenness for gabion deflector sites 4 and 5
in Emerald Creek during 1971-1972

Species and maximum diversities, evenness, and number of species were initially reduced at test transect 5-b in 1971 post-alteration samples; however, 1972 data indicated a return to above pre-alteration levels (Figures 32 and 35). Sections B and C at this site showed the most noticeable changes following gabion installation. Diversity was drastically reduced in section B as a result of deposition of large quantities of sand. In section C, sediment size and percent cobble increased, resulting in increased diversity; species composition of the insect community underwent considerable change following gabion construction.

Gabion deflectors at Site 5 had no apparent influence on the insect community at transect 5-c (Figures 32 and 35). Diversity values, evenness, numbers of species and total numbers remained fairly constant during the 2 year study. The insect community was typified by slow water, sand-substrate species (e.g., *Ephemerella hecuba*, *Centroptilum* sp., *Tricorythodes minutus*, *Hexatoma* sp., *Tabanus* sp., and Chironamidae) before and after alteration.

The net effect of gabion deflectors at Site 5 on the aquatic insect community was an increase in numbers of species and total numbers of individuals. Many common riffle species colonized the area at transect 5-b; in contrast, no changes in fauna were detected at test transect 5-c.

Gabion deflectors were determined to be effective devices for improving fish and insect habitat. Riffle conditions were created as increased current velocity flushed fine sediment and exposed a cobble substrate. This rehabilitated area was quickly colonized by typical riffle insects. Trout were also found to inhabit the area. Gabion installations require considerable time and effort to build; however, they are very durable, and will benefit the stream for many years. Immediately after construction gabions are "eye sores" and aesthetically displeasing. Other studies have shown, however, that gabions are usually colonized by a riparian flora shortly after construction, thereby considerably reducing their artificial appearance.

Benthic Dispersion and Colonization -- Field Study

Downstream drift of aquatic insects is a normal feature of lotic systems (Waters, 1972). Insect drift facilitates recolonization of denuded areas, plays a major role in secondary production and provides a readily available food supply for fish.

Field and laboratory drift and upstream dispersion studies were conducted to determine how drifting insects were affected by long silted reaches, a condition common in the main stem of Emerald Creek. The studies were designed to obtain information on distances travelled by drifting insects, upstream dispersion of insects which had "settled out" in sandy reaches and the capability of different flow rates to effectively transport insects for long distances.

Most stream insects exhibiting drift periodicity are night active, i.e., they have a high propensity for drift at night. Thus, drift studies in Emerald Creek were conducted at night during the time of greatest insect drift.

Insect drift was conducted in July and August in 1972 to determine the effect of water velocity on drift across silted reaches. July drift results exhibited extreme variability during the three-day test period (Table 4). Basket sample data was much more consistent than drift net counts (Table 5). Drift counts from the control net were much greater on the second night than the first or third nights. Increases in drift on the second night may be attributed to a late afternoon rainstorm that increased the stream flow (Table 4). Number of insect species and total numbers decreased at increasing distances downstream from the riffle at the three net positions (Table 4). Counts from nets A and B are larger than from net C. In contrast, drift rates, enumerated on a volume-flow basis, were highest at net C and lowest at A.

Basket sample counts for the control site did not increase on the second night as did the control net counts, but decreased (Table 5). It is possible that increased current velocity caused more insects to remain in the water column and not settle out. Site B basket counts were higher than counts from sites A and C (Table 5). Drift net data indicated a significant reduction in drift between B and C. Settle out appears to have been greatest near site B, resulting in higher basket counts at the same site and lower drift counts at site C.

Results from the August drift study were much less variable than those of July. No significant changes in stream velocity occurred during the 3-day study period. The control net produced reasonably consistent data and appears to be more reliable than

Table 4: Field drift analysis for number of species, total numbers/m^2, and drift rate (numbers/ft^3 and m^3) for Emerald Creek in July and August, 1972.

		8 p.m. - 1 a.m.				1 a.m. - 6 p.m.					
		Number	Total	Rate--Numbers/		Number	Total	Rate--Numbers/		Current Velocity	
Date		Species	Numbers	ft^3	m^3	Species	Numbers	ft^3	m^3	ft/sec	cm/sec
7/7/72	Control	27	863	2.92	102	24	426	1.44	51	1.97	60.05
	A	23	482	2.57	91	21	245	1.31	46	.63	19.20
7/8/72	Control	28	1293	4.73	167	27	859	3.14	111	2.08	63.40
	B	22	435	2.39	84	19	287	1.58	56	1.0	30.48
7/9/72	Control	19	712	3.00	106	26	550	2.35	83	1.62	49.38
	C	15	214	3.50	124	16	102	1.67	59	0.41	12.5
8/17/72	Control	22	336	2.46	87	22	269	1.97	70	.94	28.65
	A	14	71	1.07	38	16	99	1.49	53	.23	7.01
8/18/72	Control	19	255	1.94	68	16	372	2.83	100	1.02	31.09
	B	16	74	1.03	36	13	117	1.63	58	.40	12.19
8/19/72	Control	16	246	1.92	68	19	296	2.32	82	.99	30.18
	C	6	21	.73	26	12	57	1.98	70	.21	6.4

Table 5: Basket sample counts for numbers of species and total numbers of individuals from Emerald Creek drift and colonization studies in July and August, 1972.

		Number of Species		Numbers of Individuals	
Date	Basket	Total	Average	Total	Average
7/7/72	Control #1	13	13	40	44
	Control #2	13		48	
	A-1	11	10.5	25	20
	A-2	10		15	
7/8/72	Control #1	10	11	39	51
	Control #2	12		62	
	B-1	11	13	38	48
	B-2	15		57	
7/9/72	Control #1	13	13	50	66
	Control #2	13		81	
	C-1	7	7	15	15
	C-2	7		15	
8/17/72	Control #1	9	10	51	7
	Control #2	11		42	
	A-1	6	9	8	31
	A-2	12		54	
8/18/72	Control #1	9	9	41	72
	Control #2	9		103	
	B-1	7	8.5	18	36
	B-2	10		54	
8/19/72	Control #1	7	8	45	64
	Control #2	9		82	
	C-1	7	8	16	26
	C-2	9		36	

in July when the discharge was variable. Approximately the same number of species and total number of individuals were caught in nets A and B; net C produced fewer numbers of species and total numbers of insects than nets A and B (Table 4). The average drift rate did not appear to be significantly different among the three test nets. As in July, it appeared that many drifting insects settled out downstream from site B before reaching site C. Basket sample averages were higher in August than in July, indicating, again, that insect settle-out rates and average distances drifted are partially dependent on velocity.

Results of the field drift study indicated that low water velocities aided long-distance insect movement (drifting and crawling) over sand substrates. Insect settle-out rates appeared to increase noticeably approximately 175 feet downstream from the riffle (i.e., between nets B and C).

Field investigations were also undertaken to determine if upstream migration by insects on sand substrate was possible and serve as an offsetting mechanism for downstream drift. Three large species of insects (_Acroneuria_ sp., _Dicosmoecus_ sp. and _Pteronarcys californica_ Newport) were used to enable visual observation of dispersion in a channel erected on a sandy streambed in Emerald Creek. The stone flies _P. californica_ and _Acroneuria_ could not move upstream on sand. After several unsuccessful attempts to crawl upstream, most specimens actively swam downstream usually reaching the end of the channel (16 feet) within 2-3 minutes after release. Both species appeared to "glide" along the bottom in a swimming motion. In contrast, the caddisfly Dicosmoecus sp. moved in a random manner (i.e., upstream, downstream and cross-channel). Many were noted moving upstream, often reaching the upper end of the channel in 5-10 minutes. It is believed that this species can successfully colonize an upstream habitat when subjected to an unfavorable substrate at a lower reach.

We demonstrated that many riffle insects were unable to effectively move upstream on sand substrates. Larger substrates having pebble or cobble are necessary for upstream movement (crawling) by many insects even at very low water velocities. It has been shown that a layer of water with zero velocity exists at rock-water interfaces (Ambühl, 1959). McClelland (1972) reported that many insects live in this zone and do not experience the direct forces of currents. This zone is very thin on fine, unimpacted sediment; therefore, insects settling out on sand are directly exposed to current forces. The combination of exposure to current and instability of fine sand impede movement upstream.

It is apparent from this study that insects drift and crawl through long sedimented reaches in Emerald Creek while others are lost during the colonization cycle. Thus, colonization potential of Emerald Creek is reduced by long sedimented runs and pools characteristic of portions of this stream.

Dispersion and Colonization -- Laboratory Study

Laboratory simulation studies were conducted to describe insect movement and settle-out patterns by reducing variability of key parameters of water velocity, light conditions, substrate, and insect species. Behavioral characteristics of different species were described in the laboratory and used to interpret field drift results.

A regression equation developed by McLay (1970) and Elliott (1971) was applied to the laboratory drift study. When three factors, i.e., species, water velocity and light conditions, were investigated in the laboratory, high settle-out variability was found (Table 6). The mayfly Ephemerella grandis and the stonefly Pteronarcella exhibited similar settle-out patterns for light and dark conditions (Figure 36). Settle-out rates (R) for E. grandis and Pteronarcella sp. were highest at a water velocity of 0.4 feet per second and decreased as water velocity increased.

The settle-out patterns of another stonefly, Arcynopteryx, and a caddisfly, Brachycentrus, were highly variable (Figure 36). Both species had highest settle-out rates under lighted conditions (Table 6). The settle-out rates for Arcynopteryx and Brachycentrus did not appear to be strongly correlated to water velocity as was found with Ephemerella grandis and Pteronarcella.

Passive settle-out rates, i.e., settle-out not resulting from physical activity by the insects, were determined for all test species by using dead specimens (Table 6). Settle-out rates were nearly zero for all test species except Arcynopteryx at a water velocity of 0.4 feet per second. From these results it appears that settle-out by live specimens was "active" and not "passive". Settle-out rates determined by Elliott (1971) for dead insects in streams with cobble substrates were substantially higher than values obtained in this study.

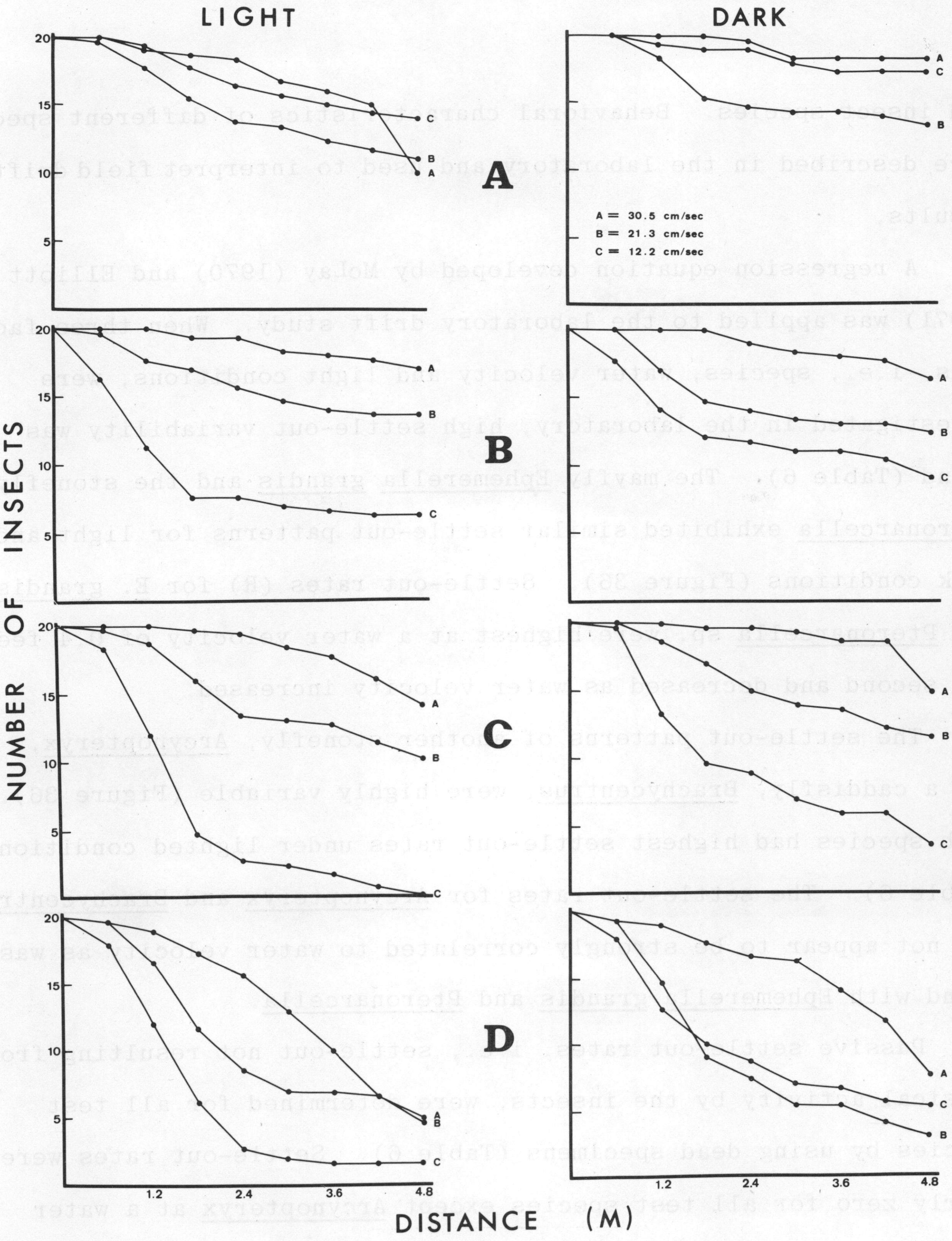


Figure 36

Settle-out patterns for A. Brachycentrus sp., B. Pteronarcella sp., C. Ephemerella grandis and D. Arcynopteryx sp. at three water velocities under dark and light conditions on a sand substrate

Table 6: Settle-out rates (R) for Ephemerella grandis, Arcynopteryx sp., Brachycentrus sp., and Pteronarcella sp. in a laboratory stream at three water velocities in light and dark conditions.

Settle-out Rates (R) for Living Insects

Water Velocity		E. grandis		Arcynopteryx		Brachycentrus		Pteronarcella	
Ft/sec	Cm/sec	Light	Dark	Light	Dark	Light	Dark	Light	Dark
0.4	12.19	1.16	.96	1.08	.81	.45	.21	.59	.49
0.7	21.34	.68	.61	1.02	1.08	.60	.44	.43	.46
1.0	30.48	.41	.27	1.13	.78	.59	.16	.22	.26

Settle-out Rates (R) for Living Insects

0.4	12.19	.05	-	.41	-	.07	-	.06	-
0.7	21.34	.03	-	.04	-	0.0	-	0.0	-
1.0	30.48	0.0	-	.07	-	0.0	-	.01	-

Most specimens settled out almost immediately after introduction into the laboratory stream, but began drifting and moving downstream after a short pause. Several species displayed mechanisms for reinitiating drift. *Ephemerella grandis* folded its legs to begin drifting, then extended them to grasp the substrate and stop; *Pteronarcella* displayed a "tuck and roll" behavior to begin drift, followed by the extension of legs and grasping the substrate. Several *Pteronarcella* were observed swimming to the surface where they were held by surface tension and usually drifted the full length of the stream. It was noted that most *Arcynopteryx* settled out very quickly; however, some specimens moved head first down the channel in a swimming manner. Others appeared to reinitiate drift by holding their legs in a fixed, posteriorly directed position.

Prior to this study it was believed that settle-out rates would be lower on sand than on pebble and cobble. However, laboratory settle-out rates were comparable to those reported by Elliott (1971) from a study conducted in a small, cobble stream. High settle-out rates obtained in this study can probably be attributed to the shallow water column and short drift interval. All test species made numerous contacts with the substrate as they drifted. In a deeper water column, as in most natural streams, fewer insect contacts with the substrate would be expected. Behavioral observations of the four test species also indicated that all specimens would probably drift or move the full distance of the channel during a longer test period, thus resulting in lower settle-out rates.

SUMMARY AND CONCLUSIONS

This study was conducted on Emerald Creek, a tributary of the St. Maries River in northern Idaho. Emerald Creek is extremely silt polluted due to private and commercial extraction of garnet. Log drop structures, debris jam removal, channel diversion and gabion deflectors were tested as means of physical and biotic rehabilitation.

Pre- and post-alteration measurements were taken for cobble factor, cobble embeddedness, sediment surrounding cobble, average sediment size and mean channel depth from established study sites. In-stream alterations were effective means for increasing sediment transport, thereby improving insect and fish habitat. Debris jam removal, channel diversion, and gabion deflectors caused flushing of fine sediment from runs and pools. Log drop structures scoured pools and increased the pool-riffle ratio. Post-alteration analysis of test transects demonstrated higher values of percent cobble, average sediment size and mean channel depth.

Monthly benthos samples from each transect were taken during the summers of 1971 and 1972. Community changes resulting from stream alterations were analyzed using a species diversity index derived from information theory. Diversity, numbers of species and total numbers increased in post-alteration sampling from the test transects. Insect community changes resulting from in-stream alterations were most pronounced at gabion sites and to a lesser extent at debris jam removal, channel diversion and log-drop sites.

Slow-water forms (e.g., Hexatoma sp., Sialis sp., Sigara sp., Tricorythodes minutus and Ophiogomphus sp.) were replaced by common riffle species (e.g. Ephemerella tibialis, Baetis tricaudatus, Pteronarcella sp., Arcynopteryx sp., Hydropsyche sp. and Brachycentrus sp.) following stream alteration.

Sediment transport in relation to the hydrologic cycle was studied using various sizes of tagged sediment. Three sizes of rock (1, 3, and 6-inch) were placed on transects in the streambed; 6-inch and 3-inch cores of tagged pebble and sand, respectively, were implanted into the streambed. Tagged sediment experiments showed that Emerald Creek has the ability to transport small rock and sand substantial distances. Massive quantities of fine sediment are flushed out of the stream system during spring runoff in the main stem, followed by sediment redeposition as the water recedes. Rock transport distance was directly related to rock diameter and weight, with smaller rocks displaced the farthest.

Insect dirft and upstream dispersion studies were conducted in the field and laboratory to explore into recolonization of heavily silted portions of the stream. A regression equation describing insect drift and settle-out was applied to simulation studies in a laboratory stream. Results revealed that long, low-gradient sandy reaches in Emerald Creek impeded normal drift and dispersion. Some insects (e.g., Ephemerella grandis, Pteronarcella sp.) do not successfully cross such areas and are lost to the downstream colonization cycle. Laboratory studies showed that settle-out rates on sandy substrates were principally a function of current velocity, light conditions, water depth, and insect species.

Emerald Creek, by virtue of its natural hydrological cycle, has the ability to flush large quantities of fine sediments annually. However, until the source of polluting sediments is eliminated, lower portions of the main stem will continue to be subjected to a heavy sand burden. In-stream alterations commensurate with retardation of the sediment source are effective for increasing sediment transport, thereby accelerating physical and biological rehabilitation.

LITERATURE CITED

Ambühl, H. 1959. Die Bedentung der Strömung als ökologischer Factor. Schweig. Z. Hydrol. 21:133-264.

Brillouin, L. 1956. Science and Information Theory. Academic Press, New York. 320 p.

Brusven, M.A. 1970. Fluorescent Pigments as Marking Agents for Aquatic Insects. Northwest Sci. 44:202-237.

Cummins, K.W. 1966. A Review of Stream Ecology with Special Emphasis on Organism-Substrate Relationships. p. 2-51. In Cummins, K.W., C.A. Tryon, and R.T. Hartman (eds) Organism-Substrate Relationships in Streams. Spec. Publ. Pymantuning Lab of Ecology, University of Pittsburgh. 4:1-145.

Elliott, J.M. 1971. The Distances Travelled by Drifting Intertebrates in a Lake District Stream. Oecologia 6:350-379.

Franco, J.J. 1967. Research for River Regulation Dike Design. Journal of the Waterways and Harbors Division, Am. Soc. Civil. Engr., Vol. 93, No. WW3, pp 71-87.

Hynes, C.D. 1969. The Immature Stages of the Genus Rhavdomastix (Diptera:Tipulidea). Pan-Pacific Entomol. 45:229-237.

Jensen, S.L. 1966. The Mayflies of Idaho. Unpubl. Master's thesis, University of Utah, Salt Lake City. 367 pp.

Kelly, T.L. 1974. Methodology for In-Stream Rehabilitation of a Silted Stream. Unpubl. Master's thesis. Civil Engineering University of Idaho, Moscow.

Leopold, L.B., and M.G. Wolman. 1960. River Meanders. Bull. Geol Soc. Am., Vol. 71, pp. 769-794.

Leudtke, J.L. 1973. Benthic Insect Community Changes in Relation to In-Stream Rehabilitation of a Silted Stream. Unpubl. Master's thesis. Dept. of Entomology, University of Idaho, Moscow.

Margalef, R., 1957. Information Theory in Ecology. Gen. Syst. 3:37-71.

McClelland, W.T. 1972. The Effects of Introduced Sediment on the Ecology and Behavior of Stream Insects. Unpubl. Ph.D. dissertation, University of Idaho, Moscow. 167 pp.

McLay, C. 1970. A Theory Concerning the Distance Travelled by Animals Entering the Drift of a Stream. J. Fish. Res. Bd. Canada. 27:359-390.

Peterson, B.V. 1960. Simuliidae of Utah, Part 1. Great Basin Nt. 20.

Prather, K.V. 1971. The Effects of Stream Substrates on the Distribution and Abundance of Aquatic Insects. Unpubl. Master's thesis, University of Idaho, Moscow. 62 pp.

Shannon, C.E. 1948. A Mathematical Theory of Communication. Bell Syst. Tech. J. 27:379-423.

Smith, D.S. 1968. The Rhyacophila of the Salmon River Drainage of Idaho with Special Reference to Larvae. Ann. Entomol. Soc. Am. 61:655-674.

Usinger, Robert L. (ed). 1968. Aquatic Insects of California. University of California Press, Berkeley. 508 pp.

Waters, T.F. 1972. The Drift of Stream Insects. Ann. Reb. Entomol. 17:253-272.

Winkley, B.R. 1971. Practical Aspects of River Regulation and Control. River Mechanics. H.W. Shen, ed. Vol. 1, Colorado State University, Fort Collins, Colorado. pp. 19-1 - 19-79.

Zeller, J. 1967. Meandering Channels in Switzerland. Intern. Assoc. Sci. Hydr., Symp. on River Morphology, Bern, Switzerland.