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An Evaluation of In-Stream Structures Designed to Provide Fish Habitat

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AN EVALUATION OF IN-STREAM STRUCTURES DESIGNED TO PROVIDE FISH HABITAT

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Master of Engineering

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Charles H. Call, Jr.

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ABSTRACT

In-stream concrete structures were studied through model tests and river tests. The model studies indicated that four designs provided good habitat in the model stream. These structures were the inverted weir, the "V" structure, the slab with legs and the cylinder. Through the river studies it was determined that these structures did not influence enough of the total river area to be effective in providing good fish habitat. Also an appreciable amount of yearly maintenance would be required to free the structures from silting in, debris, and vandalism. The slab with legs was the only promising structure.

COMMITTEE APPROVAL: ______________________________

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This project, by Charles H. Call, Jr., is accepted in its present form by the Department of Civil Engineering Science of Brigham Young University as satisfying the project requirement for the degree of Master of Engineering.

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ACKNOWLEDGMENTS

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There are two people to whom the author cannot pay enough respect and thanks for their help and guidance. They are Dr. James R. Barton, who assisted throughout this project and painstakingly reviewed this report, and Dr. Parley V. Winger, who continually aided in the field work and helped collect much of the information given in this report. Thanks are also extended to Don Billings for his help in all phases of this study.

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INTRODUCTION

STREAM CHANNELIZATION

Stream channelization (Figure 1) by dredging and straightening stream channels, bulldozing vegetation on stream banks, and draining associated swamps and flood-plains have proven to have catastrophic effects on the environment. Some of the adverse environmental effects of channelization have been elimination of fish habitat and lowered production of aquatic life, destruction of wildlife habitats, degradation of water quality, increased erosion and turbidity, increased floods and damages downstream, lowered water tables, and losses in esthetic beauty.

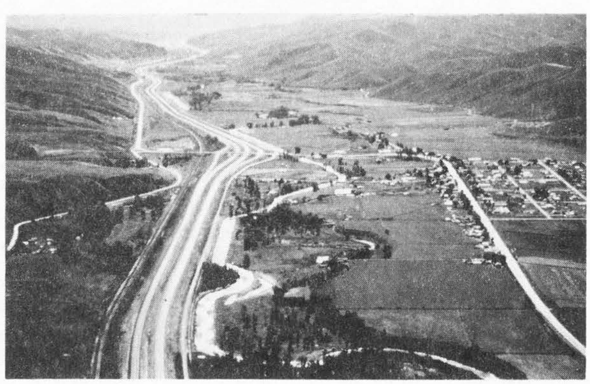


Figure 1

Channelization of the Weber River, Utah
Due to Highway Construction

Drastic reductions in the fisheries have accompanied stream alteration or channelization (Alvord and Peters, 1963; Beland, 1953; Berryman, et al., 1962; Burns, 1972; Elser, 1968; Ethnier, 1972; Hales, 1960; Irazarry, 1969.) In Idaho it was found through biological sampling in 29 different streams that there were almost seven times as many catchable-sized trout and almost ten times as many catchable-sized whitefish in unaltered stream sections as in altered stream sections. The undisturbed areas out-produced the altered areas, ranging from 1.4 to 112 times greater. In some instances altered areas produced no game fish whatsoever (Irazarry, 1969.) Studies of many areas have also shown that this reduction in fish population exists even after many years (Bayless and Smith, 1964; Gebhards, 1970; Irazarry, 1969.) This reduction in fisheries brought about by channelization is a result of a loss of conditions necessary for fish habitation (Barton and Winger, 1973a).

In general the conditions necessary for good trout fisheries are good quality water, a favorable range in water temperatures, adequate spawning areas (riffles), adequate shelter and protection, abundant food supply, absence of competitive existence, minimal flow manipulation and minimum erosion and turbidity (Clark, 1945; Silcox, 1936). Any disturbance of the natural aquatic environment, such as that done by channelization, will destroy or change one or several of these necessary conditions. In general channelization may be detrimental to a river if it does any of the following (Barton, et al., 1971; Barton and Winger, 1973a, 1973c):

1. Shortens the channel length by straighteneing a meandering channel.
2. Removes holes and cover necessary for fish.
3. Exposes the channel to erosion, which may increase the turbidity of the stream, which in turn may harm aquatic life.
4. Ruins the esthetic qualities of the river.
5. Disrupts the riffle-pool sequence.
6. Removes stream-side vegetation.
7. Increases stream velocities above those which can be inhabitated by fish and aquatic invertebrates.

Although the above detrimental effects are based on the concept of man's deliberate manipulation of the river, these same detrimental effects are sometimes caused by natural processes in streams. Natural runoff caused by rains or spring snowmelt also often do damage to the fish habitat in a natural river (Ellis, 1936).

Chapter 2

FISH REQUIREMENTS

The physical environmental requirements of game trout fall into three main areas, namely, resting areas, feeding areas, and breeding areas (Baldes and Vincent, 1969). Each of these specific areas could be considered a "microhabitat." Microhabitat is defined as physical conditions immediately surrounding an animal at a given time and place (Baldes and Vincent, 1969). In order to meet its physical environmental requirements a trout will move from one microhabitat to another, thus meeting different physical needs. To conserve energy all types of microhabitats must be available within the movement radius of the fish.

The general physical environmental parameters of each microhabitat can be fairly well outlined.

RESTING AREAS

The resting microhabitat is important as the focus from which a fish can move easily to another microhabitat (Baldes and Vincent, 1969). The physical environmental parameters which are important in resting areas are a favorable range of velocities, favorable range in temperatures, adequate living space and adequate cover.

Lewis (1969) found that current velocity was the most important factor for rainbow trout, but he did not list the most favorable range in velocities. In the study by Baldes and Vincent (1969) brown trout were found to occupy resting microhabitats within a velocity range of 0.4 to 0.7 fps. One might assume similar values for the other trout species.

Baldes and Vincent (1969) observed that turbulence may be nearly as important as velocity. They noticed that a fish can maintain spatial position in a steady low turbulent flow by slight movements or change of fin position; therefore they reasoned that more energy is required in turbulent waters to compensate for frequent changes in flow direction and velocity. Researchers have also found that as the velocity increases there is a greater dependence upon channel irregularities, such as uneven substrata, logs, boulders, etc, to form resting areas (Baldes and Vincent, 1969; Hartman, 1963; Kalleberg, 1958). The general agreement is that as flow and velocity increase, fish move closer to the bottom and utilize eddies formed by physical features such as rocks. But when heavy sediment loads exist, which are naturally concentrated near the bottom due to the lower velocity, fish are driven to the sides.

The optimum temperature range varies with different species of trout but generally can be considered from 45° F to 65° F (Novitzki, 1973; Silcox, 1936; White and Brynildson, 1967). Novitzki (1973) lists the most favorable range in temperatures for brown trout as 60° to 65° F and for rainbow and brook trout as 55° to 60° F.

The higher the water temperature in the summer time the more necessary it becomes for other conditions such as oxygen content and abundent food supply to be fully realized. Also as water temperatures become higher the environmental conditions become more favorable for fish other than trout, such as minnows and suckers (Silcox, 1936).

Trout must have enough living space to eliminate an excessive amount of competition for favorable living conditions (Baldes and Vincent, 1969; Lewis, 1969; Schuck, 1945). Investigations have shown that competition takes place for the limited number of favorable positions within a stream (Kalleberg, 1958; Newman, 1956), and thus the population levels are limited by the favorable living spaces available. The natural pools in the river provide much of this favorable living space. A pool can be defined as water of considerable depth in comparison to the size of stream (White and Brymildson, 1967). Pools generally have slowly flowing water with a smooth surface (Figure 2). Studies indicate that two or more fish seldom inhabit the same area (Baldes and Vincent, 1969); therefore numerous pools of varying depths are necessary to support large fish populations (Barton and Winger, 1973c).

However other conditions are important also. Lewis

(1969) found that cover was the most important factor for a brown trout habitat. This has been verified by the author's experience of shocking on the Provo River, where overhead cover was found to be even more important for brown trout than occupying a large hole.

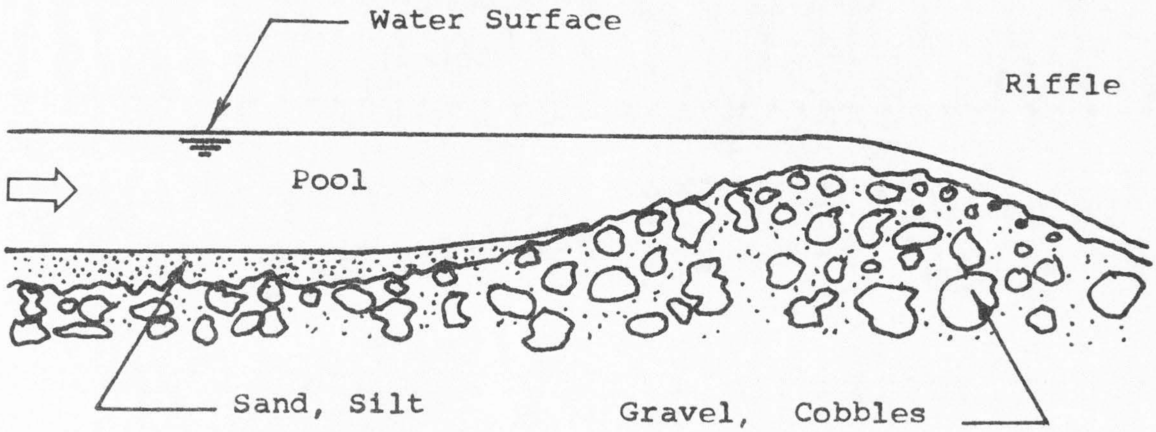


Figure 2

Riffle and Pool

Butler and Hawthorne (1968) studied the reaction of the three common trout, brook, rainbow and brown, to artificial overhead cover. They found that rainbow trout showed the lowest use of shade produced by the overhead covers and the highest activity in movements from these shaded areas. Activities of the brown trout were the lowest of the three species, but the use of shade was the highest. The brook trout was intermediate in both these aspects.

Boussu (1954) demonstrated that removal of under-cut banks and brush from a section of stream caused a decrease in the number and weight of resident trout with decreases being greatest for large fish. It is the general opinion that the bank protection and cover provided by vegetation is very important in establishing good sport fisheries (Barton and Winger, 1973a, 1973c, 1973d; Silcox, 1936; White and Brynildson, 1967).

FEEDING AREAS

The physical environmental parameters which are important in feeding areas are clear water and riffle areas, good quality water, abundant food supply, minimal flow manipulation, and minimum erosion and turbidity.

Riffles are areas of shallow water with rapid current (White and Brymildson, 1967). The substrate in a riffle area is composed of gravel-sized particles (Leopold, et al., 1964). Good riffles promote growth of food organisms and are common feeding areas of game trout (White and Brynildson, 1967).

Good quality water is also a very important requirement for trout (Alabaster, 1972; Novitzki, 1973; Silcox, 1936). Trout are the most sensitive of the game fishes and consequently are the first to respond to habitat deterioration (Novitzki, 1973).

Habitat degradation has resulted from industrial and domestic pollution (Irizarry, 1969), which imposes an oxygen demand on the receiving streams. This means that some of the dissolved oxygen in the water is used to oxidize the organic pollution material (Clark, et al., 1971) rather than to supply the oxygen needs of the fish. This oxygen demand reduces the dissolved oxygen levels in the river (Irizarry, 1969; Novitzki, 1973). Novitzki (1973) lists the lethal dissolved oxygen levels for trout as below 3 ppm. He goes on to say that normal activity of the fish can be affected at dissolved oxygen levels of 5 to 7 ppm. Any concentration above 7 ppm would be considered optimum for fish, and no adverse effect to the fish would occur at such levels.

In addition abundant food supply is necessary for a good fish population (Silcox, 1936). Sanders and Smith (1962) showed that population responded to an increase in food supply. It is self-evident that if food organisms are not available, fish cannot survive. As trout grow to maturity their food requirements vary. Barton and Winger (1973a) observed that the primary food organisms for trout on the Weber River were may flies, stoneflies, caddis flies, and flies (Figure 3).

Low flows caused by natural droughts or flow manipulation can be very harmful to the aquatic ecosystem. The low flows which occur due to natural droughts are a result of the lack of rainfall. The flow manipulations such as water storage and diversion can also cause low flows to exist during part of the year. As more and more water storage projects have been undertaken, the problem of flow manipulation has increased (Irizarry, 1969). The general practice of storing water and releasing it when needed is a practical endeavor but can be very harmful to the natural stream environment, especially when some released flows are insufficient to propagate and maintain the aquatic life (Minshall and Winger, 1968; Winger and Winget, 1974). Several methods of determining minimum flows necessary to develop stable ecological systems have been suggested. Tennant (1972) and Elser (1972), both working in Montana, determined the minimum flow necessary to maintain the fisheries on the basis of a percentage of the mean annual flow of record. They concluded that any value over 30% would be adequate. Tennant also indicated that 10% of the mean annual flow is barely enough for short-term sustenance. Wesch and Rechard (1973), working in Wyoming, felt that 25% of the mean annual flow would suffice. Other methods have also been suggested comparing habitat conditions as well as flow values (Chrostowski, 1972; Thompson and Fortune, 1968). It has also been suggested that ground water augmentation of low flows by pumping could be used to maintain adequate habitat conditions. Care must be taken though to assure that the water chemistry of the ground water matches that of the natural flow or the natural aquatic balance will be upset (Novitzki, 1973).

Another form of pollution which can smother and lower the productivity in streams is silt from the watershed erosion, channelization and irrigation of agricultural lands (Barton and Winger, 1973a, 1973d; Irizarry, 1969;

White and Brynildson, 1967). Trout prefer gravel rather than silts and sands (White and Brynildson, 1967). Therefore pools with silt bottoms become somewhat ineffective in providing good habitat.

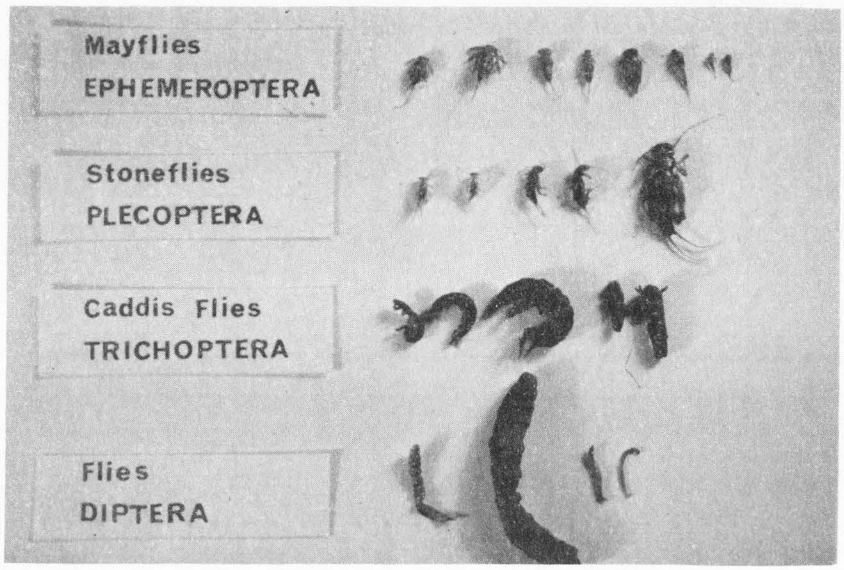


Figure 3

Fish Food Organisms

BREEDING AREAS

The physical environmental parameters which are necessary in breeding areas are clear water, riffle areas, a good riffle-pool relationship and freedom from sedimentation.

Riffles serve as spawning grounds, nurseries and food-producing areas (White and Brynildson, 1967). Trout usually use smaller tributary streams for spawning (Silcox, 1936).

The different trout species use different areas for spawning. Brook trout spawn in quiet waters along the side of the main current, in coarse sand as well as gravel. Brown trout usually spawn at the crests of riffles. Rainbow trout seem to select deeper water than the other two species (White and Brynildson, 1967). Brook and brown trout spawn in the fall and usually require spring-fed streams which are warm enough in winter to remain free from heavy accumulations of ice. Rainbow and cut-throat trout spawn in the spring (Silxoc, 1936).

The natural riffle-pool relationship has been studied by many authors. Elser (1968) indicated that successive riffles in unaltered areas of Little Prickly Pear Creek, Montana, were spaced at intervals of 5.7 stream widths. Other observers have noted that riffles normally occur at a repeating distance of 5 to 7 stream widths in natural channels (Leopold, et al, 1964; Stuart, 1960). Leopold, et al., (1964) also noted that the average length of pools may be somewhat longer than of riffles in the same stream. The pools will normally be 1.5 times the length of the riffles. He also observed that the bed material tends to be somewhat larger in the riffles than in the pools. During low flows, the riffles have relatively steep sloping water surfaces and the pools nearly flat sloping water surfaces and the pools nearly flat sloping water surfaces (Peters, 1971). (See Figure 2, page 7)

Sedimentation, caused by channelization, spring runoffs, irrigation, etc. can cover over the spawning gravels and smother the developing eggs (Peters, 1971).

Chapter 3

REHABILITATION CONCEPTS

Although it is impossible to restore an altered stream section back to its original state, measures can be taken to alleviate the detrimental effects of channelization. Studies have shown that the proper use of rehabilitation structures such as deflectors, check dams and random rocks has recovered the fish population (Baker, 1970; Barton and Winger, 1973a, 1973b; Clark, 1945; Davis, 1941; Gard, 1961; Hale, 1969; Mueller, 1954; Robinson and Menendez, 1964; Saunders and Smith, 1962; Shetter, et al, 1946; Tarzwell, 1932, 1937, 1938; Warner and Porter, 1960). Barton and Winger (1973a, 1973b) found that due to the rehabilitation measures taken on the Weber River, Utah, the fish populations in the changed structured areas were similar to those in the unchanged areas and that the riffles and pools created by the structures were similar to those in the unchanged areas. Elser (1968) also found that rock deflectors in an altered section of Wolf Creek Canyon, Montana, rendered the physical characteristics of the stream nearly comparable to the unaltered sections.

Studies have shown that channelization should be avoided if at all possible (Barton and Winger, 1973b) but that if alterations are found necessary proper rehabilitation measures can and should be taken to restore the aquatic ecosystem as much as possible (Barton and Winger, 1973c; Silcox, 1936).

The primary objective of any stream improvement should be to guide, develop and maintain the conditions necessary for growth and reproduction of the fisheries; therefore a preliminary habitat survey should be carried out to determine the minimum conditions essential for good fish populations (White and Brynildson, 1967). The survey should investigate such things as cover, holes, riffles, substrate type and flow conditions. After this has been done and the existing conditions have been determined, a stream improvement plan can then be developed which will provide the necessary additional conditions (Barton and Winger, 1973c).

There have been many different stream improvement methods used, each of which provides different habitat characteristics (Barton and Winger, 1973c; Robinson and Menendez, 1964; Silcox, 1963; White and Brynildson, 1967). The main stream improvement methods which have been used are:

1. Deflectors.
2. Check dams
3. Rock structures
4. Artificial spawning areas.
5. Artificial holes

6. In-stream concrete structures
7. Cover structures
8. Restoration of stream bank
9. Artificial meanders.

Rehabilitation structures have been successfully constructed of several different types of material, such as logs, rocks, gabions, concrete, or combinations of these materials. Gabions are heavy-gauge wire baskets which are filled with rocks from 3 inches to 8 inches in diameter. The other materials need no explanation.

Coupling a review of the literature (Barton and Winger, 1973c; Elser, 1968b; Hale, 1969; Robinson and Menendez, 1964; White and Brynildson, 1967) with current research of existing habitat structures being carried out in the Civil Engineering Department at Brigham Young University, the general habitat characteristic of each of the improvement methods can be outlined.

DEFLECTORS

Deflectors (Figures 4, 5, 6, and 7) can improve the habitat conditions by increasing the depths of holes, providing more riffle spawning and feeding areas, providing a variation in velocity, and increasing the food supply. Most observers agree that deflectors are one of the most effective structures in creating fish habitat (Barton and Winger, 1973d; Elser, 1963; Silcox 1936; White and Brynildson, 1967).

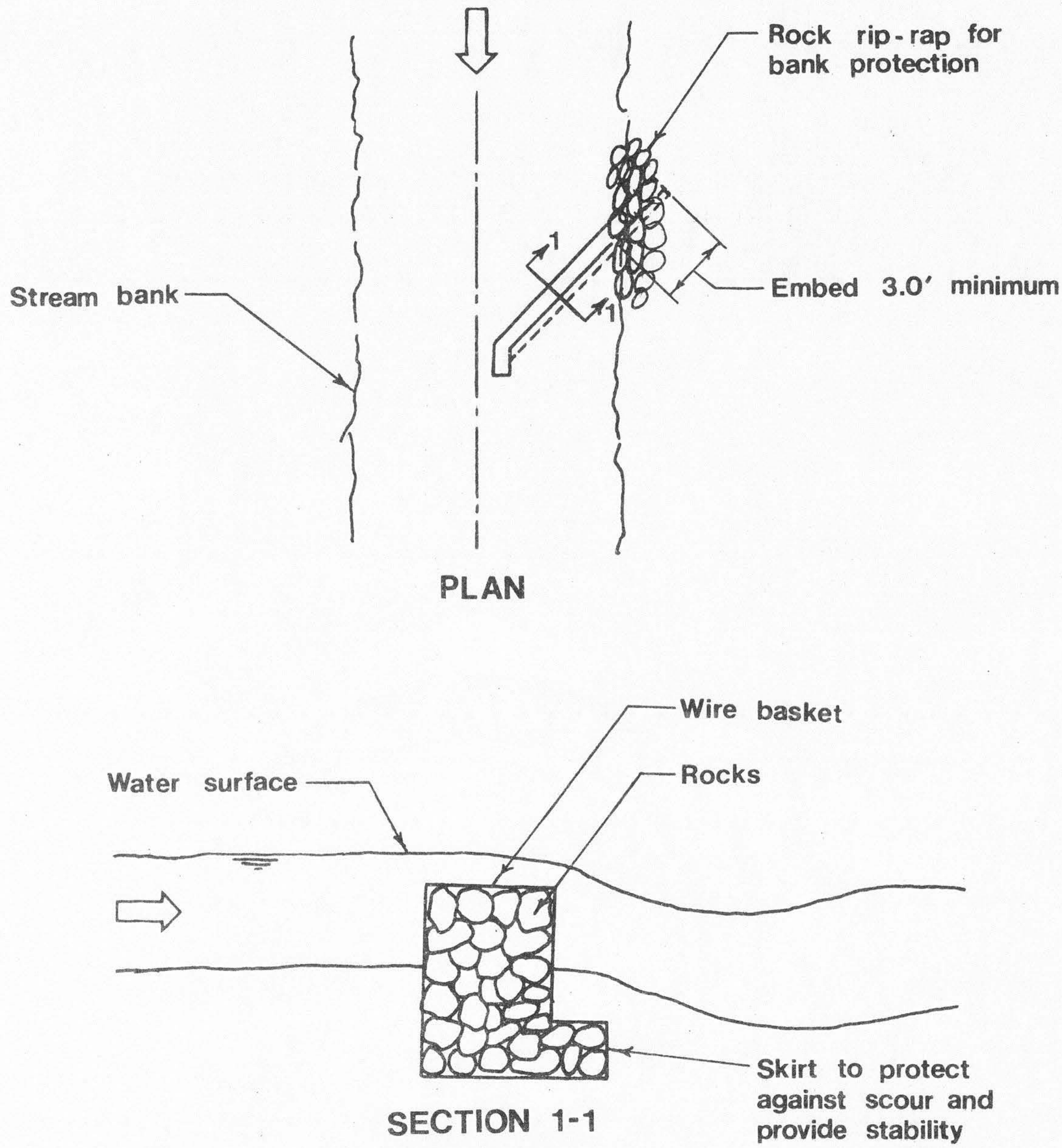


Figure 4

Gabion Deflector

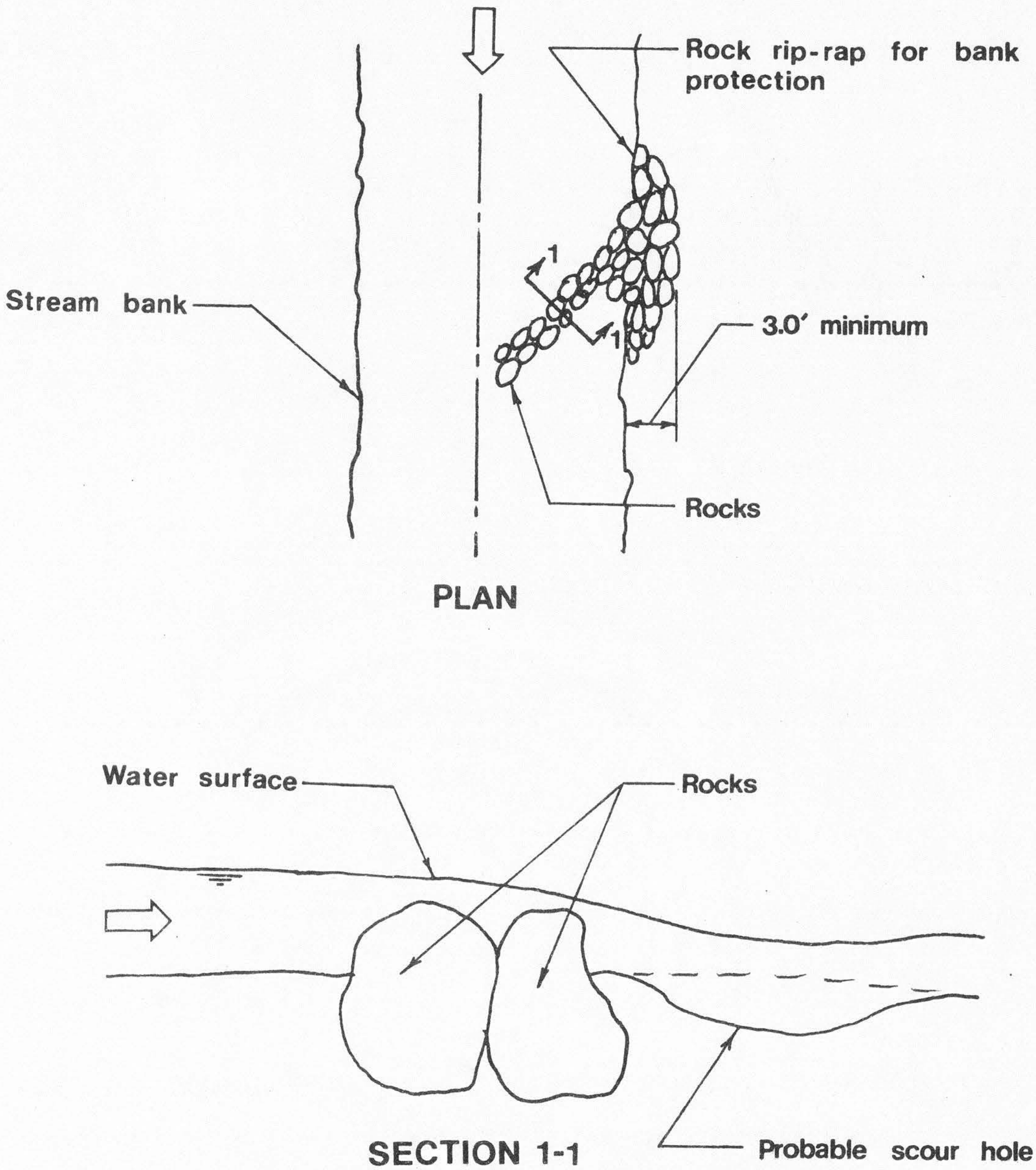
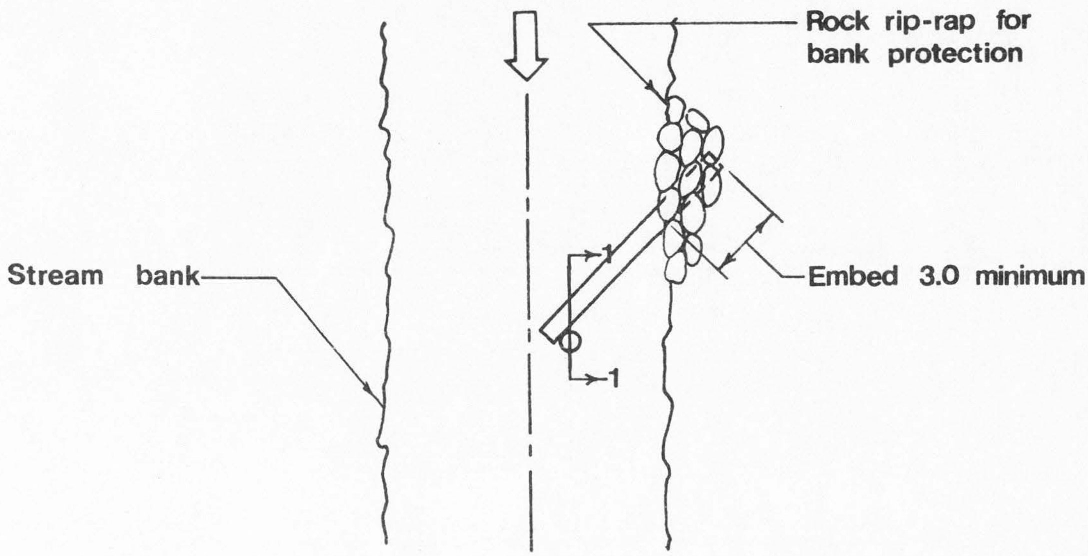


Figure 5

Rock Deflector



PLAN

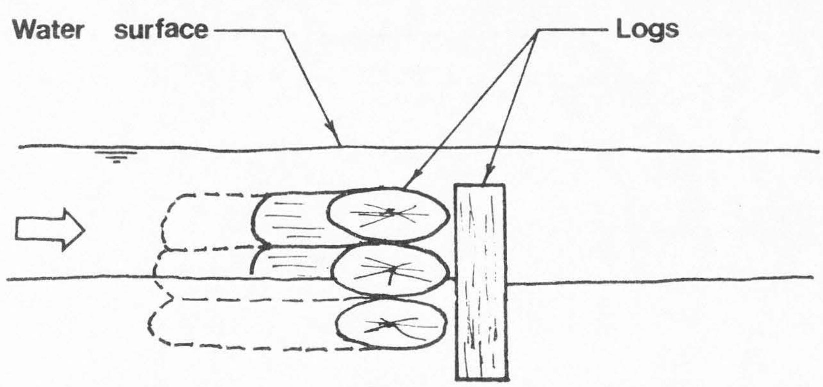


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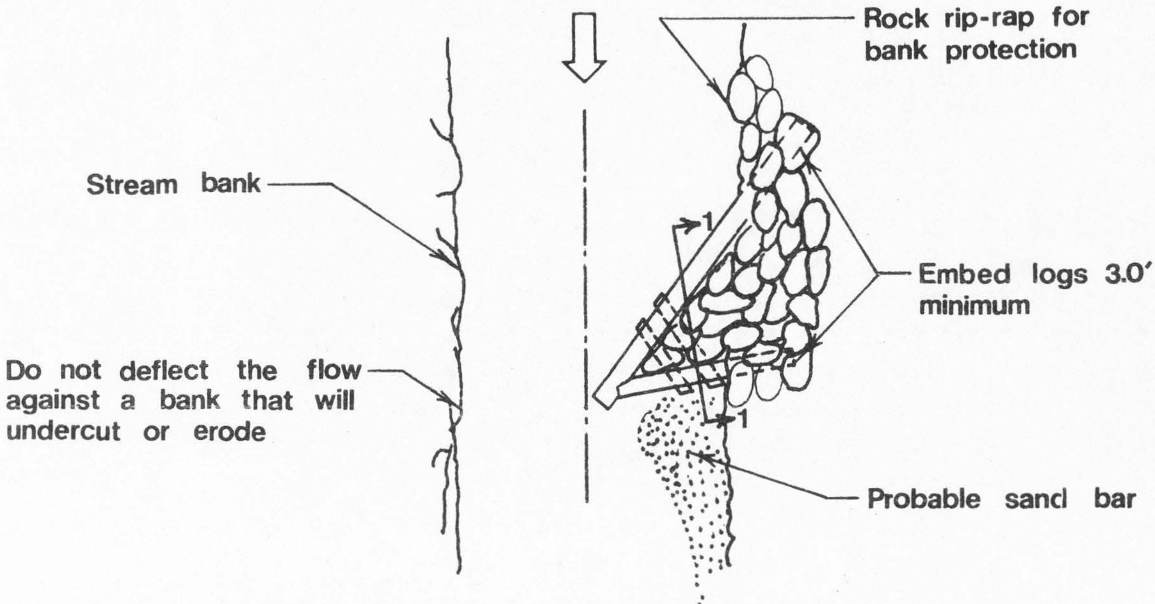
Figure 6

Log Deflector



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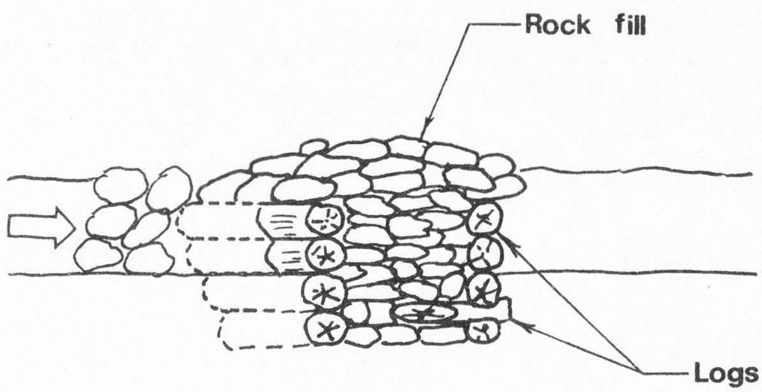


SECTION 1-1

Figure 7

Log Crib Filled with Rock

Tarzwell (1938) observed an increase in the area of gravel which was uncovered by the deflectors. Hale (1969) also noted that deflectors were effective in increasing the area of gravel in streams, thereby providing more spawning areas. Silcox (1936) stated that these gravel deposits form good sites for the growth of fish food organisms.

Barton and Winger (1973a, 1973b, 1973c, 1973d) observed that large holes were scoured at the tips of deflectors. They also noted that a riffle pool sequence similar to the natural environment could be created by using deflectors alternating from one side of the stream to the other. Elser (1968) also noticed this in his studies in Montana.

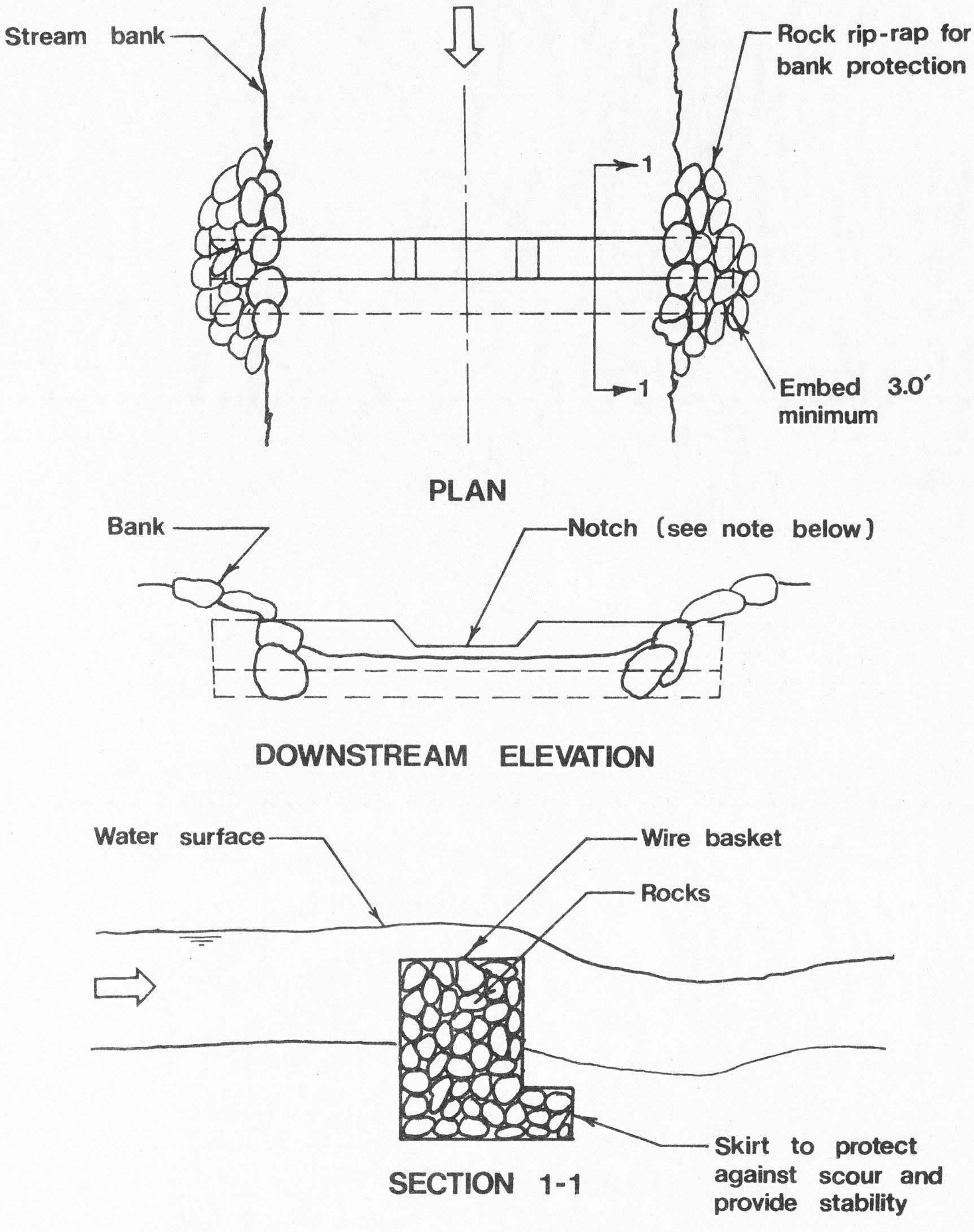
Barton and Winger (1973a, 1973c) found that the spacing, placement, and height of the deflectors were important factors in their performance. They observed that deflectors on the Weber River which were placed in the back water of other deflectors or check dams would silt in and become ineffective. Unpublished model studies of this problem performed by this author and others have indicated that sucessive pairs of deflectors (meaning one deflector in each bank, somewhat offset) should be spaced at least 2.5 stream widths apart if they extend to the middle of the stream. This would insure that no backwater silting would occur to any of the deflectors during high flows. Studies have not been completed to determine how close shorter deflectors, deflectors which do not extend to the middle of the channel, should be spaced.

CHECK DAMS

Check dams (Figures 8, 9, 10, 11, 12, 13, and 14) can improve the habitat conditions by scouring holes, reducing the gradients and reducing the velocities, thereby increasing the available living space and creating additional cover. Researchers have found that artificial low-head dams are beneficial to trout fisheries (Hale, 1969; Gard, 1961; White and Brynildson, 1967).

Observation by this author of low-log check dams on the Temple Fork of the Logan River and log ramps on the Diamond Fork River, both in Utah, have indicated that very excellent habitat can be established by check dams. These dams were low enough so as not to impede upstream migration and still provide substantial scour below them. No silting over of the gravels upstream was observed. Barton and Winger (1973a, 1973c) also observed on the Weber River in Utah that good habitat could be established by check dams. They did conclude, though, that rock check dams provided better habitat than gabion check dams because they had less of a tendency to block upstream migration of fish.

Check dams can be used very effectively to reduce the gradient on steep channelized sections (Barton and Winger, 1973a, 1973c, 1973d; White and Brynildson, 1967). They can be used effectively to create a good riffle-pool sequence (White and Brynildson, 1967). Stuart (1960) has



Note: A section near the center of check dams should be lower to permit fish migration during periods of low flow.

Figure 8

Gabion Check Dam

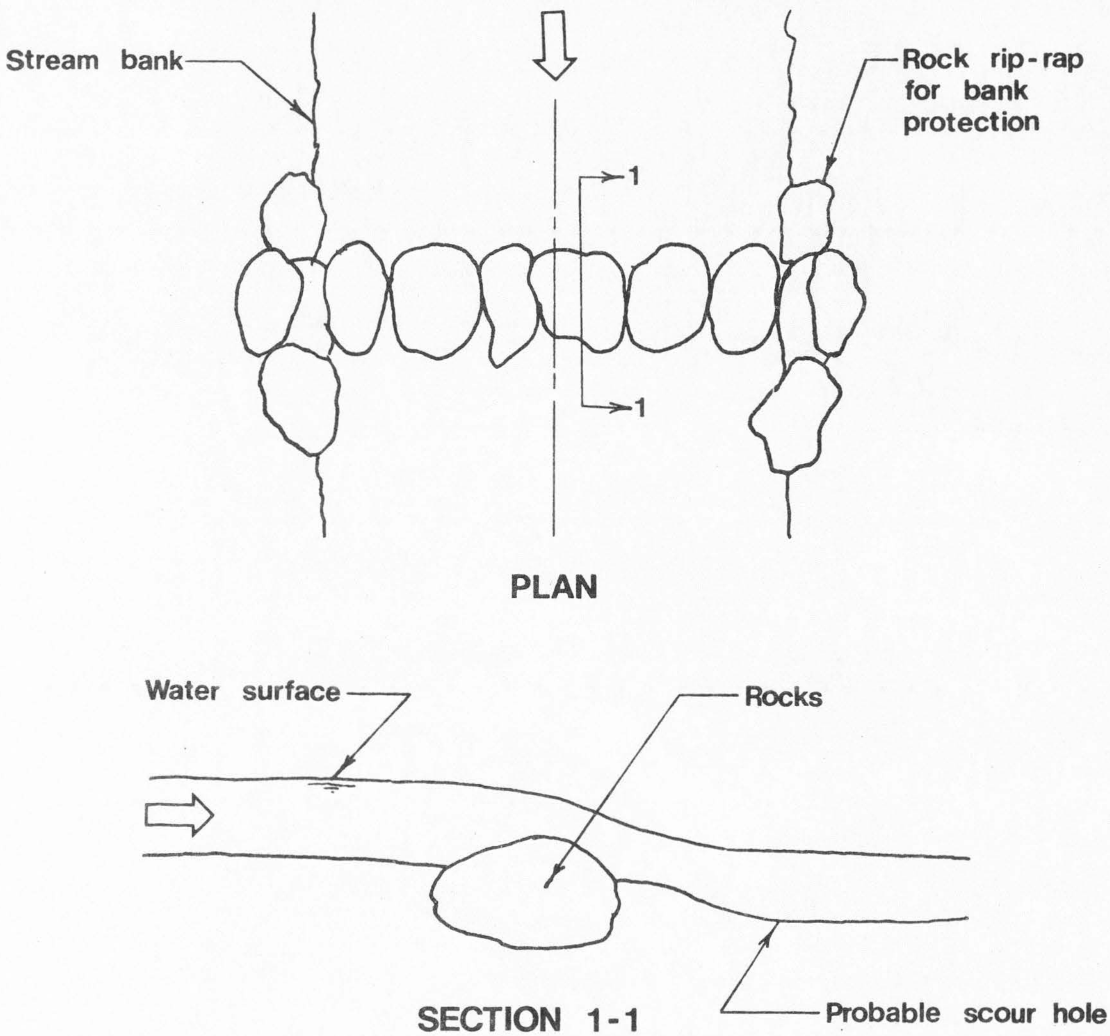


Figure 9

Rock Check Dam

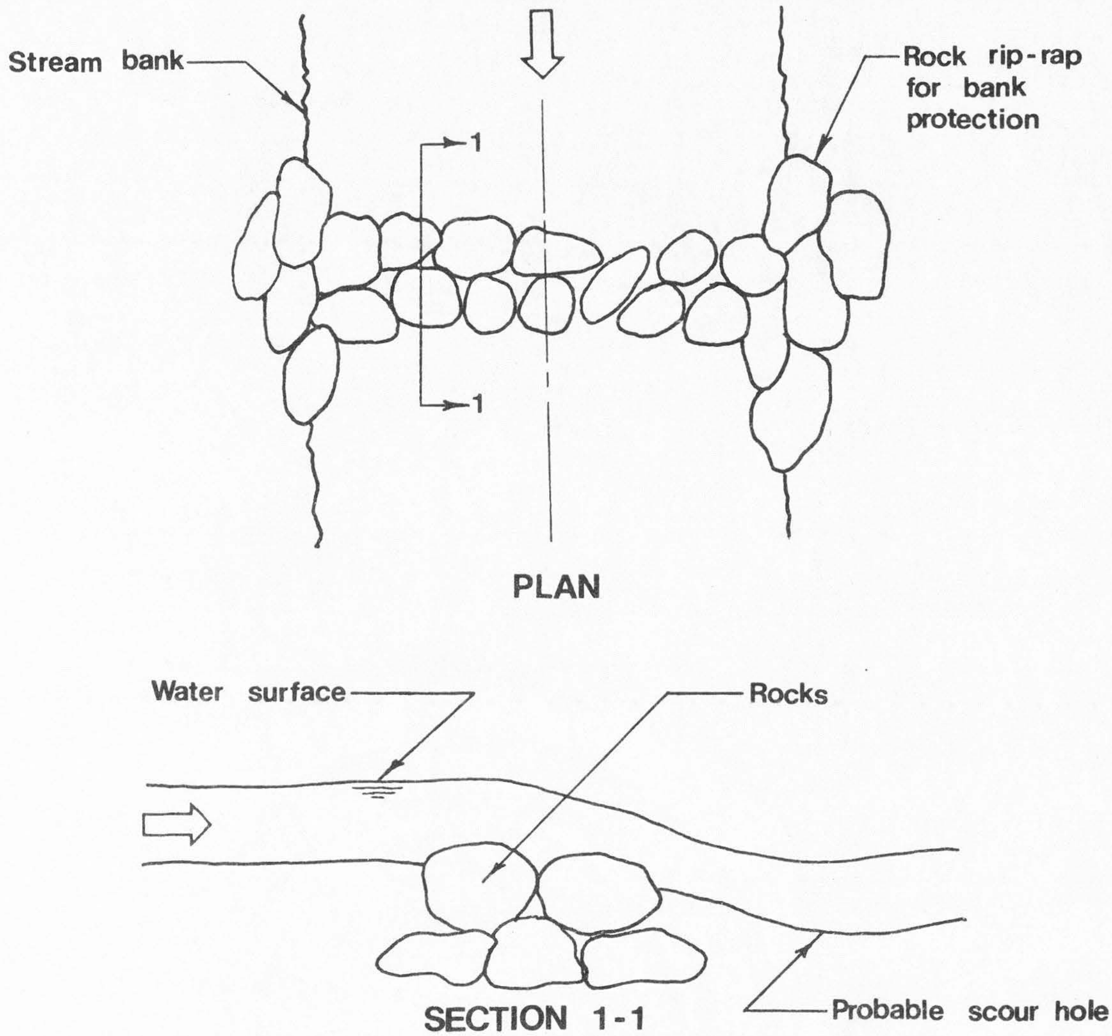


Figure 10

Rock Check Dam

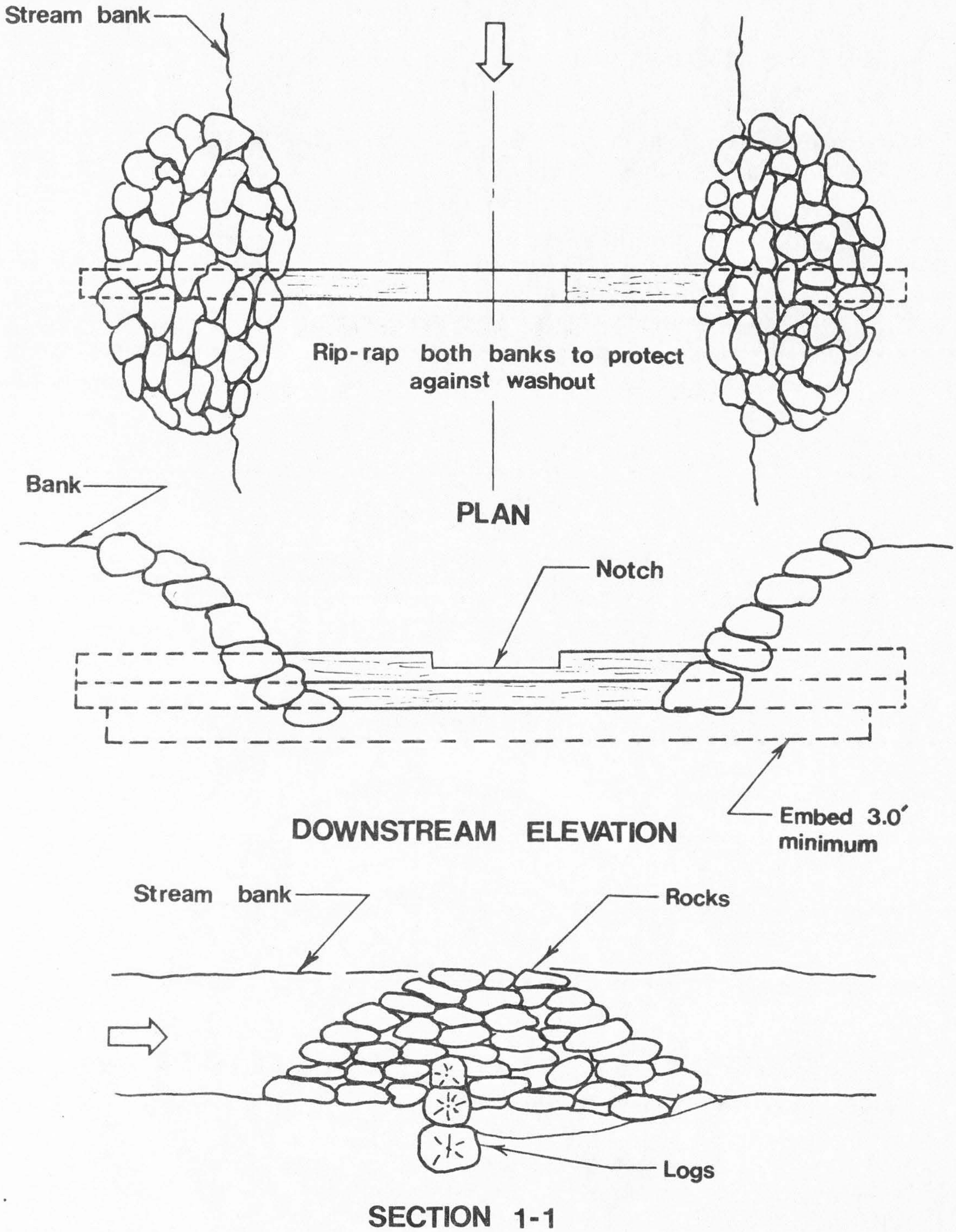


Figure 11

Log Check Dam

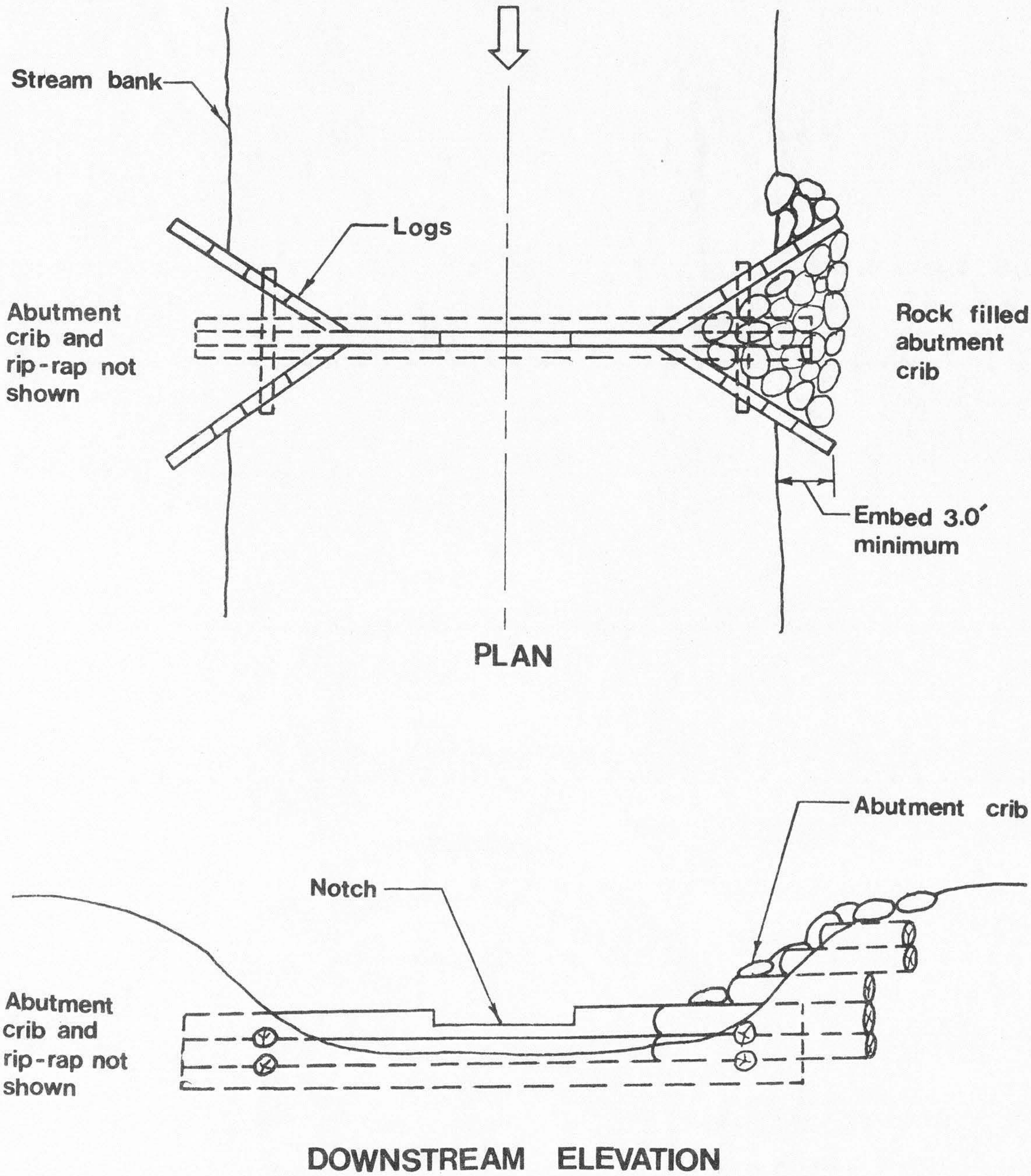


Figure 12

K-Dam

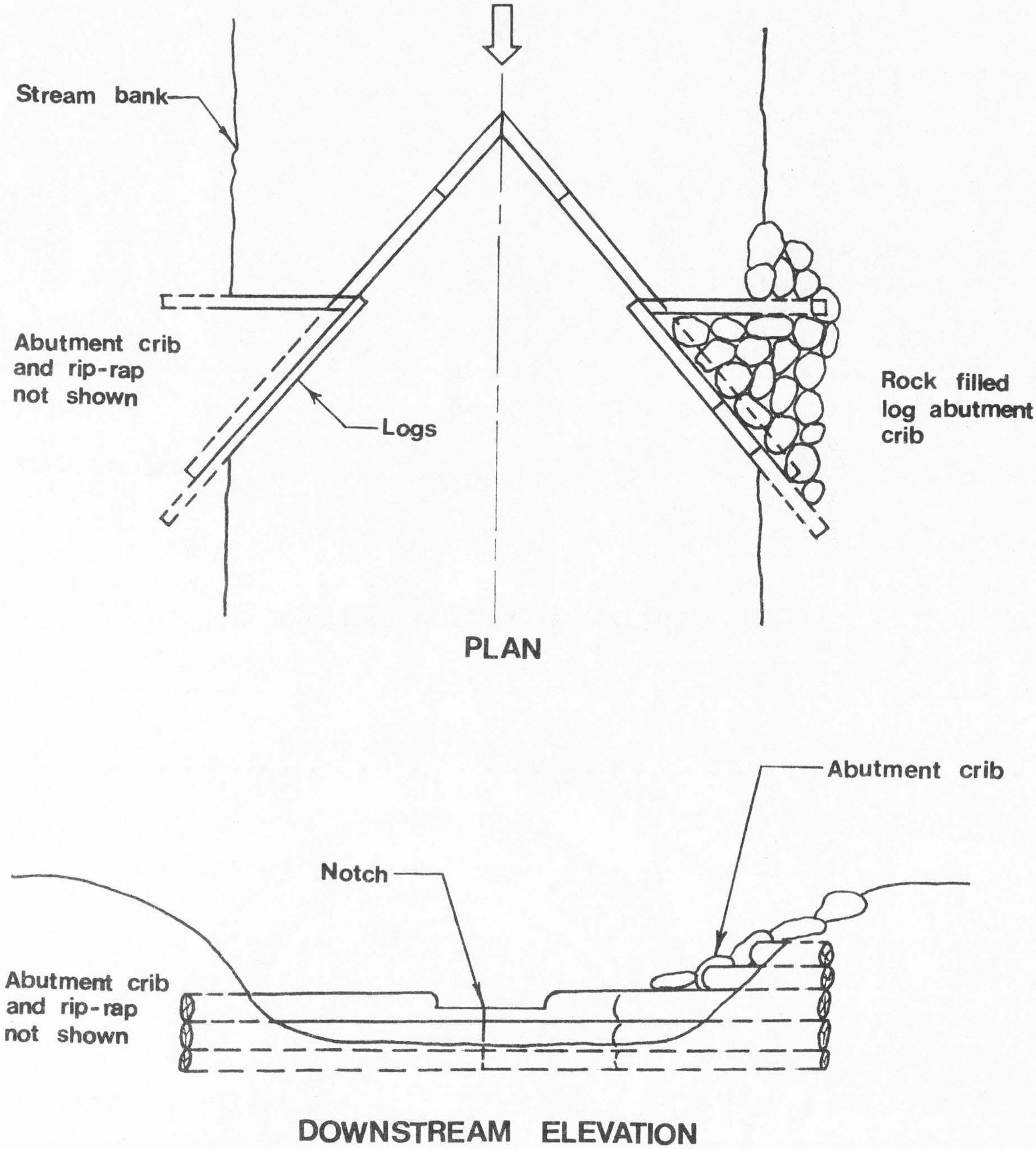


Figure 13

Log V-Dam

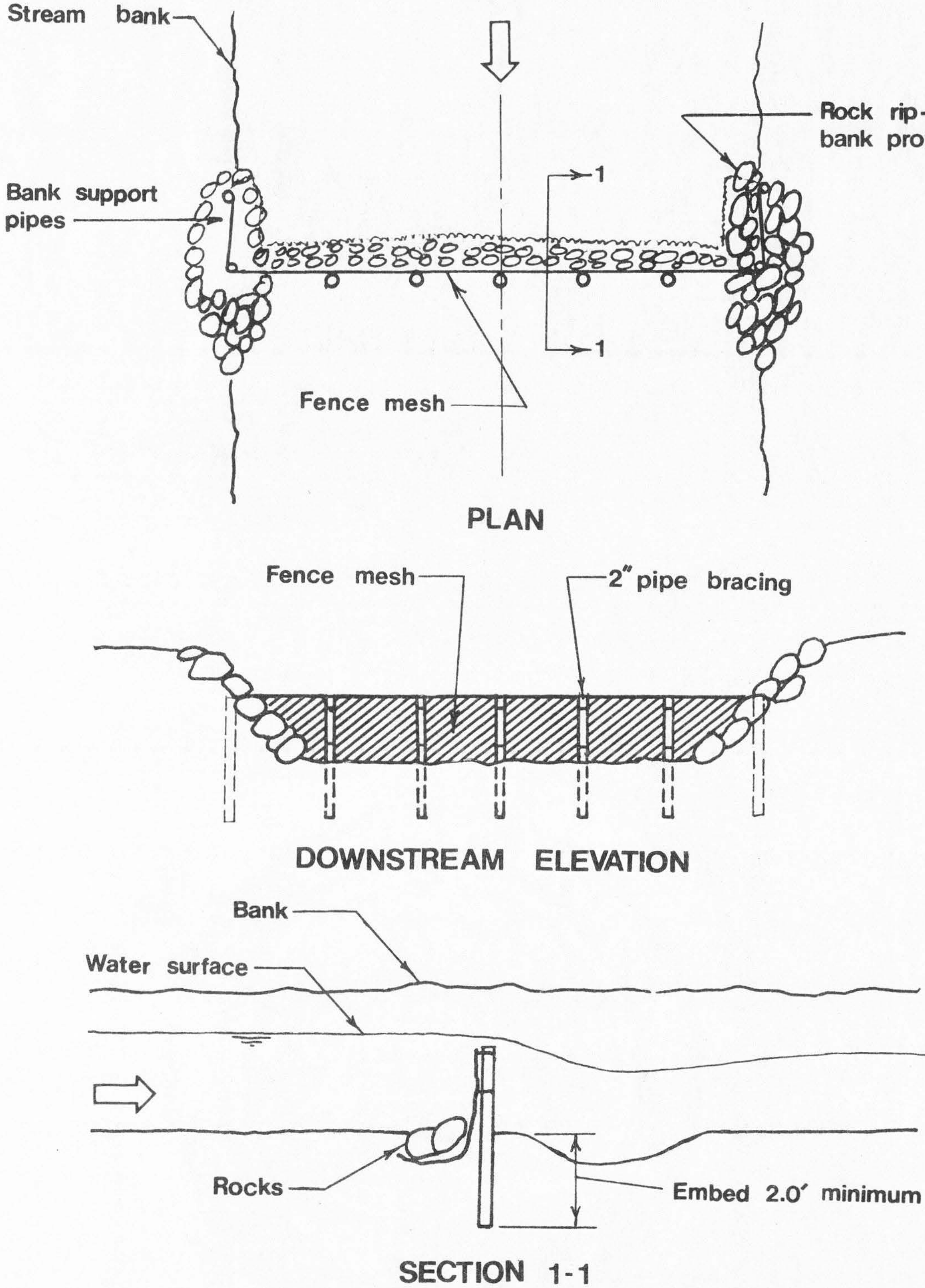


Figure 14

Trash Catcher Dam

indicated that the natural riffle-pool sequences repeat at intervals of 5 to 7 channel widths. Therefore, in order to avoid creating deep, quiet water that often serves mainly as habitat for suckers and other trash fish, successive check dams should not be constructed closer than 5 channel widths to one another.

As a general rule, according to Stuart's (1959) observation, free-falling water flowing over a check dam will erode 1.25 times the height of the waterfall. Other model studies (Barton and Winger, 1973b) have indicated that the amount of scour below a check dam varies greatly and is primarily dependent upon the size of the substrate material.

Check dams can, however, be detrimental to fish as well as helpful. In order not to impede fish migration, Barton and Winger (1973d) suggest that the height of check dams should be limited to 3 feet. Although check dams usually provide excellent habitat, they can, if not properly designed, also create some poor habitat conditions by impeding upstream migration if the dam is too high, or by causing the silting over of the coarser upstream substrate, which may kill food organisms and inhibit reproduction (Silcox, 1936; Winger, 1973).

ROCK STRUCTURES

Rock structures (Figure 15) in the form of random rocks, check-dams, deflectors and instream arrangements have

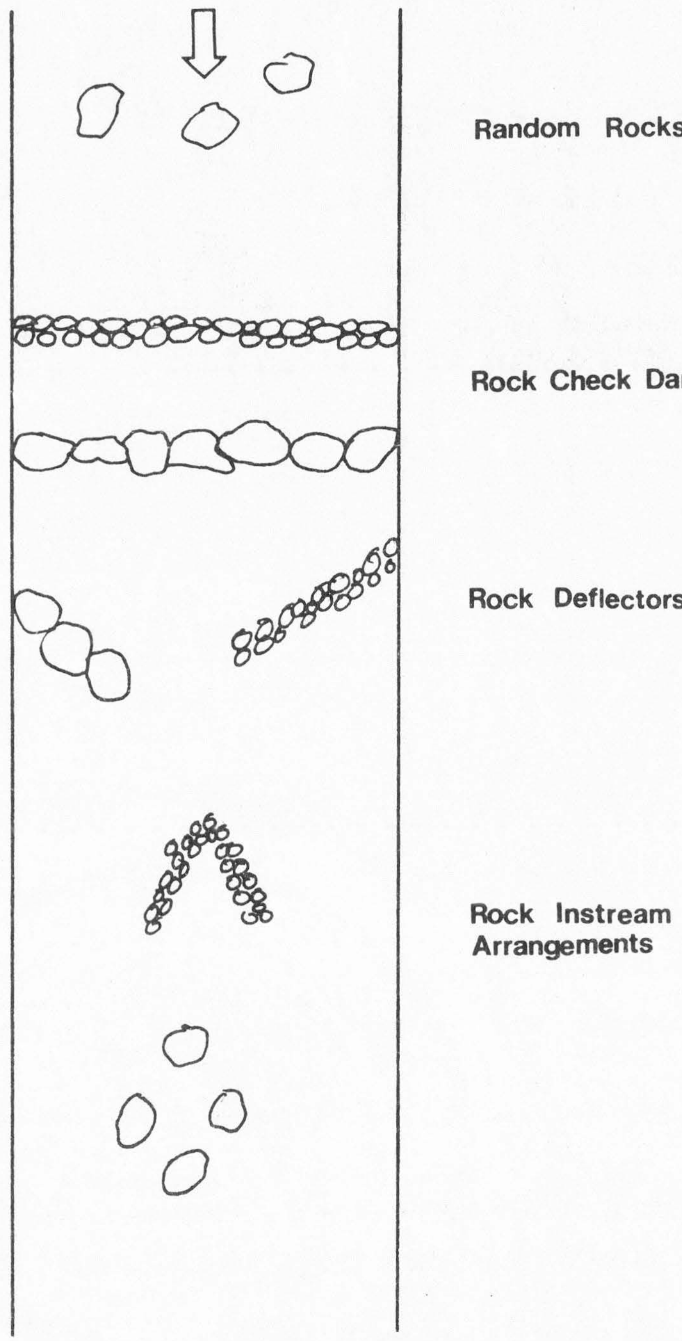


Figure 15

Summary of Rock Structures

proven to be very effective in providing good habitat (Barton and Winger, 1973a, 1973c, 1973d; Elser, 1968; Silcox, 1936). They usually provide good holes, variations in velocity, and some overhead cover (Barton and Winger, 1973b).

Observations on the Weber River indicated that single rocks or groups of rocks created good holes around them which provided the desired habitat (Barton and Winger, 1973a). Rocks have also been successfully used to stabilize erodable banks (Barton and Winger, 1973a; White and Brynildson, 1967).

ARTIFICIAL SPAWNING AREAS

Artificial spawning areas or riffles (Figure 16) can increase the fish population potential of a river by increasing the areas available for spawning and food producing (Barton and Winger, 1973d; Stuart, 1953).

Studies of natural riffles have shown that the gravel particles continually move down stream from riffle to riffle and that the natural riffles are able to maintain themselves by the supply of gravel from upstream riffles (Leopold, et al., 1964). Therefore, although it is desirable to establish riffle areas by artificial means, it is difficult to maintain them if a constant upstream gravel source is not available. Another disadvantage is that these areas are not stable and they tend to migrate downstream (Winger, 1973).

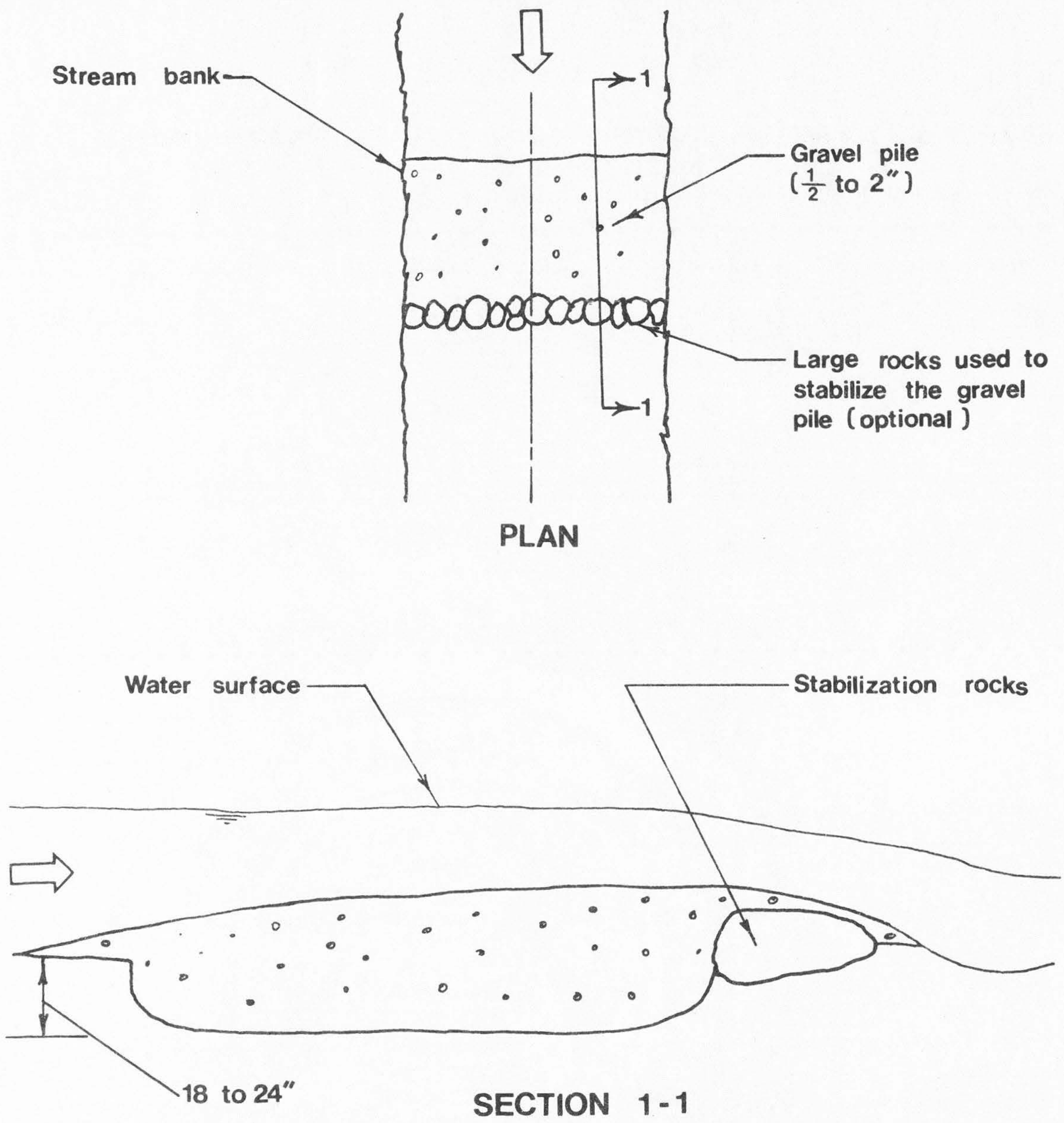


Figure 16 ·

Gravel Pile

White and Brynildson (1967) found that their attempts to build spawning beds in Dell Creek, Wisconsin, were unsuccessful due to siltation. Despite these problems artificial spawning beds for salmon on the Pacific Coast have been successful, but they show little resemblance to a natural stream (White and Brynildson, 1967). Considering these points, it may prove to be more desireous to take measures to preserve the natural riffles (White and Brynildson, 1967).

ARTIFICIAL HOLES

Artificial holes (Figure 17) increase the available living space. They can be used to replace those holes lost due to construction (Barton and Winger, 1973d). They have problems similar to those of artificial riffles.

IN-STREAM CONCRETE STRUCTURES

These structures and research on these structures will be discussed in depth in Chapter 4; therefore they will not be mentioned here.

COVER STRUCTURES

Overhead cover has been stated as one of the most important fish requirements (Butler and Hawthorne, 1968). It can be provided by artificial bank covers, (Figure 18) natural undercut banks, or streamside bushes and other vegetation.

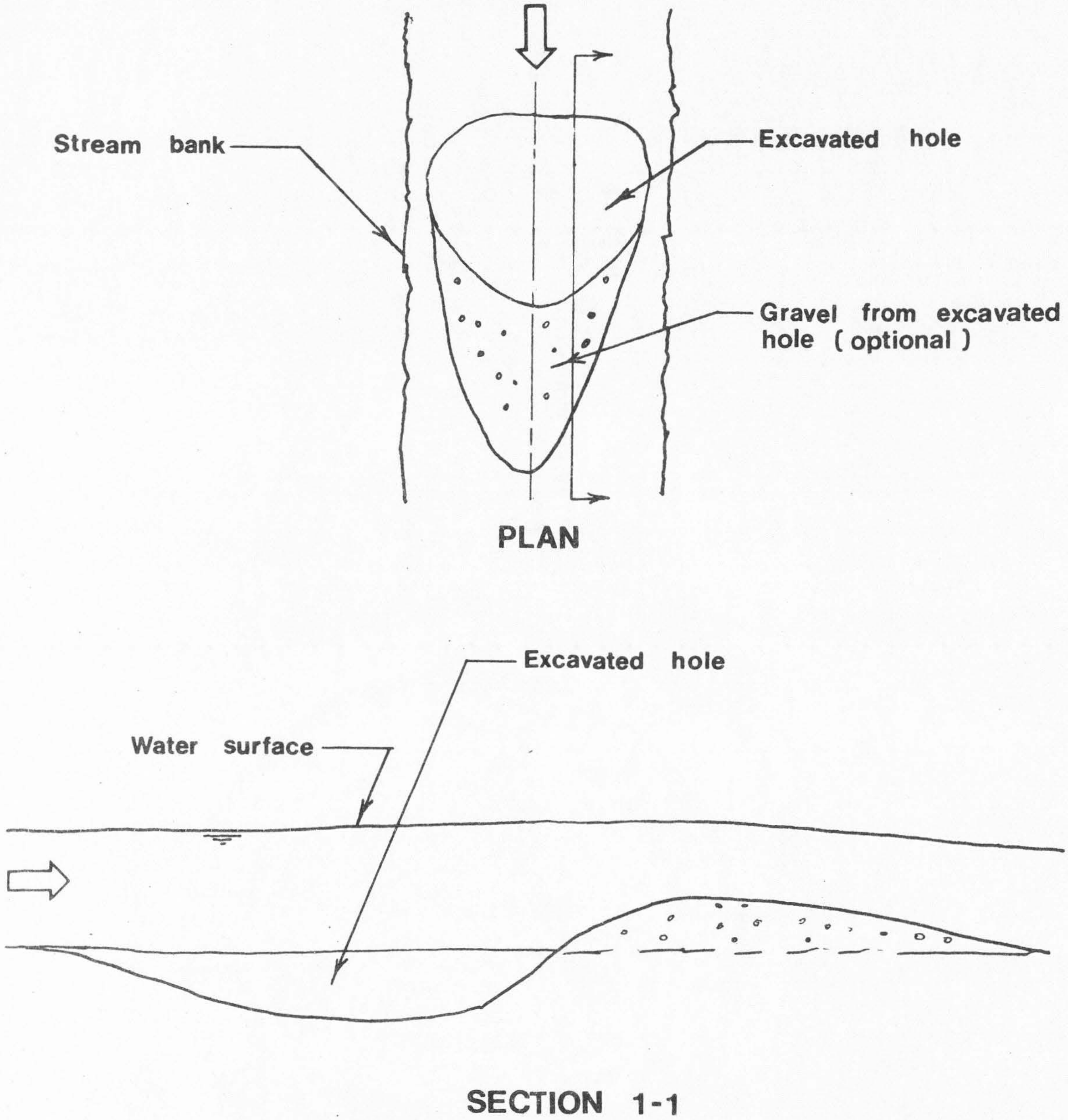


Figure 17

Excavated Hole

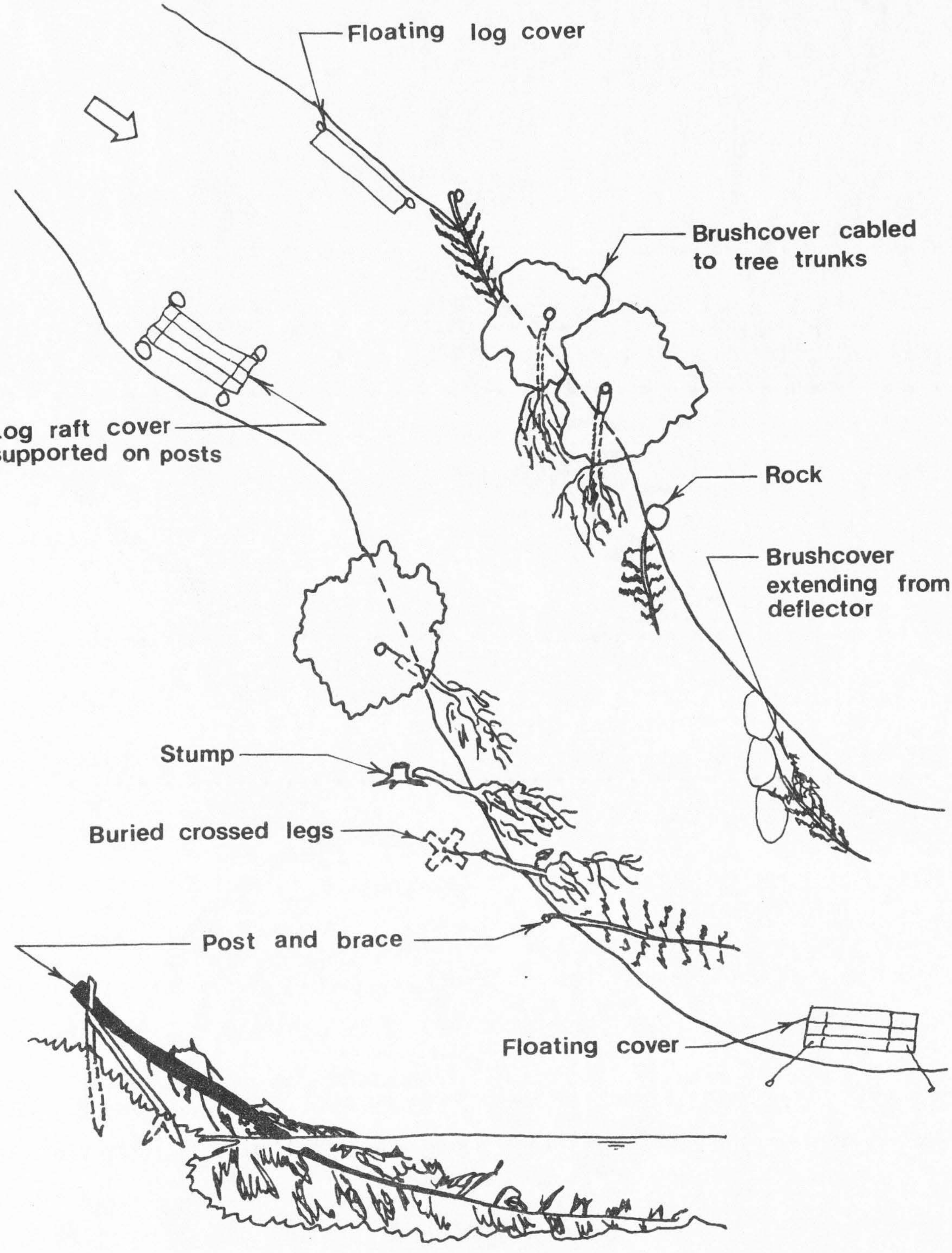


Figure 18

Brushcover

RESTORATION OF STREAM BANK

Restoration of the stream bank is usually accomplished by either rip-rapping the banks with large rock or reseeding the bank with resistent vegetation. The only habitat improvement is a decrease in erosion and subsequent deposition. Associated with this is a usual decrease in turbidity (Barton and Winger, 1973d).

ARTIFICIAL MEANDERS

Artificial meanders (Figure 19) can improve habitat conditions which were lost due to channelization, by replacing the length and living area (Barton and Winger, 1973d).

An inventory of thirteen Montana streams by Peters and Alvord (1964) revealed that the total river length of the streams was shortened by 68 miles when 137 miles of natural stream was rerouted into 69 miles of stream. This drastically reduced the available living space in these rivers. Other studies have also cited similar results. One of the great disadvantages of an artificial meander is generally the high cost required to build a stable meander.

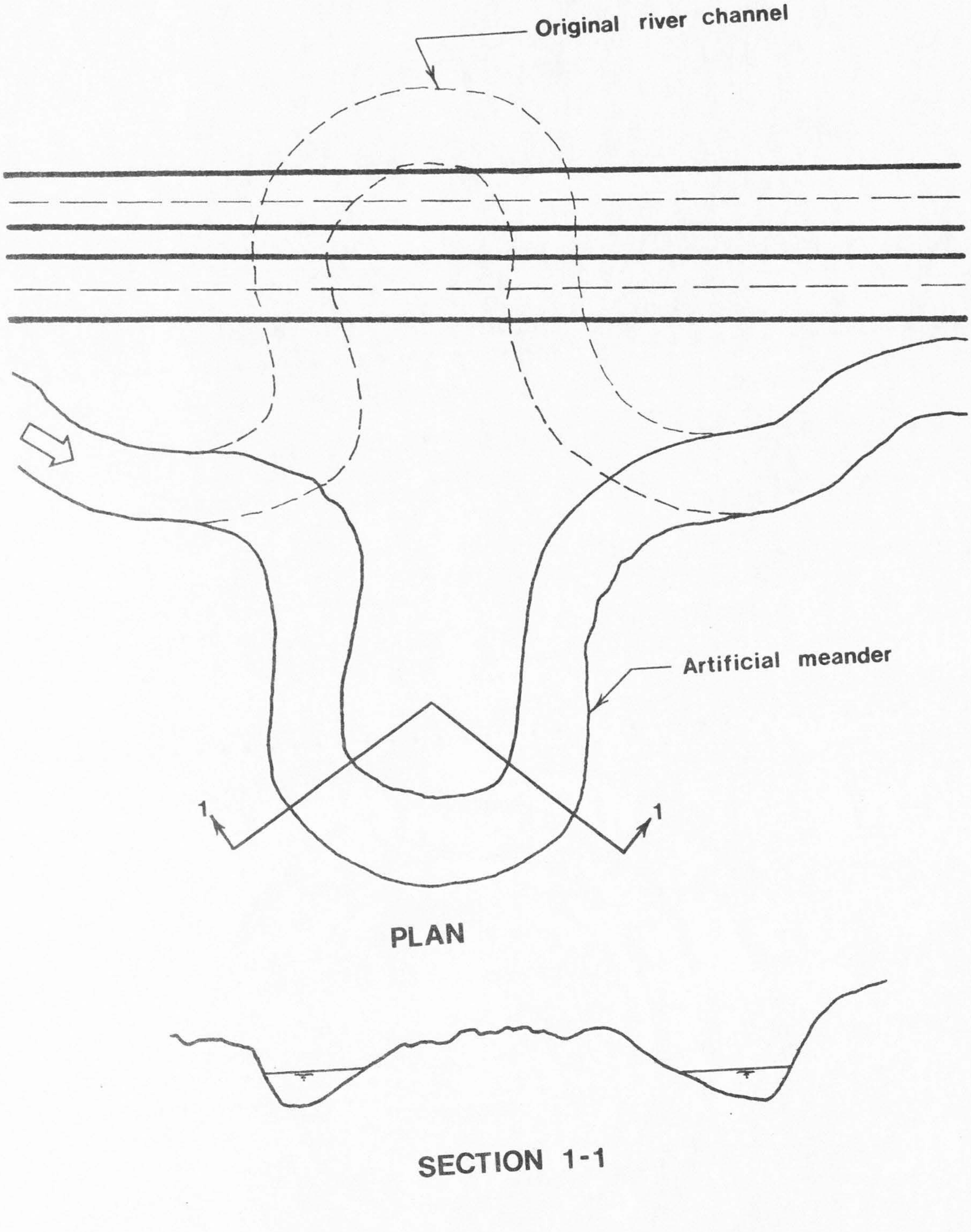


Figure 19

Artificial Meander

Chapter 4

IN-STREAM CONCRETE STRUCTURES

The research on in-stream concrete structures was carried out in two phases, first, as a model stream study followed by a river prototype study.

MODEL STUDIES

An extensive model stream study was carried out to develop in-stream structures that could be used in rehabilitating and improving habitat conditions in streams. The model study allowed for the examination of a large variety of structures in a short period of time with a minimum amount of effort and cost. It also enabled a more complete study of all the possible alterations to a particular type of structure.

There are, however, definite problems in trying to model all the conditions that exist in the natural environment (Albertson, et al., 1960; Bagnold, 1960; Barton and Winger, 1973b; Lane, 1957; Leopold, et al., 1964; Schuman, 1960). Two of the major forces in any hydraulic system are gravitational and frictional forces. In setting up a model either of these conditions can be duplicated but only by very special and often expensive alterations in the model set-up can both conditions be met. In a natural channel the gravitational forces are predominant; therefore the Froude Law is used to establish similitude between the model and the natural environment. This completely ignores the frictional forces, which may be of major importance in the model stream (Albertson, et al, 1960).

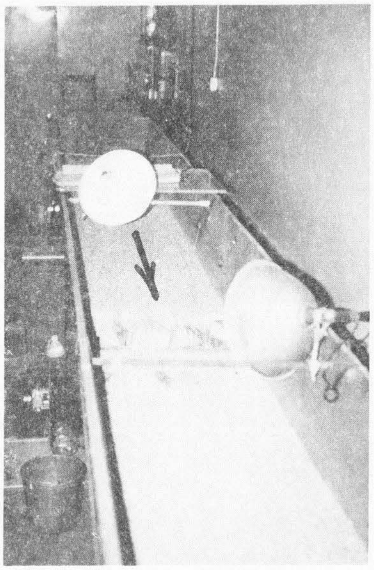
In these model studies exact similitude was not a major concern. Only general qualitative observations were needed to determine which habitat conditions were established and the relative comparison between one structure and another. Therefore strict control of all the hydraulic conditions was not considered necessary.

The model structures were evaluated on their effectiveness in creating good habitat conditions, such as holes, overhead cover, riffle areas, and areas of reduced velocity.

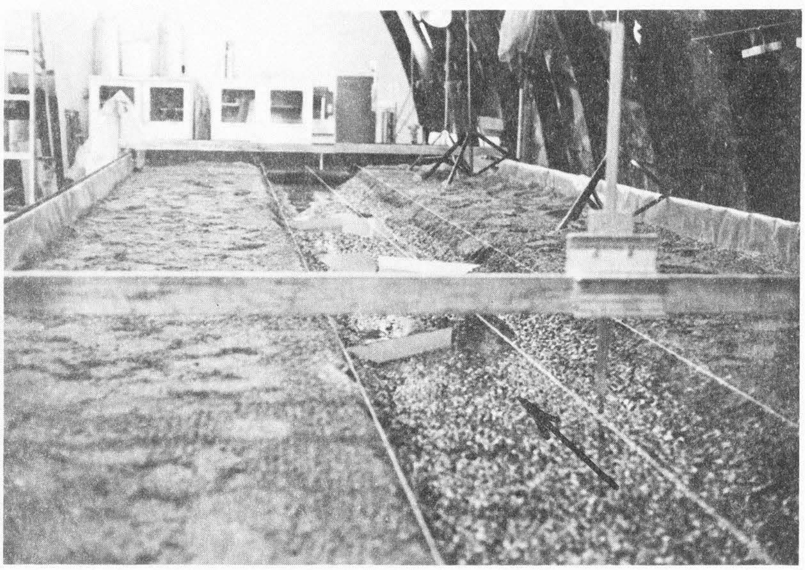
Test Apparatus and Procedure

Two model stream channels (Figure 20) were used in this study. The first model stream channel was a trapezoidal flume 19.6 feet long with plywood side slopes of about 1:5. The flume sides were 0.94 feet deep and 1.69 feet wide at the surface of the stream bed and 2.08 feet wide at the top. The flume and the stream bed had a slope of 0.007. The stream bed (Figure 21) was composed of coarse sand which was about 0.75 feet deep. This flume will be referred to as the small flume.

The second model stream channel was a large 8-foot-



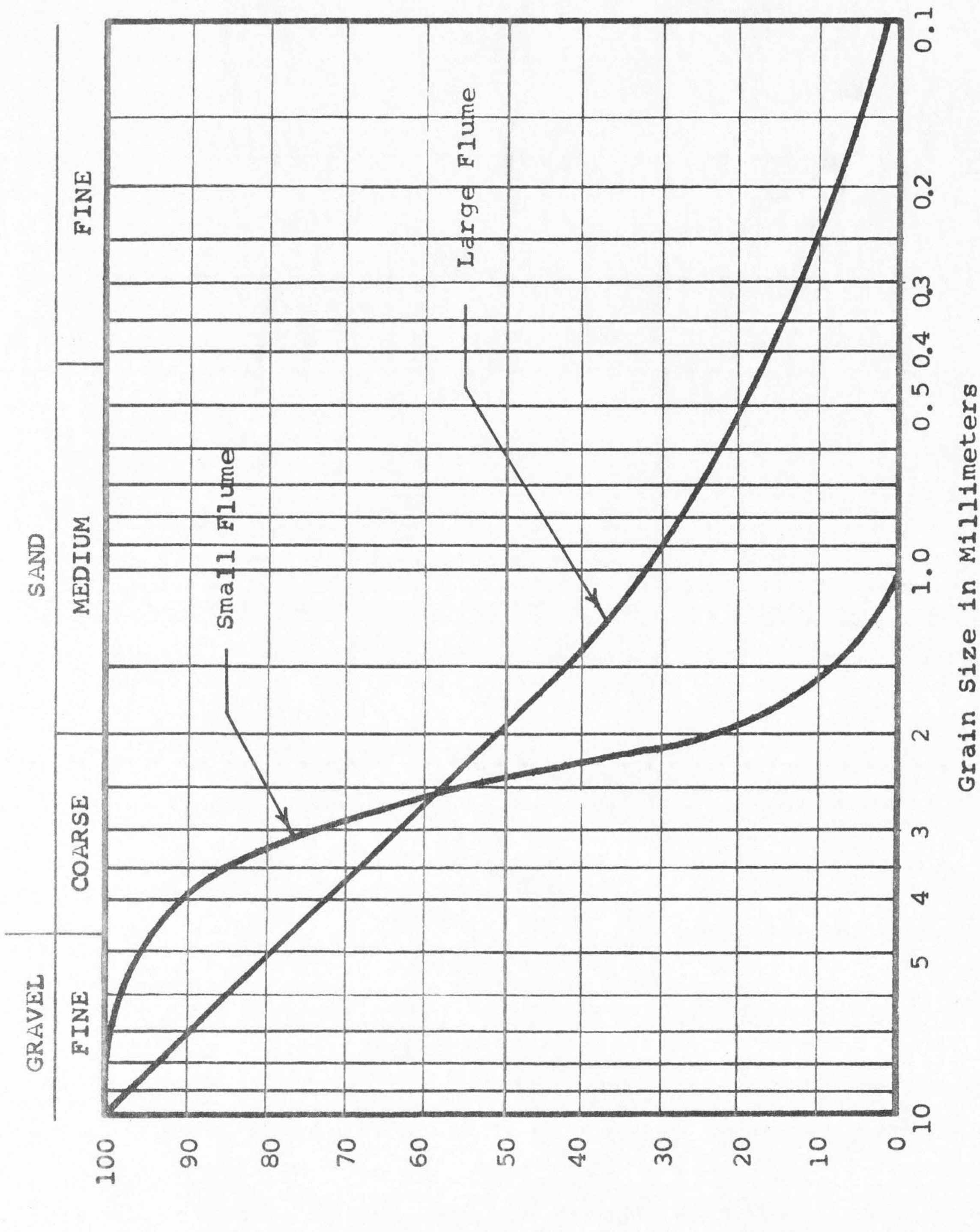
Small Flume



Large Flume

Figure 20

The Model Stream Flumes



Percent Finer by Weight

Figure 21

Grain Size Analysis of the
Model Stream Substrate

wide flume filled with a sand-gravel mixture (Figure 21) in which the channel formed by the flowing water could be allowed to meander. The flow channel was approximately 2.0 feet wide at the base and 0.33 feet deep with side slopes were formed out of the erodible materials in the flume. The flume and stream bed had a slope of 0.01. This flume will be referred to as the large flume.

A similar test procedure was followed for tests in both flumes. First the structure was installed and the substrate smoothed out to a constant slope. The pump was then started and the flow was varied through a sequence from high flow to low flow in an effort to simulate the annual flow conditions a structure may be subjected to. During the test, observations were made of the flow conditions. After the test, the habitat conditions created, such as holes and deposition, were measured and pictures taken.

The high flow and low flow for the small flume were 0.32 cfs and 0.09 cfs respectively. The corresponding water depths were 0.14 feet and 0.08 feet.

The high flow and low flow for the large flume were 0.78 cfs and 0.15 cfs respectively. The corresponding water depths were 0.32 feet and 0.15 feet.

Results

The initial model studies were performed on the small flume and later verified in the large flume. The small flume studies outlined the general habitat conditions provided by each structure; whereas the large flume determined the structure stability with larger flows and any tendency to erode the channel banks.

A total of sixty-seven model tests were conducted covering a wide range of types of structures. The types included were in-stream geometrical structures, rock structures, deflectors, and check dams. Four of the in-stream structures tested appeared to provide the desired conditions for good fish habitat. These were the inverted weir, the "V" structure, the slab with legs, and the cylinder (Barton and Winger, 1973b). An additional eight model tests were performed on these structures. These are the structures referred to in this report as in-stream habitat structures.

These in-stream structures can be defined as follows:

1. Inverted weir--This structure is a slab supported on four legs with a hanging weir placed on the under side at the midpoint of the slab and running perpendicular to the flow.

2. "V" structure--This structure consists of two slabs placed in a "V" shape with the open end facing downstream. A cover is then placed in the space between the two slabs either on the top or down at the substrate level. This cover may either be solid or have a notch in the downstream edge.

3. Slab with legs--This structure is a flat slab which is tilted up on an angle and supported by legs along the downstream edge. The upstream edge rests on the channel substrate.

4. Cylinder--This structure is a cylinder with a plug or partial plug in the upstream end.

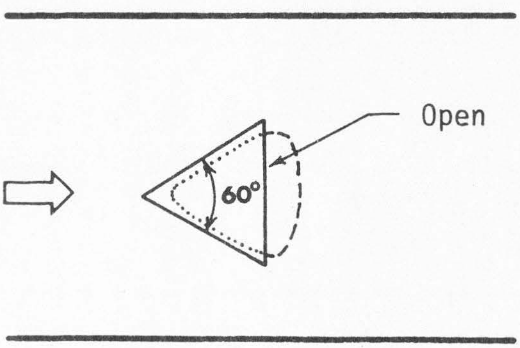
The information collected for each structure was described in a standard format. The experiment description contains a sketch of the structure with pertinent dimensions and a written description of the structure and the conditions provided. The sketches of the structures tested were drawn to scale (1 in = 12 in.). The word <u>structure</u> as used in the experiments indicates the object placed in the channel.

The top drawing within the heavy parallel lines is a plan view of the test performed. The drawings labeled <u>side view</u> or <u>front view</u> are not necessarily to scale. The following symbols were used in the experiment write-ups:

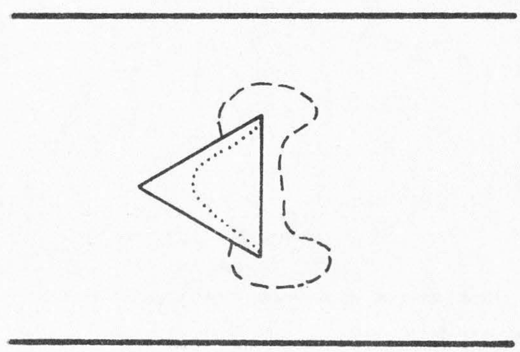
━━━━━━━━━━━━━━━━━━━━	Edge of flume
────────────────────	Outline of structures
──── ─ ──── ─ ──── ─ ────	Outline of hidden portion of structure
─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─	Outline of scour or excavated hole
....	Outline of hidden portion of hole
	Substrate
	Direction of flow during test

Experiment 19

Before the Test



After the Test

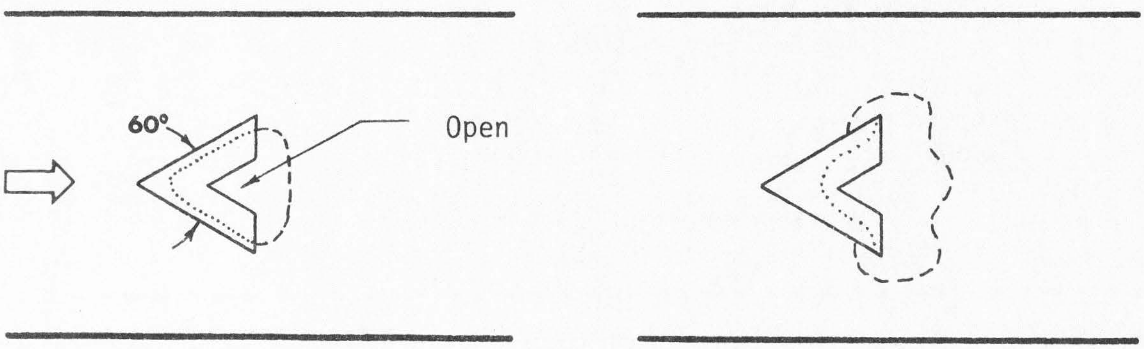


Structure Description:	This structure was an open ended 60° triangle with cover on top and hole excavated under it.
Hole(s):	A large hole was scoured at each corner besides the excavated hole under the structure.
Cover:	Overhead cover was provided by the cover plate.
Sedimentation:	The excavated hole had a tendency to fill in at the corners when the water was turned on and the initial side scour occurred. Deposition occurred downstream from the hole and in the center of the channel.
Velocity:	The velocities were greatly reduced inside and directly behind the structure.
Comments:	When the cover is placed down even with the substrate, there is a tendency to keep the hole open.

Experiment 20

Before the Test

After the Test



Structure Description: This structure was an open ended 60° triangle with a notched cover plate placed on the top of the structure with a hole excavated under it.

Hole(s): A medium hole was scoured at each side corner. The excavated hole was enlarged due to the notch in the cover plate.

Cover: Overhead cover was provided by this structure.

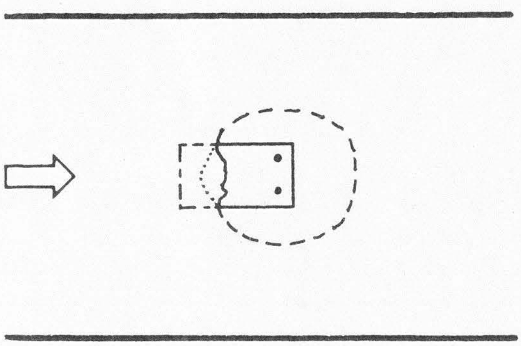
Sedimentation: There was extensive erosion along the sides at the start of this experiment. Some deposition occurred downstream from the holes. Sand which was poured in front of the structure was deposited downstream and not in the excavated hole.

Velocity: The velocities were greatly reduced inside and directly behind the structure.

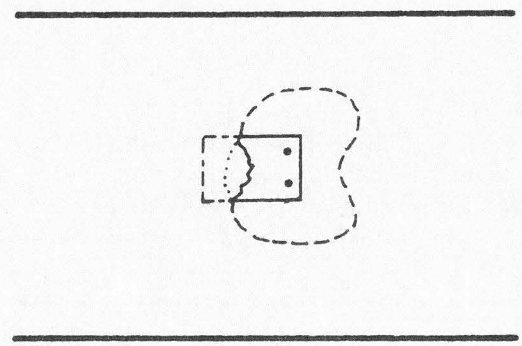
Comments: The notch had a tendency to keep the hole scoured out in back of the structure and avoid deposition. Due to the scouring effects of the sides, this structure may have a tendency to over turn.

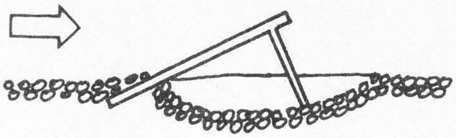
Experiment 25

Before the Test



After the Test





Side View (not to scale)

Structure Description: This structure consisted of a flat slab with legs. A hole was initially excavated out under this structure. The structure width was 0.2 of the channel width. The height of the structure exceeded the height of the water surface at low flow and was submerged during high flow.

Hole(s): A medium hole existed beneath and downstream from the structure.

Cover: Good cover was provided underneath the structure.

Sedimentation: Once the hole stabilized, it appeared to be somewhat self-cleaning, even with the addition of sediment upstream, the hole remained unchanged.

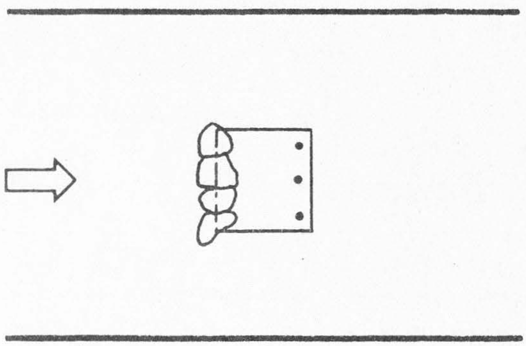
Velocity: Calm water with some turbulence existed in the excavated hole.

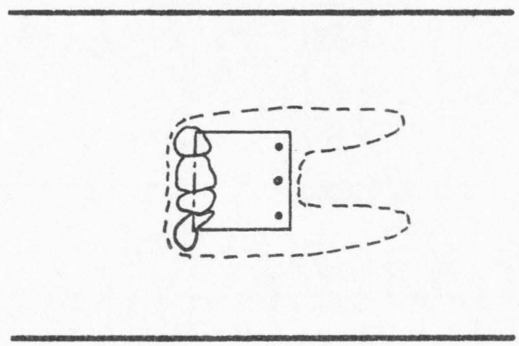
Comments: The rippling effect which extended from the structure was large as it neared the bank and could erode the bank.

Experiment 26

Before the Test

After the Test



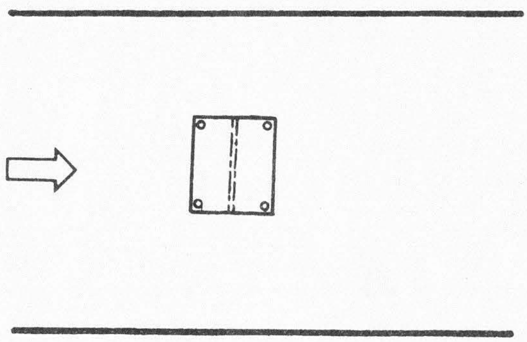


Side View (not to scale)

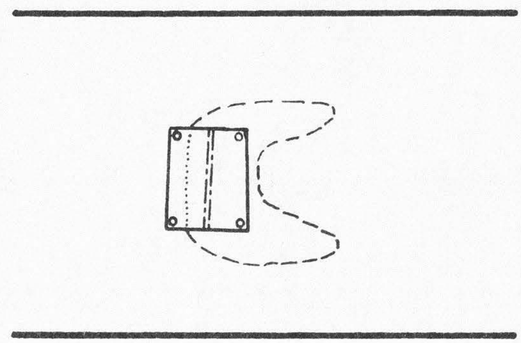
Structure Description:	The structure was a slab with three legs which were placed on the downstream edge. One end of the slab rested on the stream bottom with rocks placed on the upstream edge.
Hole(s):	A large hole was scoured in front of and at sides of the structure. The scour hole extended 50 cm down-stream.
Cover:	This structure provided overhead cover.
Sedimentation:	There was some deposition behind the structure and downstream from the holes.
Velocity:	Reduced velocity existed behind the structure.
Comments:	The side legs had a tendency to scour and fall into the cour hole; however, the center leg supported the structure. Sides were placed on the outside edges but this did little to alter the pattern of scour. When the rocks were removed from the front, a hole was scoured and the structure fell into the hole.

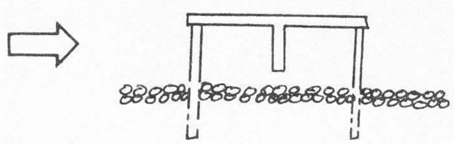
Experiment 29

Before the Test



After the Test





Side View (not to scale)

Structure Description: This structure was an inverted weir placed on four legs. The structure was rectangular without the U shaped notch on the downstream end. The structure width was 0.3 of the channel width.

Hole(s): A large hole was scoured beneath the hanging weir.

Cover: Overhead cover was provided in the area underneath the slab.

Sedimentation: Deposition occurred directly downstream from the structure.

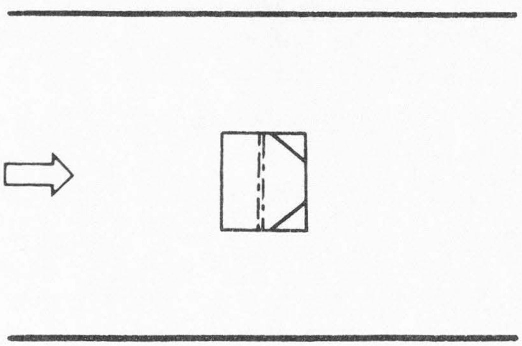
Velocity: Calm water existed underneath the slab and in front of and behind the hanging weir.

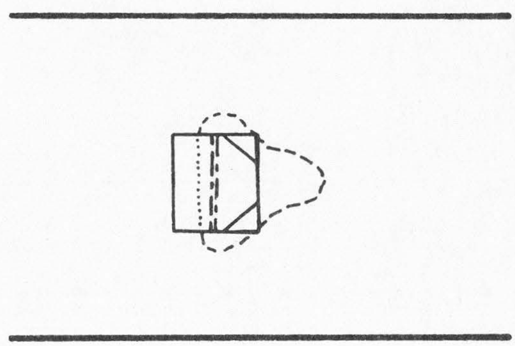
Comments: The best results were obtained when a small space existed between the hanging weir and the stream bed prior to the test.

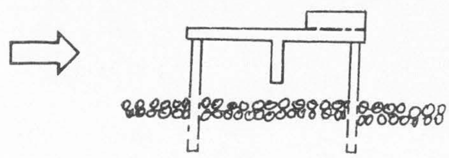
Experiment 30

Before the Test

After the Test







Side View (not to scale)

Structure Description: This structure was a slab with an inverted weir underneath and water foils on top to direct the flow into the middle of the channel.

Hole(s): The foils directed the flow and increased the scour to form a large hole behind structure. A hole was also formed underneath of structure.

Cover: Overhead cover was provided by this structure.

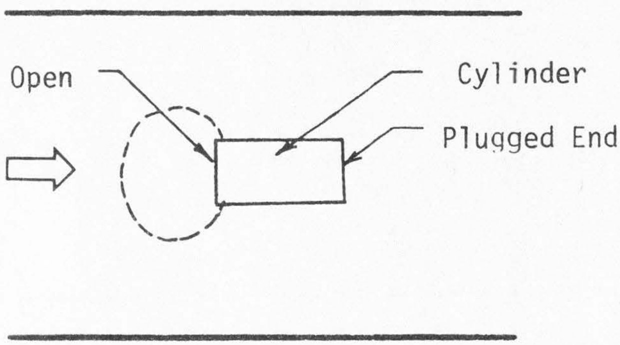
Sedimentation: Deposition occurred downstream from the scour hole.

Velocity: The velocities were decreased under and directly behind the structure.

Experiment 35

Before the Test

After the Test



Same

Structure Description: This structure was a pipe buried 2/3 of its height into the sand. It had one end plugged with the open end facing upstream. The structure width was 0.2 of the channel width. The structure was submerged during high and low flows.

Hole(s): A large hole existed within and in front of the structure.

Cover: Overhead cover was provided within the structure.

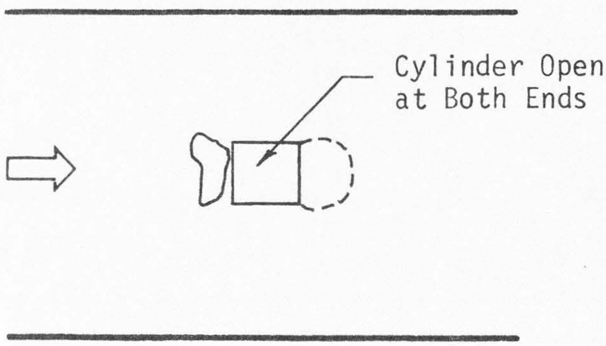
Sedimentation: There was no deposition within the structure as it appeared to be self-cleaning, even with the addition of sediment upstream, the hole remained unchanged.

Velocity: Turbulent water with some calm water existed within the structure.

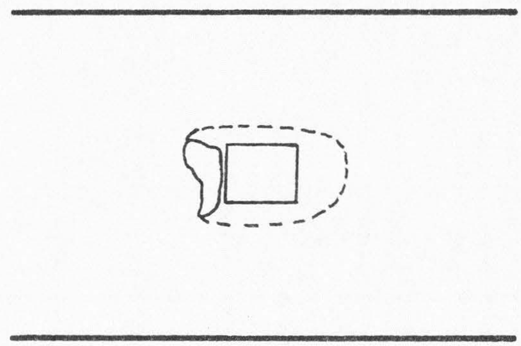
Comments: The rippling effect which extended from the structure was negligible as it neared the bank. This experiment was also performed with a plugged and partially plugged end on the upstream end of the cylinder. This arrangement performed very well in maintaining the hole and an area of reduced velocity within the cylinder. No appreciable deposition occurred within the cylinder.

Experiment 36

Before the Test



After the Test



Structure Description:	This structure was an open cylinder with a rock placed in front of it.
Hole(s):	A small hole was scoured around the rock and along the sides of the cylinder.
Cover:	Overhead cover was provided by the cylinder.
Sedimentation:	There was deposition downstream from the structure and very little inside of the cylinder.
Velocity:	The velocity behind the rock and in the cylinder was reduced but there was still some flow through the cylinder.
Comments:	This experiment was tried with several versions of rock placement, e.g., two rocks were placed in front of the cylinder but they caused excessive scour around the cylinder and made it very unstable.

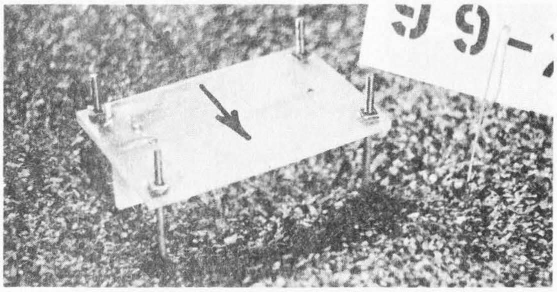
Analysis

These in-stream structures provided good cover, good holes, and calm water in the model stream, as can be seen in Figure 22.

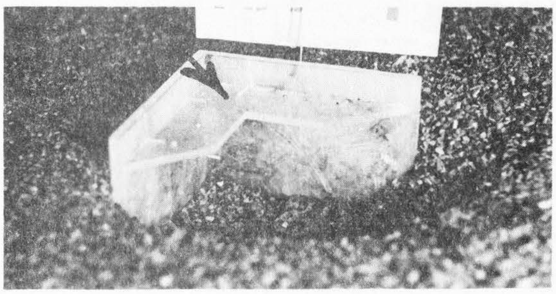
The inverted weir (Experiments 29 and 30) scoured a very good hole under the weir projection. It was also found that deflector vanes placed on top of the slab would tend to keep any deposition directly downstream from the structure from building up.

The "V" structure (Experiments 19 and 20) was placed in a hole which was excavated prior to running the test. The real value of model tests was realized in the study of this structure. It was first tested as an open-ended triangle; then the cover plate was added and tested both on top and at the substrate level. Next a notch was made in the cover plate and it was also tested at both levels. And finally holes were drilled in the sides of the "V." Through this process of modification it was determined that the best design was to have a notched cover plate placed at the substrate level and holes in the sides of the "V." This design maintained a self-cleaning hole within the "V" and minimized the deposition build-up directly down-stream from the structure. Cover was also provided.

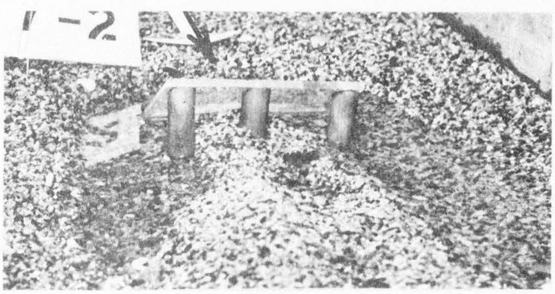
The slab with legs (Experiments 25 and 26) provided a hole, overhead cover, and variations in velocity. Due to flow through this structure from the side, very little deposition occurred under the slab.



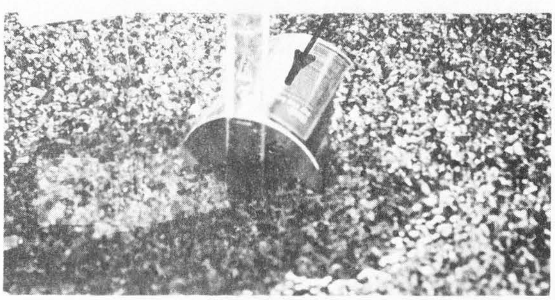
Inverted Weir



"V" Structure



Slab with Legs



Cylinder

Figure 22

Model Tests

The cylinder (Experiments 35 and 36) was also placed in a hole which was excavated prior to the test. It provided a hole and cover as well as calm water. No major sediment build-up appeared to occur within this structure during the flow variations.

RIVER STUDIES

The model studies indicated that the four in-stream structures provided conditions which were favorable for trout fisheries, but in order for these to be of any practical use they needed to be tested in the natural environment. Therefore these four structures were installed in four different rivers at six different locations. The following is a summary of the site conditions and structure effectiveness.

Description of Test Sites

Six test locations, (Figure 23) were chosen which would give a wide variety of channel characteristics and flow conditions. Each section had been altered in some way. The flows on the Provo River were regulated by various dams, canals and diversion works. The test sites were located in the Provo, Hobble Creek and Spanish Fork drainage basins.

The six locations were as follows:

1. Provo River at Lemon Grove--The structures were located at the end of the Lemon Grove Camp road. The Lemon

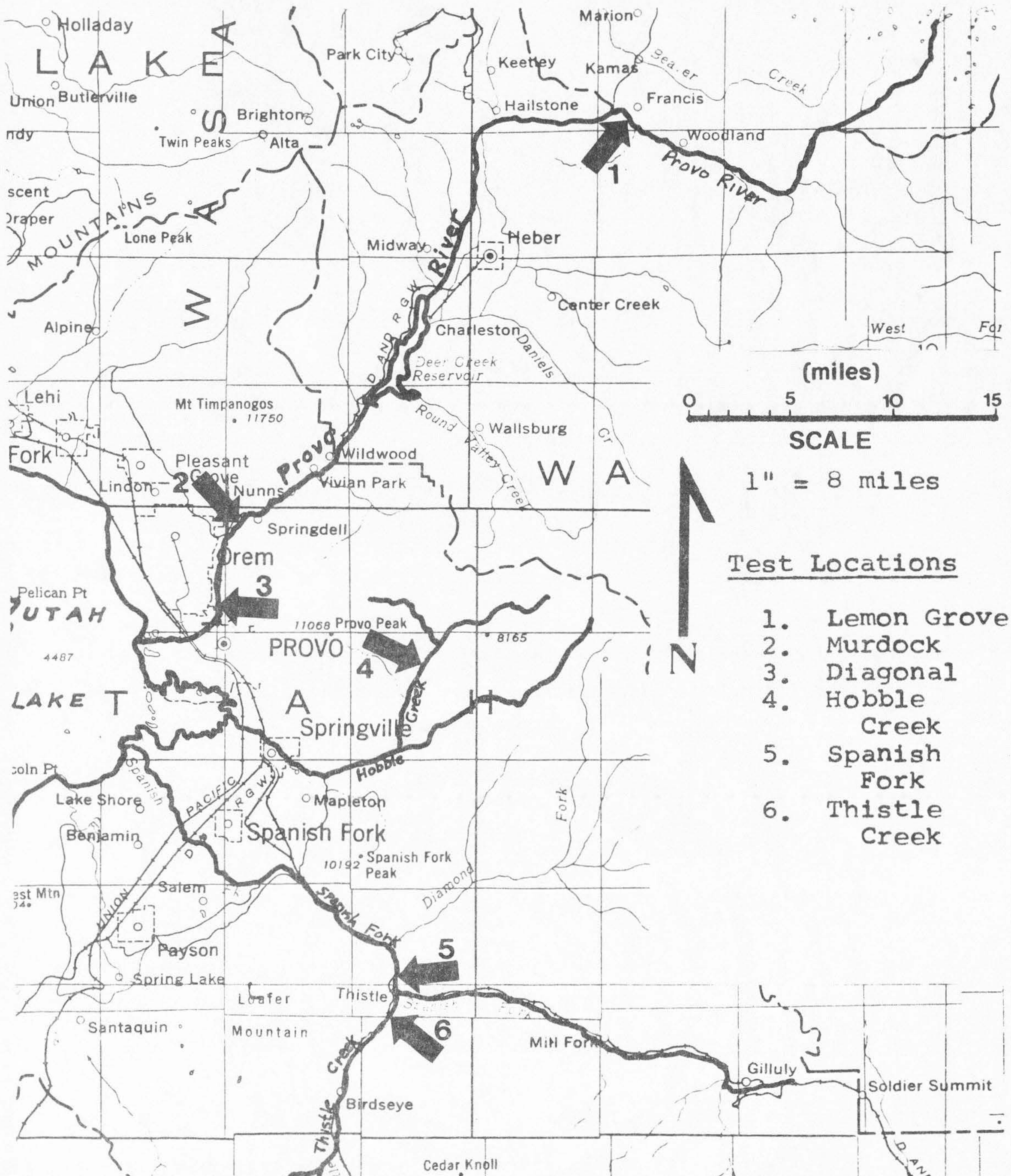


Figure 23

Map Showing Test Locations

Grove Campgrounds are located about 2.0 miles west of Francis, Utah, and 1.0 mile east or upstream from the Weber River diversion into the Provo River. The campgrounds are located on U. S. Alternate Highway 189. This test site will be referred to as Lemon Grove. This test section had been altered to increase the channel-carrying capacity. The flows here were regulated by the Duchesne Tunnel, which diverts water into the Provo River near Kamas, Utah.

2. Provo River below the Murdock Diversion Dam--The structures are located 0.1 mile downstream from the Murdock Diversion Works. This test site will be referred to as Murdock. The flows are affected by the Deer Creek Dam and several other diversions above the site.

3. Provo River near the diagonal--The structure is located 100 yards downstream from the artificial diamond factory and 0.25 miles upstream from the Diagonal Bridge crossing. This test site will be referred to as Diagonal. The test section had been altered to increase the channel-carrying capacity.

4. Left Fork of Hobble Creek--The structures were located 0.25 miles past the end of the pavement on the right side of the road, or 3.75 miles up the Left Fork of Hobble Creek. This test site will be referred to as Hobble Creek. As with the other test sites this one also had been altered.

5. Spanish Fork River--The structures are located

1.2 miles upstream from the confluence of the Diamond Fork and the Spanish Fork Rivers, 0.2 miles upstream from the "D" Gas Station and 1.3 miles downstream from the Thistle turnoff on U.S. Highway 89. This test site will be referred to as Spanish Fork. This test section had been altered by highway construction.

6. Thistle Creek--The structures are located 1.0 mile upstream from the Thistle turnoff on U.S. Highway 89. This test site will be referred to as Thistle Creek. This test section had been altered due to highway construction.

Hydrology of Test Sites

The weather at each of the test sites is fairly typical of the intermountain region. Snow on the higher northern slopes of the mountains can be seen during the entire year wherever the terrain is shaded from the sun. Frost usually appears about the middle of September and ceases about the first of May. Precipitation (Table 1) in the general area varies from 12 inches per year near Thistle to over 30 inches per year in the northern mountains. Severe wind storms rarely occur. Summer storms or cloudbursts (averaging one to two inches of precipitation in one-half hour's time) are common, but storms of over four inches of precipitation during any 24 hour period would be very rare.

The average total annual flows (Table 2) at the test sites range from 200,000 ac. ft. per year at Lemon

Table 1

Summary of the Precipitation, Air Temperatures, and Water Temperatures at the Test Sites

Location	Annual Mean Precipitation (Inches) [1]	Annual Mean Air Tempera- (°F) [1]	Water Temperatures[2]		
			High (°F)	Low (°F)	Mean (°F)
Lemon Grove	16	45.4	65	32	48
Murdock	16	48.9	71	32	52
Diagonal	16	48.9	71	32	52
Hobble Creek	16	48.0	61	32	48
Spanish Fork	17.4	52.8	70	32	51
Thistle Creek	12.4	49.5	65	32	48

[1]From Climatological Data and Wernsteat, 1972.

[2]Whitaker, 1971.

Table 2

Summary of the Flow Conditions at the Test Sites

Location	Approximate Drainage Area (Sq. Mi.)	Average Total Annual Flow (Ac.Ft./yr.)	Maximum Discharge (cfs)	Minimum Discharge (cfs)	Mean Dis-Charge (cfs)
Lemon Grove[1]	200	200000	2300	25	275
Murdock[2]	650	72000	1400	0	100
Diagonal[3]	700	126000	2000	25	174
Hobble Creek[4]	50	18000	600	1	25
Spanish Fork[1]	500	65000	1800	10	90
Thistle Creek[4]	200	26000	720	4	35

[1]This information comes from USGS maps and Water Supply papers 1314, 1734 and 1927.

[2]This information comes from the Reports of the Provo River Water Commissioner.

[3]These values were estimated from a study of all available information.

[4]This information was estimated using a ratio of the drainage areas and the USGS Water Supply papers for stations below the test sites.

Grove to no discharge at certain times of the year at Murdock. This condition of no discharge below the Murdock Diversion is obviously disasterous to the fisheries in this section of the river and is a common result of the total appropriation of the waters to such purposes as irrigation and power production. At this location trade-offs with Utah Power and Light are being made so that some flow will be in the river at all times. As stated earlier, some people feel that a minimum amount of flow, such as 30% of the natural mean annual flow, should not be subject to appropriation so that the fisheries can be maintained during low-flow periods. However this is not very practical unless enough public support can be mounted because almost all of the surface waters have been already appropriated. Augmenting low flows with unappropriated ground water does offer some promise.

Floods may impose failure forces on the structures. Leopold (1962) observed that unregulated channels overflow and spill onto their flood plains on the average of once every two years: therefore it is important to have a good general idea of flood conditions such as velocities, water depths, and discharges. This author found through an extensive flood study of Spanish Fork Canyon that the largest floods occurred due to snow melt rather than cloudbursts. Other observers of this area have also made this observation (U. S. Army Corps of Engineers, 1971). This would probably be a general rule for the test sites in this study. The maximum floods were estimated (Table 3) using a flood envelope of maximum floods in the Great Basin and related locations in the Colorado Basin (Figure 24). Flooding very rarely occurs at any of these sites. In fact it appears from comparing the maximum observed natural flows with the estimated maximum floods that major floods have never been measured at any of the test sites; in fact the maximum observed flows are only about half the estimated maximum floods. If a major flood did occur the habitat structures tested in this study might have stability problems. However it was fortunate that both 1973 and 1974 were high runoff years in comparison to the other years of record; therefore substantial forces were imposed on the test structures.

The annual mean air temperature (Table 1) for the test areas is about 48°F. Temperatures average from 60° to 100°F during the summer months and 0° to 60°F during the winter months. The minimum temperature is about 30° below zero in the headwater regions.

The water temperatures (Table 1) range from 71°F to freezing with a mean of about 50°F although the water temperatures may reach an excess of 70°F during some of the summer days; this condition is sustained for only a short period of four to five hours during the day. The water is then cooled down each evening; therefore there is no great threat to the fisheries from high water temperatures.

Table 3

Estimated Flood Flows

Location	Effective Drainage Area (Sq. Mi.)	cfs/sq.mi.[1]	Estimated Flood (cfs)	Maximum Observed Discharge (cfs)
Lemon Grove	200	25	5000	2300
Murdock	100[2]		3000[3]	2520[3]
Diagonal	150[2]		3000[3]	2520[3]
Hobble Creek	50	35	1900	600
Spanish Fork	500	19	9500	1800
Thistle Creek	200	25	5000	720

[1]This information comes from Figure 24.

[2]This figure is the drainage area below Deer Creek Dam. The U.S. Army Corps of Engineers (1971) suggested that the maximum flood which would be experienced at the mouth of Provo Canyon would likely come from the drainage area below Deer Creek Dam because the peak of a flood passing into Deer Creek Reservoir would be appreciably reduced due to the great amount of surcharge storage available in the reservoir and the natural routing effect through the spillway and outlet works.

[3]This information comes from the U.S. Army Corps of Engineers (1971).

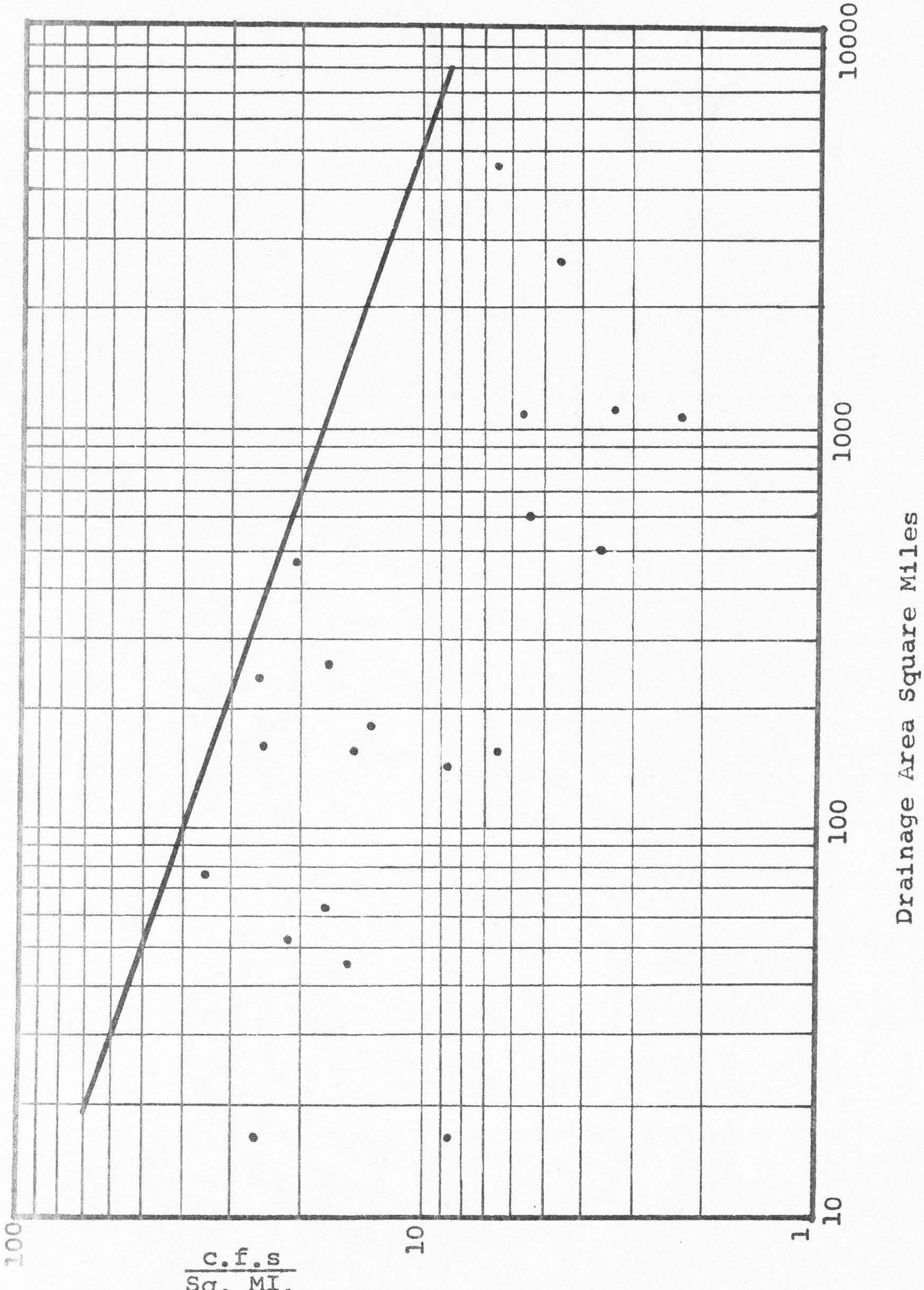


Figure 24

Flood Envelope of Maximum Floods in the Great Basin and the Colorado River Basin (Data from Water Supply Papers 1683 and 1684)

A study of the records of the U.S. Geological Survey and the U.S. Bureau of Reclamation (Subitsky, 1962) shows that the total dissolved solids in the study rivers is lower than 400 ppm. The waters are slightly alkaline with a PH varying from 7.5 to 8.25. The water in each of the rivers would be considered hard with a hardness generally greater than 200 ppm.

Hydraulics of Test Sites

The test rivers would all be considered mountain rivers or rivers which flow down a narrow mountain canyon. The slopes of the test sections ranged from 0.014 on Hobble Creek to 0.004 on the Spanish Fork River. The average water depths which were observed throughout the year ranged from 1.5 feet to 1.0 feet. Occasionally at Murdock the flow depth would be as shallow as 0.5 feet.

The maximum observed velocity was about 9.0 fps, but the U.S. Army Corps of Engineers (1971) estimated that flood velocities on the Provo River could average 10 fps. The average channel velocities throughout the year range from 2.0 to 3.0 fps.

The substrate, or streambed, was analysed by two methods to determine a particle size distribution curve. For the first method two instruments were used to collect the data, an area quadrangle and a plastic template. The area quadrangle was a square which was made of angle iron and enclosed an area of 900 cm^2. This quadrangle was thrown at random on the substrate, the size of the rocks enclosed on the inside of the quadrangle were then measured with the plastic template, which was a plastic sheet with various sized square holes in it. The holes varied from 1 cm x 1 cm to 12 cm x 12 cm. All of the surface rocks within the quadrangle were then measured and recorded by determining the smallest hole in the template through which the rock would fall.

As the substrate composition varied with depth, it was felt that the top surface layer was the most important with respect to the scour performance of the test structures. Therefore only those rocks with some evidence of insect or vegetative growth on them were recorded. It was felt that by following this procedure only the "crust" layer would be measured. This procedure was repeated anywhere from 5 to 10 times for each location. The data were then converted to a percent finer by area versus particle size by assigning a given area to the rocks falling through a given hole.

There appeared to be two problem areas on the particle size distribution curve, which was derived in above manner. First the large particles (larger than 12 cm x 12 cm) had to be measured individually and therefore left room for error. Second the small particles (less than 1 cm x 1 cm), which are very important with respect to scour and deposition (Schumm, 1960), could only be visually estimated.

Recognizing these problems, a second method had to be devised to determine the particle size distribution curves. A conventional sieve analysis was performed on samples from the Spanish Fork River, the Provo River at Murdock, and Hobble Creek. Samples were collected during low-flow conditions at the edge of the water. Care was taken so as not to wash out any fines from the samples. A percent finer by weight versus particle size was then determined. The particle size distribution curves were shifted slightly up and to the right, but surprisingly enough they were parallel to the curves derived from the first procedure in the range from 12 cm to 1 cm. The final curves are shown in Figure 25 and can also be visually compared in Figure 26.

Samples of the material which was deposited under and inside of the test structures in areas of reducing velocity were collected during the winter of 1973. A particle size distribution curve was determined for each of these samples, which is given in Figure 27. Every structure filled in somewhat by sediment during the winter flows; then during the high flow in May, 1974, all of the structures except those at Lemon Grove completely filled in and became totally useless, thereby requiring an appreciable amount of annual maintenance to keep the structures functioning as habitat improvements.

It is interesting to note in comparing Figures 27 and 28 that, in order to keep 50% of the bedload material

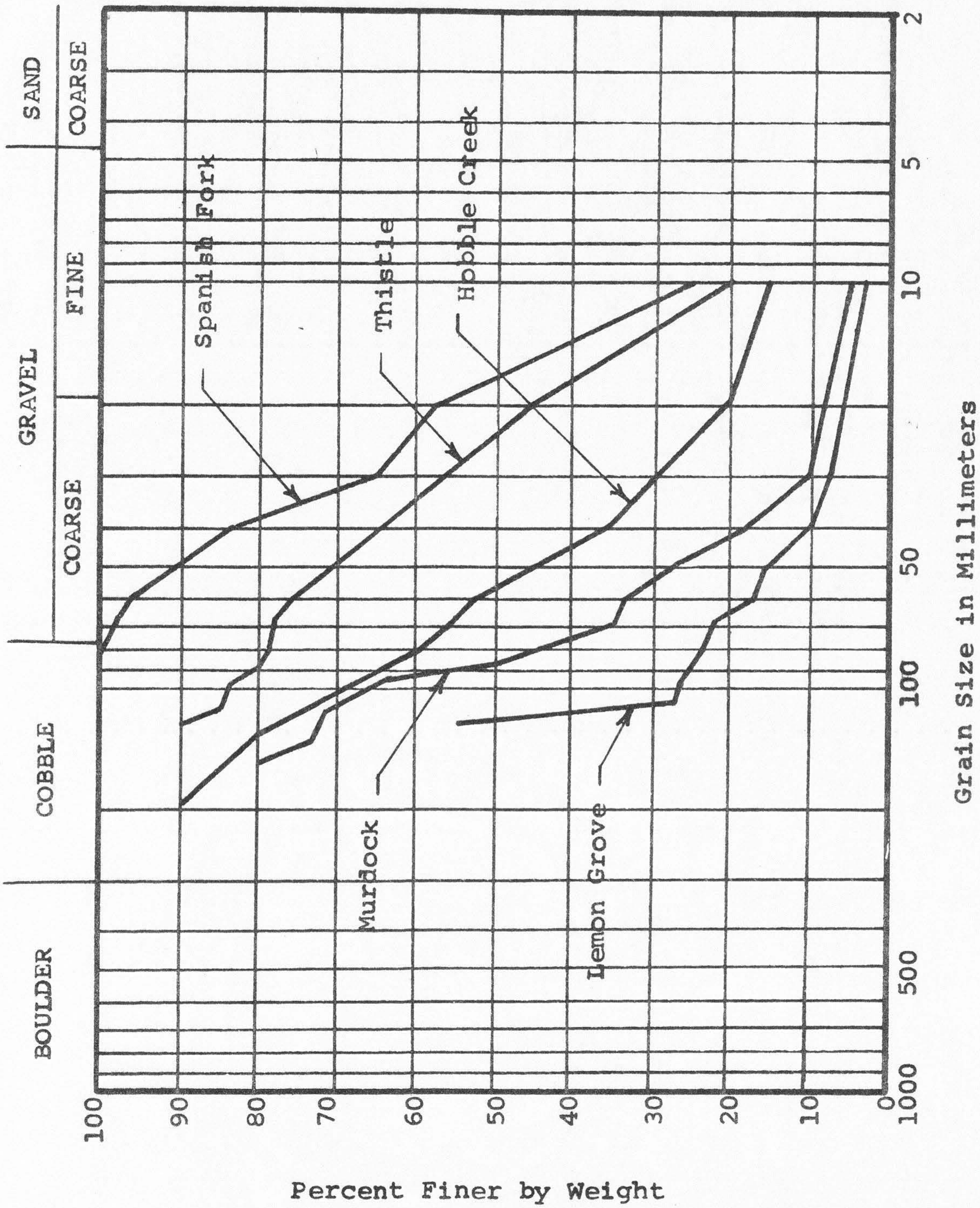
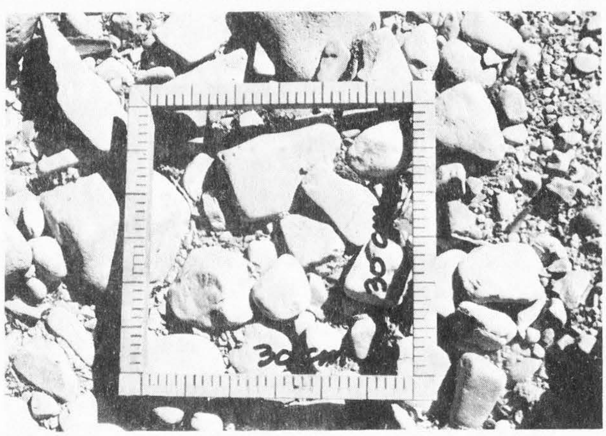


Figure 25

Grain Size Analysis of Stream Substrate
(Stream Bed) Material

Spanish Fork Substrate



Provo River Substrate

Figure 26

Substrates on the Spanish Fork River and the Provo River below the Murdock Diversion

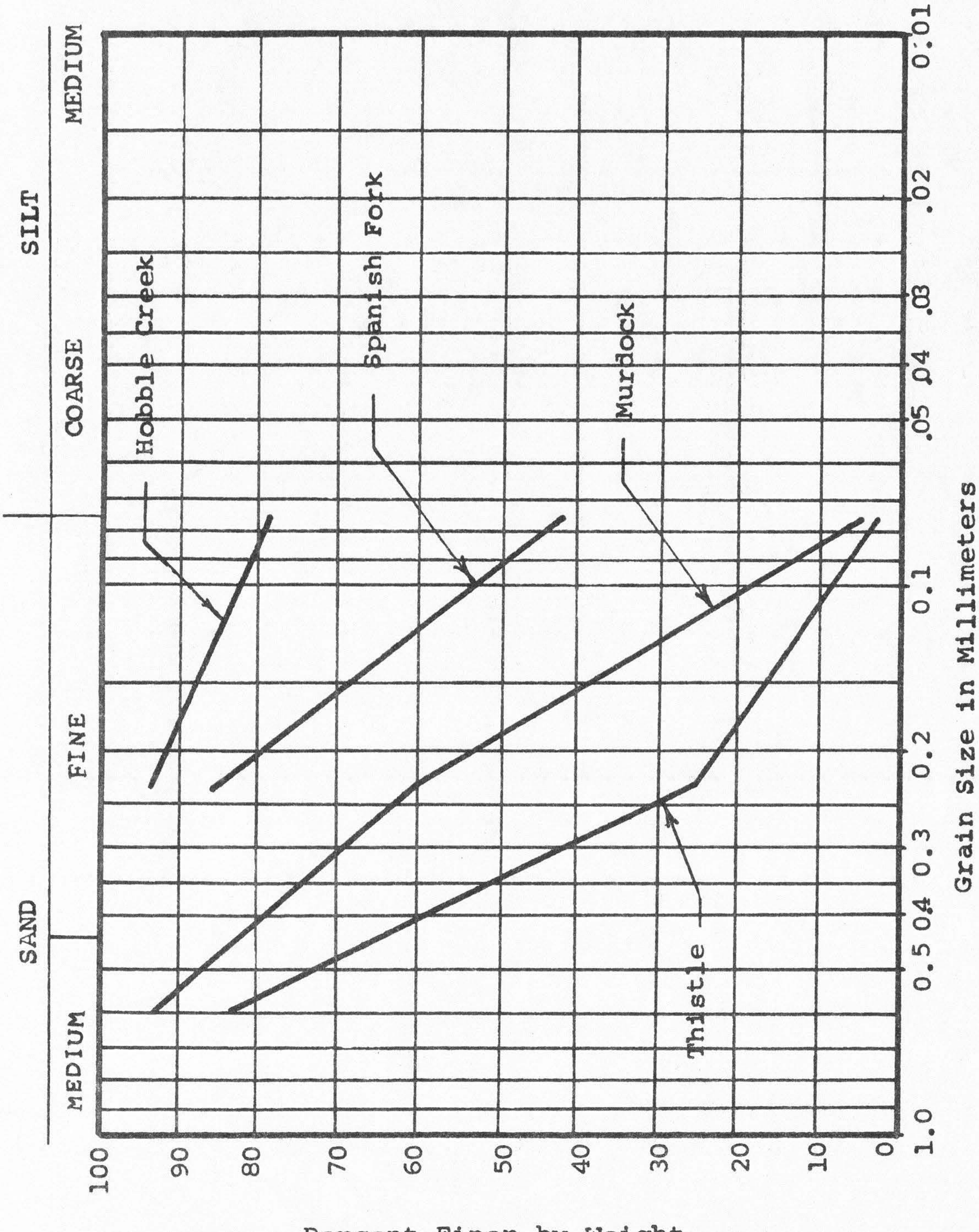


Figure 27

Grain Size Analysis of Winter Deposition Samples

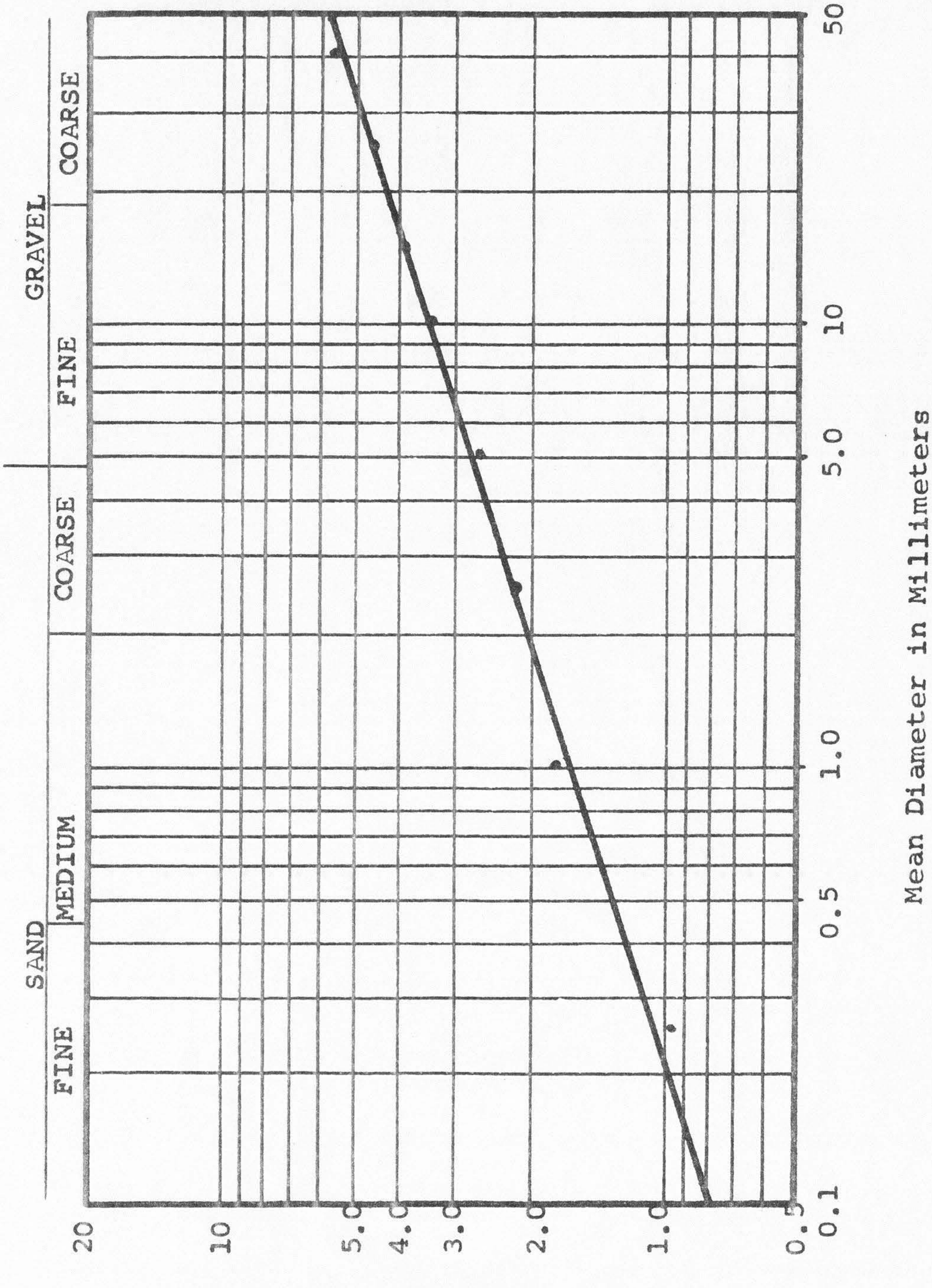


Figure 28

Sizes of Stream Bed Materials which can be
Transported by Various Velocities
(Data from Leliausky, 1955)

depositing in Thistle Creek, a velocity of at least 1.0 fps. must be maintained. The hydraulic characteristics of the test sites are summarized in Table 4.

Construction and Installation

The structures (See Figures 29,30,31 and 32) were constructed out of concrete reinforced with a 10-gauge welded wire mesh and placed in the test rivers during the summer of 1973. They were constructed of different dimensions as noted in Table 5.

Six concrete cylinders were tested to determine what strength of concrete was being used in the structure. The lowest 7-day strength was 3300 psi, and the highest 28 day strength was 6200 psi. A sand mix was used consisting of four parts sand to one part cement. Both types 1 and 1A cement were used. It was interesting to note that the strength of sand-mix concrete is comparable to the strength which would be expected from an aggregate sand-mix concrete.

Each of the structures was installed as follows:

1. Inverted weir--Four 6' metal fence posts were driven into the substrate and the inverted weir was attached to them by means of a metal bracket at each corner.

2. "V" structure--A hole was excavated into the substrate and this structure was placed in it.

3. Cylinder--A hole was excavated into the substrate and this structure was rolled into it. Then a metal

Table 4

Hydraulic Characteristics of the Test Sites*

Location	Slope	Average Velocity (fps)	Estimated Maximum Velocity (fps)	Mean Depth (Ft.)	Average Width (Ft.)
Lemon Grove	.010	3	12	1.2	50
Murdock	.010	2-3	10	1.0	45
Diagonal	.009	2-3	10	1.5	45
Hobble Creek	.014	2-3	12	1.5	10
Spanish Fork	.004	2-3	9	1.0	45
Thistle Creek	.007	3	9	1.0	20

*The water velocities and depths around the test structures were measured periodically throughout the year, as well as the river width and slope. This information is reported in the appendix of this report.

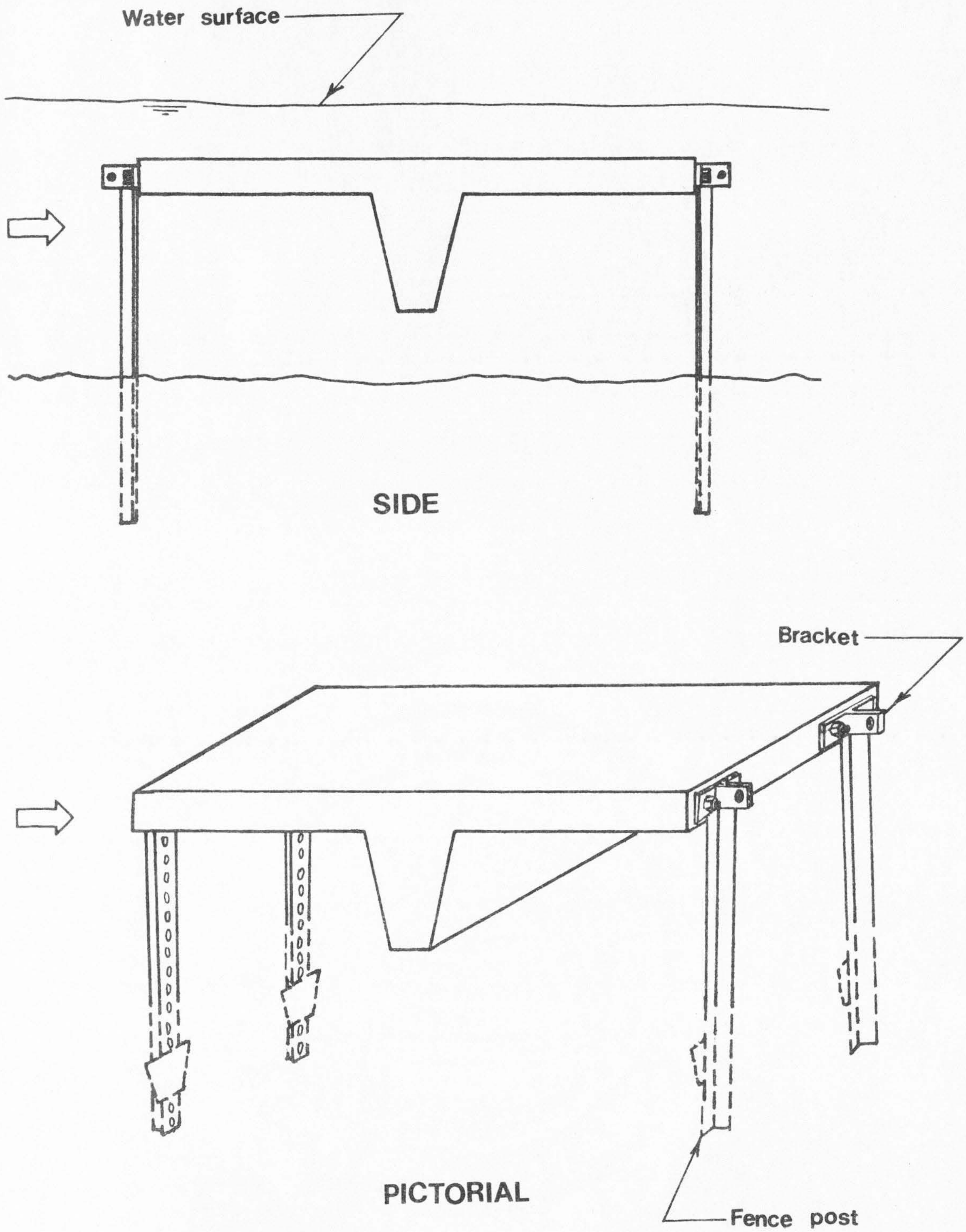


Figure 29

Inverted Weir

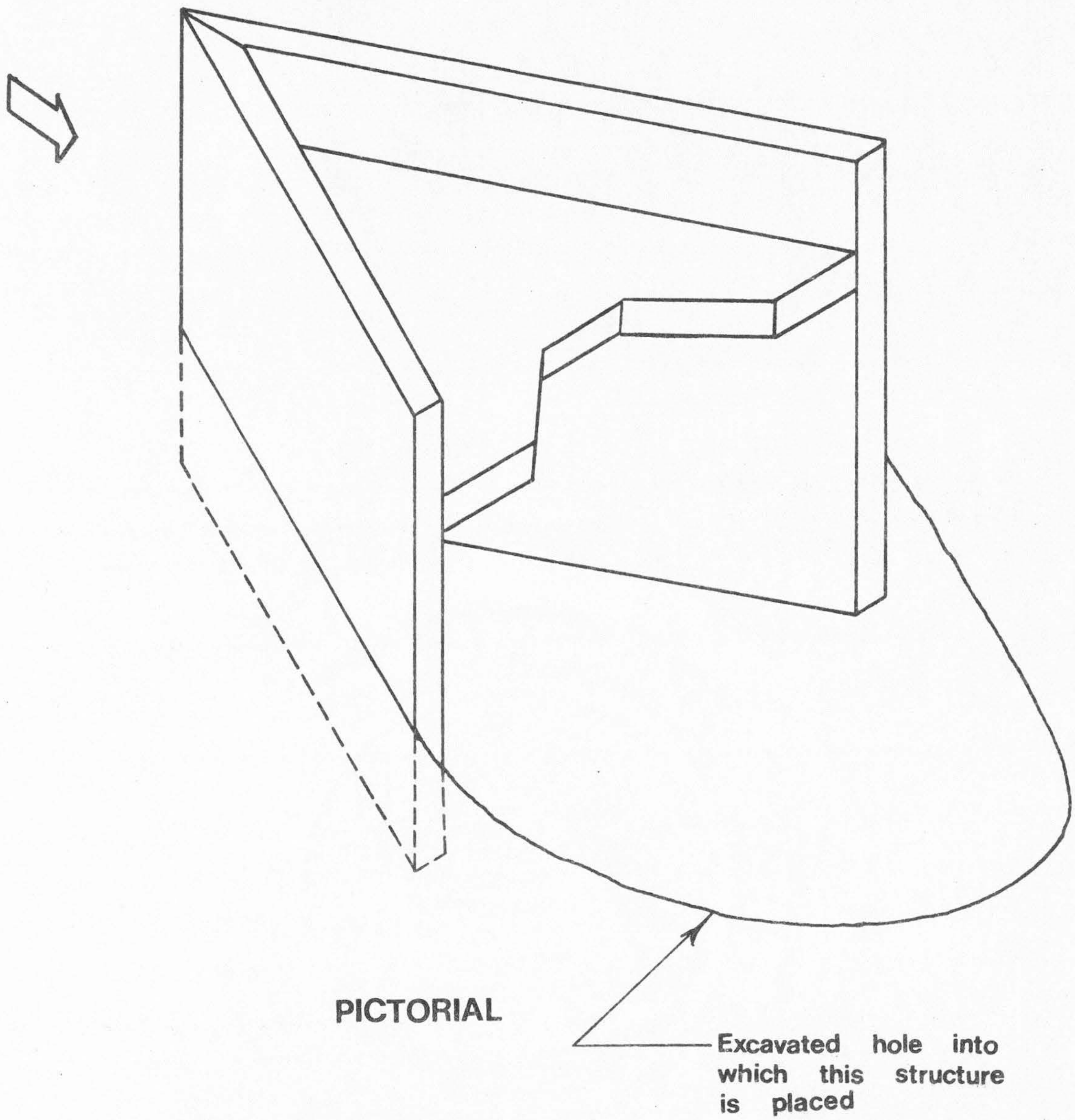


Figure 30

Inverted "V"

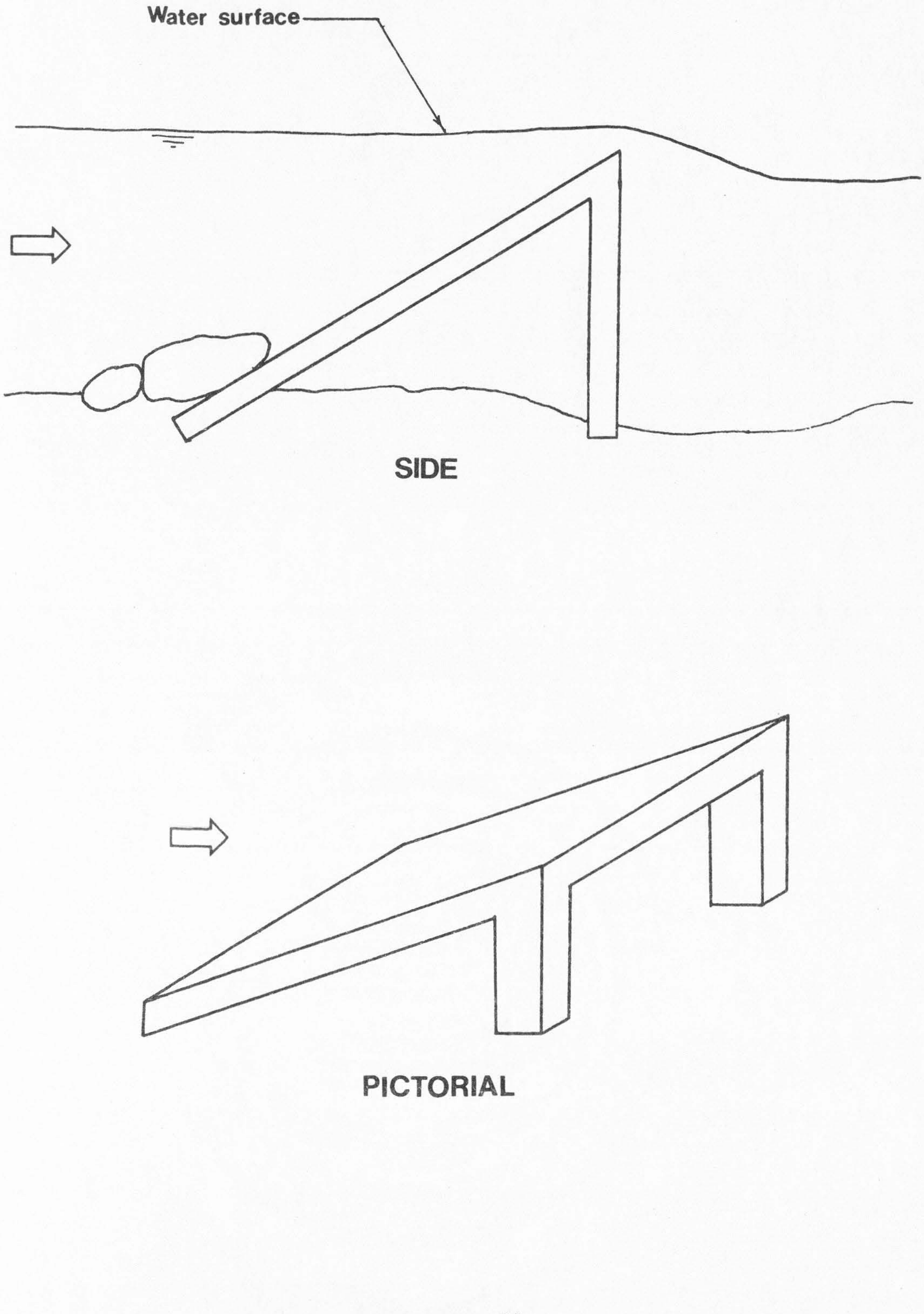


Figure 31

Slab with Legs

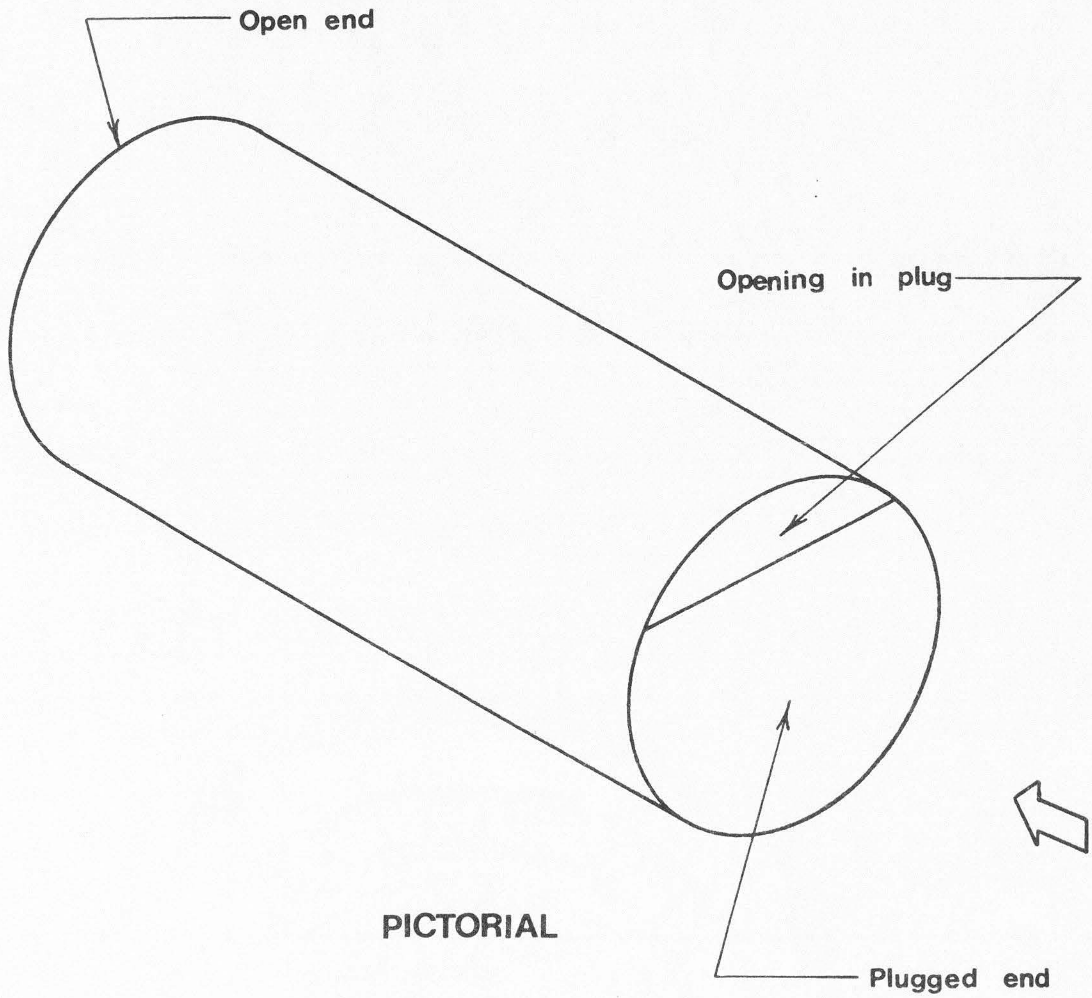


Figure 32

Cylinder with Plug

Table 5

Summary of the Structure Installation Schedule

Date	Location	Type of Structures	Note
5-7-73	Lemon Grove	Inverted Weir	4" thick (washed out)
5-8-73	Spanish Fork	Inverted Weir	4" thick
5-11-73	Murdock	Inverted Weir	4" thick
6-7-73	Hobble Creek	Inverted Weir	2" thick
6-12-73	Thistle Creek	Inverted Weir with deflectors	2" thick
6-20-73	Murdock	"V" Structure	3 ft. tall
6-20-73	Murdock	Cylinder	18" dia.
6-28-73	Diagonal	Inverted Weir	4" thick
6-21-73	Spanish Fork	"V" Structure	3 ft. tall
7-2-73	Hobble Creek	"V" Structure	3 ft. tall
7-2-73	Hobble Creek	Cylinder	18" dia
7-3-73	Lemon Grove	2-Inverted Weir	Both installed with the front edge tied down. 4" thick 3" thick
7-6-73	Thistle Creek	"V" Structure	2' tall
7-20-73	Thistle Creek	Slab	3' wide x 4' long x 18" high (3'x4' x 18")
7-20-73	Thistle Creek	Cylinder	18"dia
7-20-73	Spanish Fork	Slab	4' x 4' x 18"
7-20-73	Spanish Fork	Cylinder	18" dia
7-20-73	Hobble Creek	Slab	3' x 4' x 18"
7-23-73	Murdock	Slab	4' x 4' x 18"
7-24-73	Lemon Grove	Cylinder	18" dia
8-10-73	Lemon Grove	Slab	5' x 4' x 18"

fence post was driven into the streambed in front of the cylinder. This post was attached to a cable which was looped in front of the cylinder and embedded into the plug. This stabilized the cylinder from moving downstream.

4. Slab with legs--This structure was easiest to install. It simply rests on the stream bed.

The summary of structure placement is given in Table 6. The structures can be seen in Figures 33 and 34.

Results

It is evident when analyzing fish habitat structures that several important requirements must be met. First, the general fish requirements must be met, such as overhead cover, holes and riffles. Second, the structure must be able to maintain itself through the freeze-thaw cycle and high discharges. Next, the structure must be able to remain useful over a long period of time with very minimal maintenance required to keep it functional. Lastly, it must be utilized by the fish.

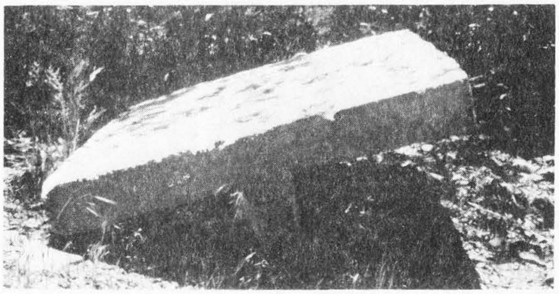
With only a short, one year, evaluation period some of the requirements cannot be fully explored, but here is a summary of the results which have been determined:

1. All of the structures gradually filled in with sediment throughout the year. During the high spring runoff, all of the structures except those at Lemon Grove completely filled in with sediment thereby eliminating any favorable

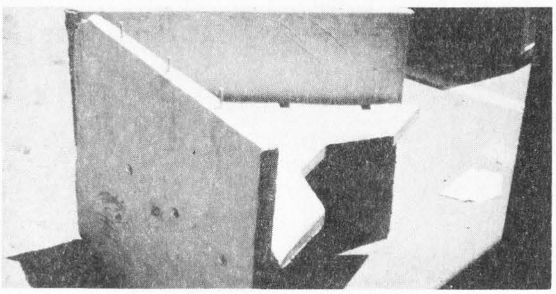
Table 6

Summary of the Structure Placement

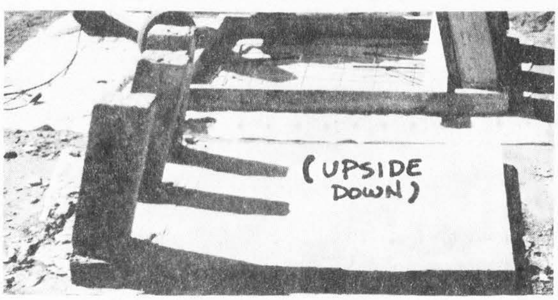
Location	Structure
Provo River	
Lemon Grove	2 Inverted Weirs
	1 Cylinder
	1 Slab with legs
Below Murdock Diversion	1 Inverted Weir
	1 "V" with cover
	1 Cylinder
	1 Slab with legs
Near Diagonal	1 Inverted Weir
Spanish Fork River	1 Inverted Weir
	1 "V" with cover
	1 Cylinder
	1 Slab with legs
Thistle Creek	1 Inverted Weir
	1 "V" with cover
	1 Cylinder
	1 Slab with legs
Hobble Creek	1 Inverted Weir
	1 "V" with cover
	1 Cylinder
	1 Slab with legs



Inverted Weir



"V" Structure



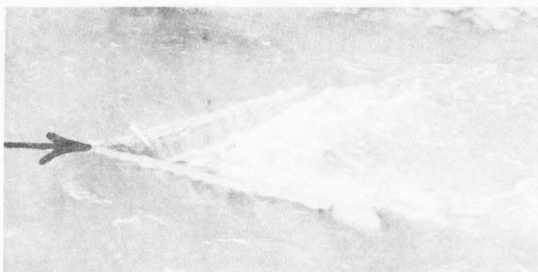
Slab with Legs

Cylinder

Figure 33

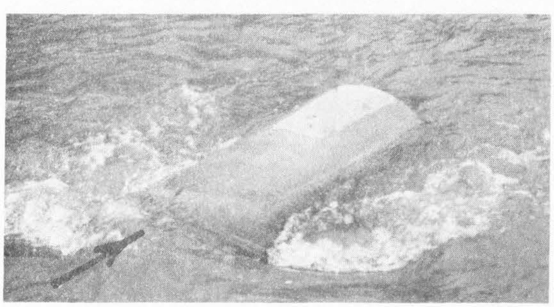
Structure Prototypes

Installing Inverted
Weir



River Performances of
"V" Structure

River Performance of
the Slab with Legs



River Performance of
the Cylinder

Figure 34

Installation and River Performance of the Structure habitat conditions.

2. The holes bored in the sides of the "V" structure were effective in retarding the deposition inside this structure during the low-flow periods but when the high spring runoff flows came this structure also filled in. It cannot be determined yet whether the flow through these holes would gradually scour out the deposition inside this structure.
3. Holes were not scoured under the inverted weir structure as was indicated in the model studies. It appeared that the inverted weir should be installed so that the weir projection is up off the stream bed so that some flow will go under the weir and tend to keep the back cleaned out.
4. There were discrepencies between the results of the laboratory experiments and the river studies. This appears to be due primarily to the larger-sized substrate material in the rivers, which cause it to be more stable and less apt to scour.
5. All of the structures were "out of water" much of the time due to the great variation in water depths. For this reason the "V" structures which were 3 feet tall were considered too tall.
6. Only one of the structures failed due to high flow (the inverted weir at Lemon Grove).
7. The structures did not need to be anchored down

to be stable during high flows.

8. Vandalism may be a problem with these structures. The "V" structure at Murdock was tipped over several times.
9. Some of the structures were placed in existing holes and therefore were limited in their effectiveness in rehabilitating the stream.
10. There were no failures due to poor-strength concrete, but concrete tends to be not esthectically pleasing when exposed out of the water.
11. The inverted weir catches debris and requires frequent maintenance to keep it free and cleaned out.
12. The inverted weir and the "V" were both difficult to install.
13. The cylinder and the slab with legs were both easy to install.
14. Several fish were observed around the test structures, but no fish shocking was carried out. Both moss and invertebrates attached to the test structures.
15. Using the quadrangle and size template was a fast and easy method of analysing the type of substrate, but it does not accurately determine the smaller and larger particles.

CONCLUSIONS

1. These structures did not influence enough of the river area to be effective.
2. There is an appreciable amount of maintenance required on these structures due to silting in, debris, and vandalism. The slab with legs required the least amount of maintenance.
3. A major part of the deposition within these structures occurs during the high spring runoff and yearly maintenance is required to keep them cleaned out and functional.
4. Concrete is not esthectically pleasing when exposed out of the water.
5. If care is taken in installing these structures, they can withstand the forces imposed on them by high runoffs without failure.
6. The inverted weir and "V" structure are very difficult to install.
7. The "V" structures which were 3 feet tall were too tall.
8. The slab was the only promising structure.

RECOMMENDATIONS

1. A combination of four or five slabs should be placed in a section of river so that a larger percentage of the river can be influenced. This

could be done in a geometric shape or like a ramp check dam with spaces left between the slabs for fish migration.

2. The cylinder should be put in without a plug in it. It would provide cover but not silt in.

APPENDIX

EVALUATION OF HABITAT STRUCTURE

The following is a summary of the observations of the in-stream structures made from May 1973 to May 1974:

I. Provo River

   A. Lemon Grove--The slope of the river through the test section was 1%.

      1. Inverted weir--A 4 inch thick inverted weir was installed at Lemon Grove on May 7, 1973. This structure was washed out during the high flow at least by May 20, 1973. Observations of the structure on May 29, 1973 were:

         a. On the downstream post brackets, the concrete below the bolts had "popped" out and the bolts were easily removed.

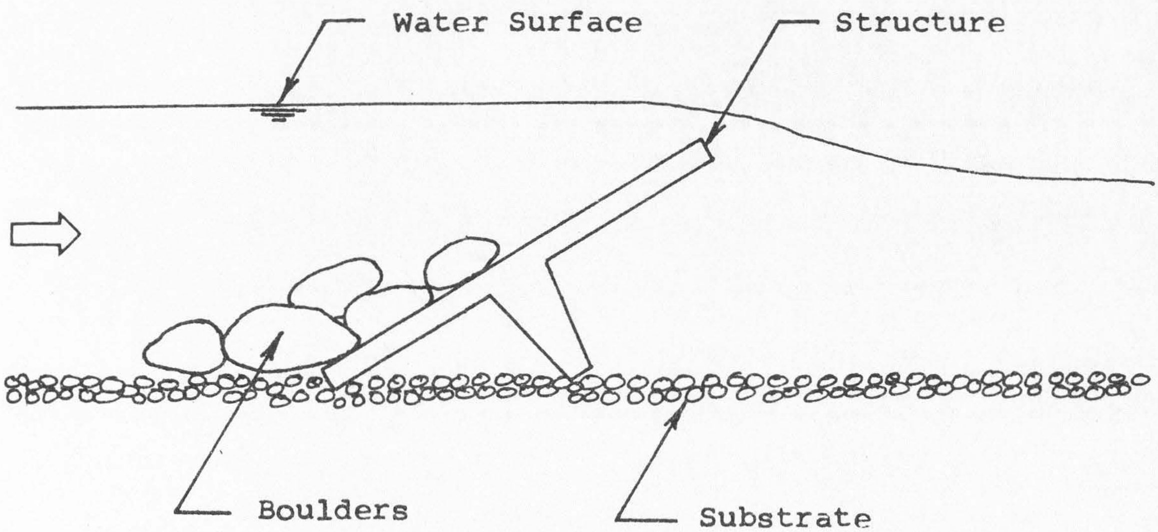
         b. The concrete was worn down to the aggregate and the structure was chipped up a little but not too excessively.

         c. The upstream bolts were also loose.

         d. One of the upstream support posts is still in the river bottom but it is completely bent over. All the other support posts were pulled out when the structure failed.

         e. There were invertebrates on the structure.

2. Inverted weir--On July 3, 1973, this failed inverted weir was dragged back into the river and installed similar to a slab structure with rocks placed on the front end to stabilize the structure. (See drawing below)

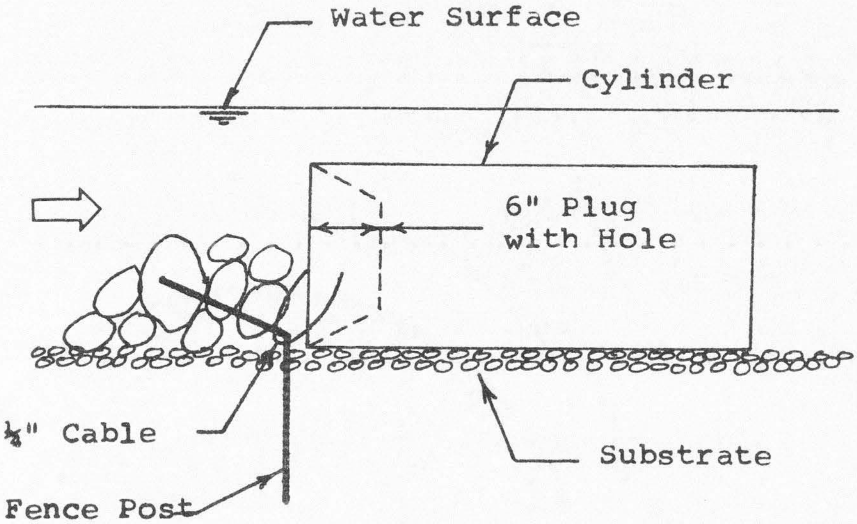


Side View

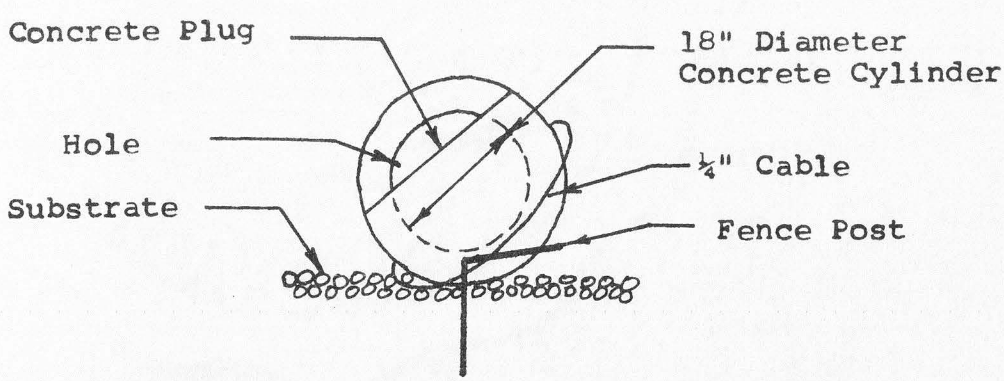
3. Inverted weir--Also on July 3, 1973, another inverted weir 3 inches thick was installed similar to a slab structure. The reason for installing the structure in this manner was that the back support posts could not be driven into the substrate. (See drawing above)

Both of these structures appear to be very stable. They have maintained a good clean hole under the front and the back. Overhead cover is provided. These structures also have good invertebrate growth on them.

4. Cylinder--On July 24, 1973 an 18" diameter pipe with a plug in it was installed at Lemon Grove. There is a hole in the plug which provides for some flow through the structure but the velocities within the pipe are almost non-detectable. This is in direct relation to the area differences of the openings. The hole is approximately 0.30 ft^2 while the inside of the pipe is 1.77 ft^2 which gives a ratio of about 1:6. The pipe has not silted in with any fine material.

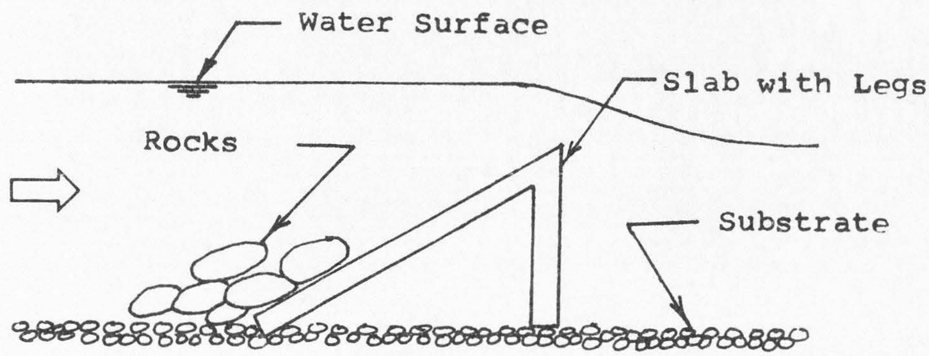


Side View

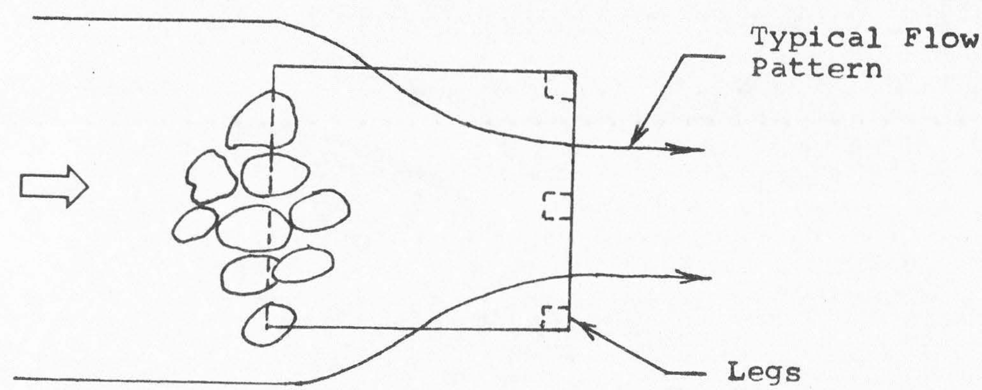


End View

5. Slab with legs--On August 10, 1973 a 5 foot wide slab was installed at Lemon Grove. This structure was fairly easy to install taking only 1 hour for three men. The flow conditions were very good around and through this structure. (See drawings below)



Side View



Top View

B. Murdock--The slope of the river through the test section was 1%. The flow conditions were very eratic, ie. one day the flow depth would be three feet and the next day only a few inches, therefore occasionally these structures were out of water. This condition is caused by varying diversions of water from the Murdock diversion dam.

1. Inverted weir--On May 11, 1973 an inverted weir was installed near the Murdock diversion dam. This structure then went through a heavy runoff flow cycle, after which several items were observed: (a) There was a lot of algae growth on this structure. (b) By June 22, 1973, it had completely silted in with large rocks and cobbles at both the front and the back, thus providing no hole or overhead cover. On July 23, 1973 this structure was cleaned out. It was also noted that this structure tended to snag debris (logs, old coats, foam rubber, etc.). It filled in again during the 1974 high spring flows.

2. "V" with cover--On 20 June 1973 a three foot tall "V" strucutre was installed near the Murdock diversion. There was much difficulty in digging the hole to set the "V" into. It was finally left out of water about 8". At this time there was a little flow going through the structure. By July 6, 1973 the flow had receeded enough so that our structure was high and dry (meaning about 1½ feet of the structure was out of water and 1½ feet in water.) On July 24, 1973 one fish was observed around this structure. He appeared to like to

stay on the wings of the "V". On August 10, 1973, the "V" was found tipped over and downstream about 10 feet. This was apparently done by vandals. This structure was then put back in place, but was very unstable. The structure was again tipped over and is presently 30 feet downstream from its original location.

3. Cylinder--On June 20, 1973, an 18" diameter pipe was installed near the Murdock diversion. This pipe did not have a clean-out hole in the plug; therefore there was zero velocity through the structure. Sand immediately began to accumulate in the end of this structure but had not, as of August 15, 1973, accumulated to the extent that the structure would be considered silted in. Throughout the year the silting-in continued to increase until on March 9, 1974, this cylinder was one half filled in with fine sand. Then during the 1974 high spring flows it completely filled in.

4. Slab with legs--On July 23, 1973, a 4 foot wide slab with legs was installed below the Murdock diversion. As of March 9, 1974, this structure had caught some debris with the back legs. It had a good moss growth on it. Then during the 1974 high spring runoff it completely silted in.

C. Near Diagonal--The slope of the river through the test section was 0.9%.

1. Inverted weir--On June 28, 1973, an inverted weir was installed. It was 4 inches thick and 3 feet by 4 feet. Occasionally throughout the year this structure was out of water. It also silted in during high flows.

II. Left Fork of Hobble Creek--The slope of the river through the Test section was 1.4%.

1. Inverted weir--On June 7, 1973, an inverted weir was installed in Hobble Creek. From time to time fish have been observed around this structure. There is about a 2.0 fps variation in the velocities. Through March 9, 1974, this structure maintained a good clean hole with cover. Then during high flow the downstream end was completely filled in with cobble-sized rocks. The variation in water depth is another problem with this structure at this location.

2. "V" with cover--On July 2, 1973, a 2-foot tall structure was installed on Hobble Creek. Fish have been observed around this structure and also directly upstream from it. This structure has filled approximately ½ foot in with a very fine silt. If holes were installed in the sides of this structure it might remain clean. It was installed at the end of a pool, which limits its effectiveness in rehabilitating the stream.

During the high flow it filled in with a fine sand.

3. Cylinder--On July 2, 1973, an 18-inch diameter pipe was installed on Hobble Creek. There has been flow through the clean-out hole but no detectable velocity inside. There is about a 2.0 fps variation in velocities around this structure. Throughout the year there was only minor deposition inside this structure; then during high flow it was completely filled in with sand.

4. Slab with legs--On July 20, 1973, a 3-foot wide slab was installed on Hobble Creek. There is about a 1.0 fps variation in velocities around this structure. This structure also maintained a nice hole throughout the year, but during high flow conditions it was completely filled in with cobble-sized rocks.

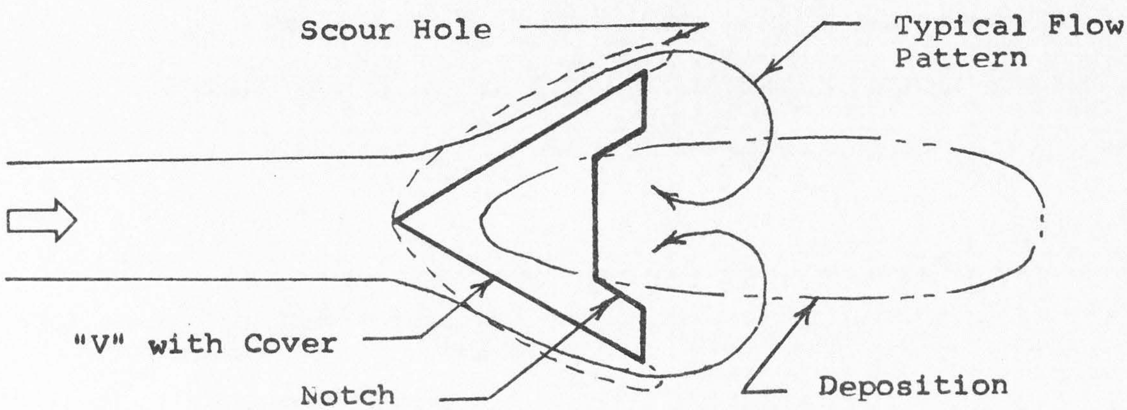
III. Spanish Fork River--The slope of the river through the test section was 0.4%.

1. Inverted weir--On May 8, 1973, an inverted weir was installed in the Spanish Fork River. It was 4 inches thick and 3 feet by 4 feet. It sustained high runoff flows during May of 1973 and, according to V.L. Jensen (of Payson), the discharge technician for the USGS, velocities were as high as 9 fps. The velocities around

the structure varied considerably within a range of about 9 fps to 1.0 fps. This was not placed in the main flow channel. It was placed on the inside of a bend and consequently there was a problem with silting in. After the high flows the top of the structure was left out of water and the back end was silted in within 4" of the top slab. There remained about 4" of flow under the weir. Cover was provided, but the hole was minimal. By March 9, 1974, the downstream half of this structure had completely filled in with fine sandy silt. There was also some sand in front of the weir. The legs col--lected debris and were cleaned out several times throughout the year. The brackets became very rusty. This structure completely silted in and was not effective.

2. "V" with cover--On June 21, 1973, a "V" structure was installed in the Spanish Fork River. It was 3' tall and was difficult to install (dig hole). It was placed in the deepest part of the flow channel. Within minutes it silted in with fine silt and sand. The cover plate for this structure was placed down 8" from the top of the structure and supported with brackets. There was a notch cut out of the back of the cover plate. Throughout the year it progres-

sively silted in more and more until on March 9, 1974, it was filled in with sandy silt up to the cover plate. A substantial hole has been scoured along both sides. There is a velocity variation of about 2 fps around this structure. (See drawing below.) This structure also completely silted in during the 1974 spring runoff.



Top View

3. Slab with legs--On July 20, 1973, a 4-foot wide slab with legs was installed in the Spanish Fork River. There was a velocity variation of about 3 fps. This structure maintained a good hole with cover with only a small amount of deposition inside but filled in during the 1974 spring runoff.
4. Cylinder--On July 20, 1973, an 18-inch diameter pipe was installed in the Spanish Fork River. It has a clean-out hole in the plug. There has

been a velocity variation of about 3.0 fps around this structure. Some silt had settled into the pipe within several weeks but did not continue to increase in quantity. As of March 9, 1974, this structure still only had a small amount of sand deposition inside it, then in May of 1974 it completely filled in with sediment.

IV. Thistle Creek--The slope of the river through the test section was 0.7%.

1. Inverted weir--On June 12, 1973, an inverted weir with deflectors was installed in Thistle Creek. It was placed in a 3.0 foot-hole with about 1.0 feet of flow over it. It has had a velocity variation of about 3.0 fps. (From 4 fps to about 0.5 fps.) This structure progressively silted in until on March 9, 1974, it was filled in right up to the back half of the structure with a medium sand. It has also been collecting debris throughout the year. It appears that this structure was installed too low to get any effective scour from the weir.
2. "V" with cover--On July 6, 1973, a 2-foot tall "V" structure was installed in Thistle Creek. It quickly promoted algae growth. This structure was installed low enough that it is always submerged. By August 15, 1973, it had silted in

up to the cover plate with coarse to fine sand material, thereby making the structure incapable of habitat. Model studies were then performed to determine what modifications could be made to make the structure self-cleaning. It was determined that holes in the sides of their structure would keep it from silting in; therefore one 12 inch hole was made in each side of this structure. It was observed on March 9, 1974, that the structure had remained relatively clean with some deposition of medium sand downstream. The habitat conditions were very favorable. But during the high runoff in May of 1974 this structure completely filled in with sediment. More time is needed to determine whether or not the holes will scour this material out again.

3. Cylinder--On July 20, 1973, an 18 inch diameter pipe with a plug was installed in Thistle Creek. It has a clean-out hole in the plug which has provided flow through the structure. There is a velocity variation of about 3.0 fps around the structure. It progressively silted in until on March 9, 1974, it was completely full of medium sand. It is totally ineffective.
4. Slab with legs--On July 20, 1973, a 3-foot wide slab was installed in Thistle Creek. It has

remained fairly clean with the velocities around and through the structure being greater than the velocities of the approaching water by about 1 fps. Over the year only minor deposition has occurred directly downstream from the the structure. It then filled in completely during the 1974 spring runoff.

FISH REQUIREMENTS

I. Resting Areas

1. Favorable range in velocities (0.4 to 0.7 fps)
2. Favorable range in temperatures (45° to 65° F)
3. Adequate living space (pools)
4. Adequate overhead cover

II. Feeding Areas

1. Clear water and riffle areas
2. Good quality water
3. Abundant food supply
4. Minimal flow manipulation
5. Minimum erosion and turbidity

III. Breeding Areas

1. Clear water and riffle areas for spawning
2. Good riffle-pool relationship
3. Freedom from sedimentation

BIBLIOGRAPHY

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Alabaster, J. S. 1972. Suspended solids and fisheries. Proc. R. Soc. London B. 180:395-406.

Albertson, M. L., J. R. Barton, and D. B. Simons. 1960. Fluid mechanics for engineers. Prentice-Hall, Inc. pp. 487-511.

Alvord, W., and J. C. Peters, 1963. Channel changes in thirteen Montana streams. Montana Fish and Game Comm., Fisheries Div. 22p.

Apman, R. P., and M. B. Otis, 1965. Sedimentation and stream improvement. New York Fish and Game Journ. 12(2):117-126.

Bagnold, Ralph A. 1960. Some aspects of the shape of river meanders. U. S. Geol. Surv. Prof. Paper 282-E.

Barton, J. R., and P. V. Winger, 1973a. A study of the channelization of the Weber River, Summit County, Utah. Final Rept. to Utah Div. Wildlife Resources and Utah State Department of Highways.

Barton, J. R., and P. V. Winger, 1973b. Model stream studies. Research report submitted to Utah State Department of Highways and Utah Div. of Wildlife Resources.

Barton, J. R., and P. V. Winger, 1973c. Rehabilitation of a channelized river in Utah. Proc. Annual Hydraulics Specialty Conf. Hydraulic Engineering and the Environment, Montana State University, Bozeman, Montana 21:1-10.

Barton, J. R., and P. V. Winger, 1973d. Stream rehabilitation concepts. Research report submitted to Utah State Department of Highways and Utah Div. of Wildlife Resources. 44p.

Baldes, R. J., and R. E. Vincent. 1969. Physical parameters of microhabitats occupied by brown trout in an experimental flume. Trans. Amer. Fish. Soc. 98:230-238.

Bayless, J., and W. B. Smith. 1964 The effects of channelization on fish populations of lotic waters in eastern North Carolina. Proc. North Carolina Wildlife Resource Comm. 15p.

Beland, R. D. 1953. The effect of channelization on the fishing of the lower Colorado River. California Fish and Game 39(1):137-139.

Berryman, J. H., J. W. Floyd, A. D. Smith, J. M. Neuhold, and F. W. Kearns. 1962. Road construction and resource use. Utah State University, Ext. Circ. 297. 15p.

Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. J. Will. Mgmt. 18:229-239.

Brown, G. W. 1970. Predicting the effect of clear cutting on stream temperature. Jour. Soil and Water Cons. 25(1):11-13.

Burns, J. W. 1972. Some effects of logging and associated road construction on northern California stream. Trans. Amer. Fish. Soc. 101(1):1-17.

Butler, R. L., and V. M. Hawthorne. 1968. The reactions of dominant trout to changes in overhead artificial cover. Trans. Amer. Fish. Soc. 97:37-41.

Chrostowski, H. P. 1972. Stream habitat studies on Uinta and Ashley National Forests. U.S. Dept. Agric., For. Ser., Intermountain Region, Ogden, Utah. 150p.

Clark, J. W., W. Viessman, and M. J. Hammer. 1971. Water supply and pollution control. International Textbook Company: 661p.

Clark, O. H. 1945. Stream improvement in Michigan. Trans. Amer. Fish. Soc. 75:270-280.

Davis, H. S. 1941. The management of trout streams. Trans. North Amer. Wildl. Conf. 6:169-175.

Ellis, M. M. 136. Erosion silt as a factor in aquatic environments. Ecology 10:29-42.

Elser, A. A. 1968. Fish population of a trout stream in relation to major habitat zones and channel alterations. Trans. Amer. Fish. Soc. 97(4):389-397.

Elser, A. A. 1972. A partial evaluation and application of the "Montana Method" of determining stream flow requirements. In: Transcript of Proc. Instream Flow Requirement Workshop, Pacific Northwest River Basin Comm. p. 3-15.

Etnier, D. A. 1972. The effect of annual rechanneling on a stream fish population. Trans. Amer. Fish. Soc. 10(2): 372-375.

Gard, R. 1961. Creation of trout habitat by constructing small dams. Jour. Wildl. Mgt. 25:384-390.

Gebhards, S. 1970. The Vanishing stream. Idaho Wildlife Review. March-April 1970.

Hale, J. G. 1969. An evaluation of trout stream habitat improvement in a north shore tributary of Lake Superior. Minnesota Fish. Invest. 5:37-50.

Hales, D. C. 1960. Rape of the rivers. Utah Fish and Game Mag. 16(2):3-4.

Harrison, J. S. 1965. Evaluation of stream improvement structures. New Mexico Fish and Game, Fed. Aid Proj. F-22-R-6.

Hartman, G. F. 1963. Observations on behavior of juvenile brown trout in a stream aquarium during winter and spring. J. Fish. Res. Bd. Canada. 20:769-787.

Irizarry, R. A. 1969. The effects of stream alteration in Idaho streams. Idaho Fish and Game. Job Comp. Rept. Proj. F-55-R-2. 26p.

Kalleburg, H. 1958. Observations in a stream tank of territoriality and competition in juvenile salmon and trout. Inst. Freshev. Res. Drottningholm. 39:55-98.

Lane, E. W. 1957. A study of the shape of channels formed by natural streams flowing in erodible material. U.S. Army Corps of Engineers. Missouri River Basin Sediment Series No. 9. 106p.

Leopold, L. B. 1962. Rivers. American Scientist. 50(4): 511-537.

Leopold, L. B., M. G. Wolman and J. P. Miller. 1964. Fluvial processes in geomorphology. Freeman Press: 522p.

Lewis, S. L. 1969. Physical factors influencing fish populations in pools of a trout stream. Trans. Amer. Fish. Soc. 98:14-19.

Minshall, G. W. and P. V. Winger. 1968. The effect of reduction in stream flow on invertebrate drift. Ecology 49(3):580-582.

Mueller, J. W. 1954. Wyoming stream improvement. Wyoming Wildlife 18(5):30-32.

Newman, M. A. 1956. Social behavior and interspecific competition in two trout species. Physical Zool. 29:64-81.

Novitzki, R. P. 1973. Improvement of trout streams in Wisconsin by augmenting low flows with ground waters. Water Supply Paper No. 2017.

Peters, J. C. 1971. Effects of channelization on aquatic ecosystems. Unpublished.

Peters, J. C., and W. Alvord. 1964. Man-made alterations in thirteen Montana streams and rivers. Trans. North Amer. Wildl. Conf.

Robinson, D. W., and R. Menendez. 1964. Stream improvement on three northwestern West Virginia warm-water streams. West Virginia Dept. Nat. Res., Div. Fish and Game. Charleston, West Virginia. 18p.

Saunders, J. W., and M. W. Smith. 1962. Physical alteration of stream habitat to improve brook trout production. Trans. Amer. Fish. Soc. 91:185-188.

Schuck, H. A. 1945. Survival, population density, growth and movement of the wild brown trout in Crystal Creek. Trans. Amer. Fish Soc. 73:209-230.

Schumm, S. A. 1960. The shape of alluvial channels in relation to sediment type. U. S. Geol. Surv. Prof. Paper 352-B.

Shetter, D. C., O. H. Clark, and A. S. Hazzard. 1946. The effects of deflectors in a section of a Michigan trout stream. Trans. Amer. Fish. Soc. 76:248-278.

Silcox, F. A. 1936. Fish stream improvement handbook. U. S. Forest Service. 39p.

Stuart, T. A. 1953. Water currents through permeable gravels and their significance to spawning salmoniods. Nature 172:407-408.

Stuart, T. A. 1960. The influence of drainage works levees, dikes, dredges, etc., on the aquatic environment and stocks. Proceedings Internat. Union for Conservation of Nature Tech. Meeting, 1959:4:337-345.

Subitsky, S. 1962. Records of selected wells and springs, selected drillers' logs of wells, and chemical analysis of ground and surface waters, Northern Utah Valley, Utah County, Utah.

Tarzwell, C. M. 1932. Trout stream improvement in Michigan. Trans. Amer. Fish. Soc. 61:48-57.

Tarzwell, C. M. 1937. Experimental evidence on the value of trout stream improvement in Michigan. Trans. Amer. Fish. Soc. 66:177-187.

Tarzwell, C. M. 1938. An evaluation of the methods and results of stream improvement in the southwest. Trans. North Amer. Wildl. Conf. 3:339-364.

Tennant, D. L. 1972. A method for determining instream flow requirements for fish, wildlife, and the aquatic environment. In: a transcript of Proc. Instream Flow Requirement Workshop. Pacific Northwest River Basin Comm.

Thompson, K. E., and J. D. Fortune, Jr. 1968. The fish and wildlife resources of the North Coast Basin, Oregon, and their water requirements. Oregon State Game Comm., Fed. Aid to Fish Restoration Proj., Prog. Dept. F-69-R-5:43.

U. S. Army Corps of Engineers. 1971. Flood plain information, Provo River and Rock Canyon Creek, Provo-Orem, Utah. 34p.

U. S. Forest Service. 1969. Wildlife habitat improvement handbook. Chapt. 10. Stream improvement. U. S. Forest Service Handbook.

Warner, K., and J. R. Porter. 1960. Experimental improvement of a bulldozed trout stream in northern Main. Trans. Amer. Fish. Soc. 89:(1):59-63.

Wernsteat, F. L. 1972. World Climatic data. Climatic Data Press. P. O. Box 413 Lemont, Pennsylvania, 16351.

Wesche, T. A., and P. A. Rechard. 1973. Parameters influencing minimum stream flow. In:ASLE Hydraulic Engineering and the Environment, Proc. Ann. Hydraul. Div. Spec. Conf., Bozeman, Montana, Aug. 1973. 21:21-30.

Winger, P.V. 1973. Private lectures on diverse subjects.

Winger, P. V. and R. N. Winget. 1974. Determination of minimum flow requirements for mountain streams. Research proposal.

White, R. J., and O. M. Brynildson. 1967. Guidelines for management of trout stream habitat in Wisconsin. Wisconsin Dept. of Nat. Div. Cons. Tech. Bull. No. 39. 65p.